Title

Plate Deformation Behavior of Polymer Matrix Composite-Ti Honeycomb-Metal Sandwiches for Pressurized Propulsion Component Applications

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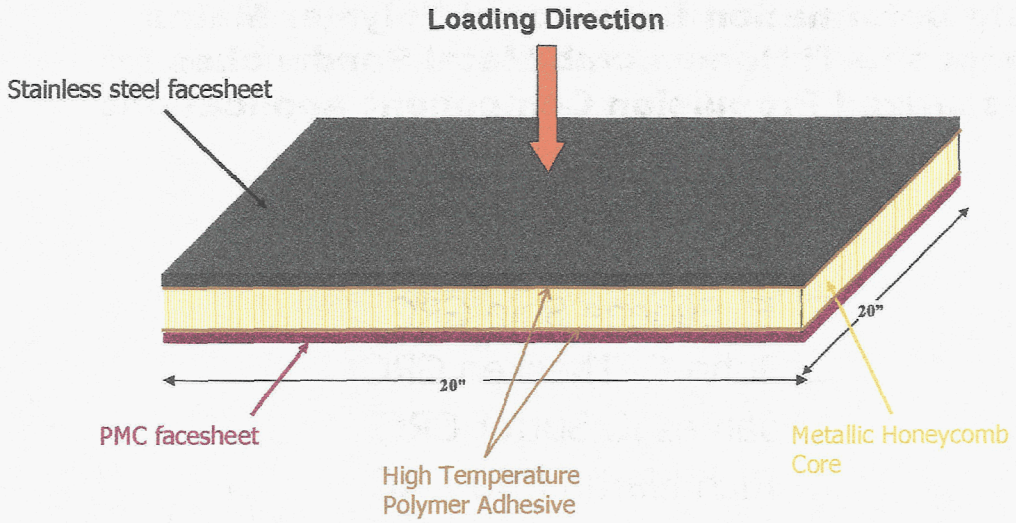
Objectives

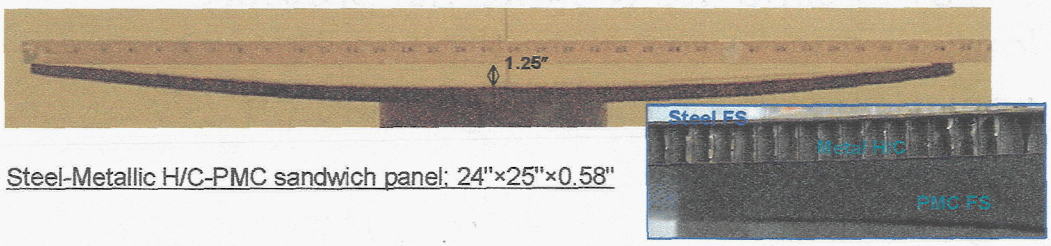
- To experimentally validate bi-axial plate flexural performance of PMC-Ti H/C-A286 sandwich panels for the internally pressurized RBCC combustion chamber support structure
- To explore ASTM 2-D plate flexure test (D 6416) to simulate the internal pressure loading and to correlate the results with analytical and FE modeling based on 2-D flexure properties

Sandwich Panel Configuration



Experimental

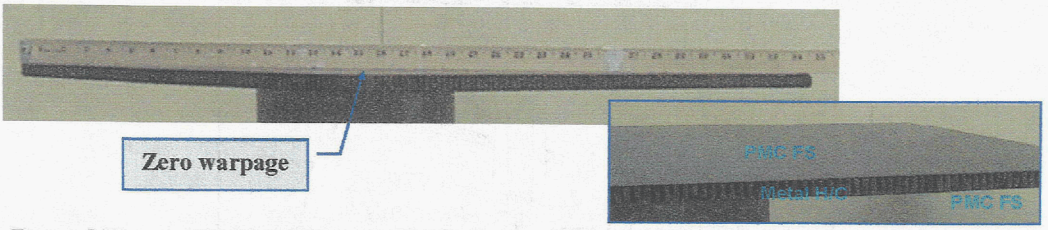
- Fabrication of sandwich panels
  1) PMC facesheet fabrication (4HS M40J/PMR-II-50, $[0_f, 90_f]_{1S}$), cured @ 700 °F/25in-Hg/200psi
  2) Surface treatment of metal f/s and metallic Honeycomb core (Turco etching/Boegel-AM Sol-Gel/Primer); PMC by scotchbrite or grit blast
  3) Vacuum bagging the sandwich lay-up with high temp adhesive
  4) Cure at 370°F/22in-Hg/10 psi for 4 hours, remove from vac-bag
  5) Postcure at 700 °F for 16 hours in air-circulated oven
- CTE mismatch-induced warpage



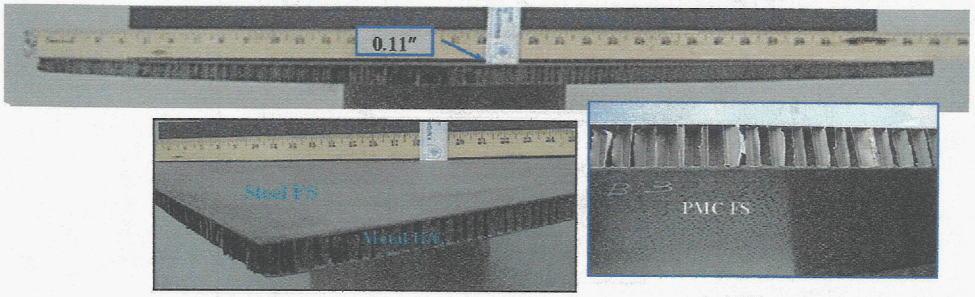
Steel-Metallic H/C-PMC sandwich panel: 24"×25"×0.58"

Experimental

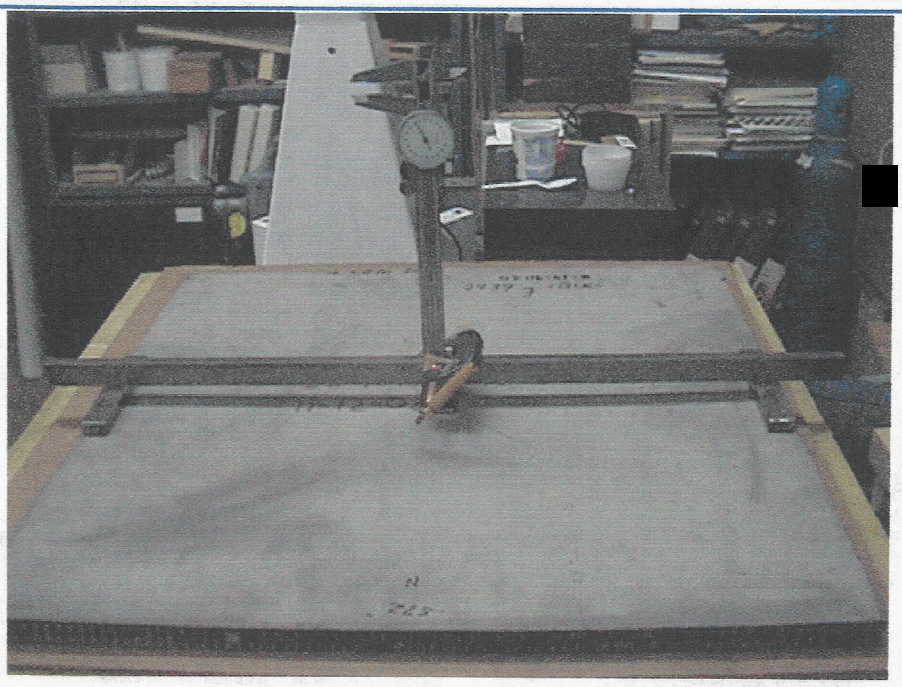
- Panel Type I (BLB2): PMC-Metal H/C-PMC for symmetry and to validate the 700°F PI adhesive



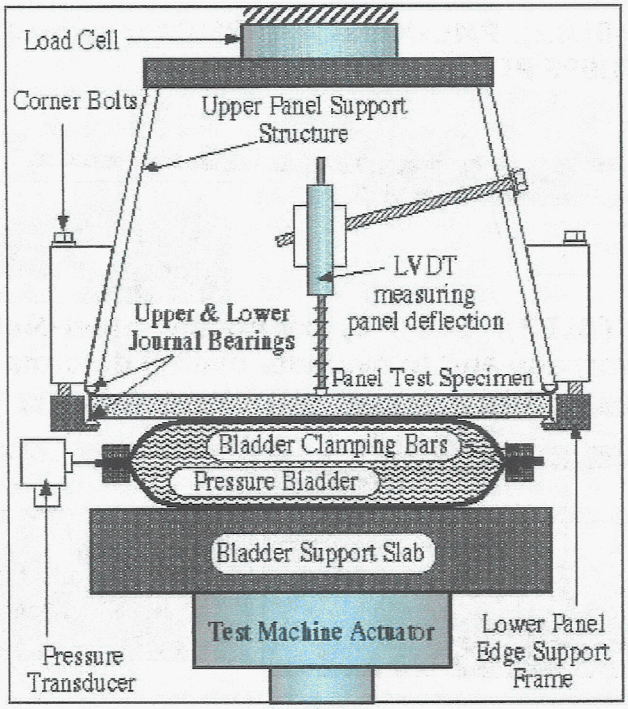
- Panel Type II (BLB3): 140°F Epoxy Bonded Steel-Metal H/C-PMC for minimal warpage and to evaluate overall deformation behavior



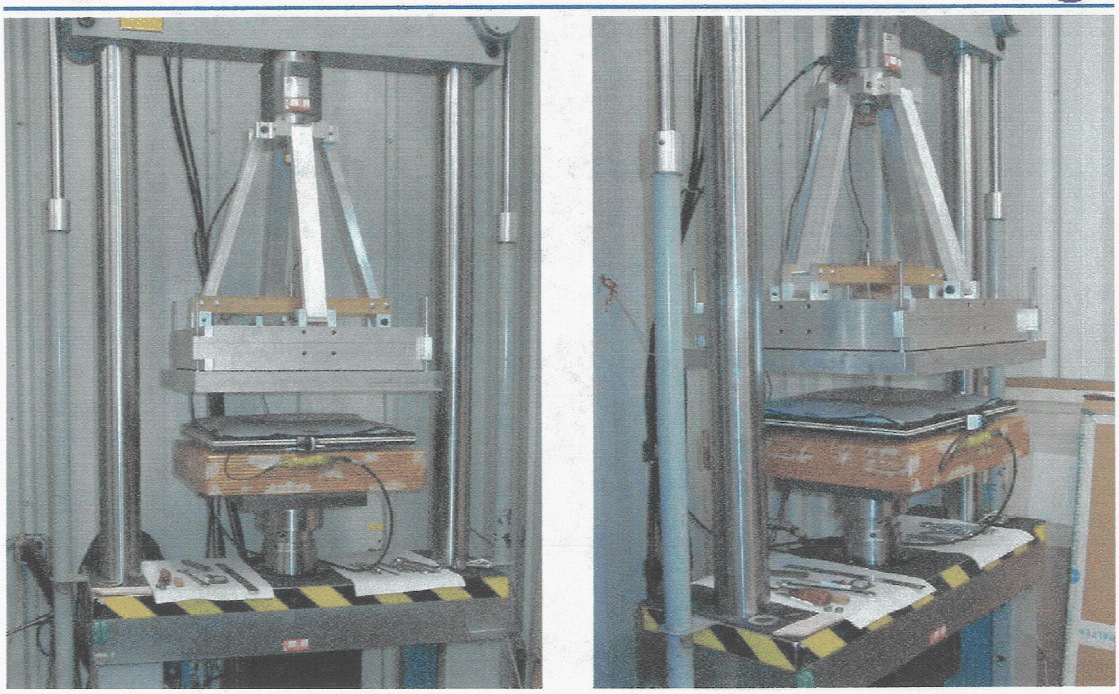
Experimental



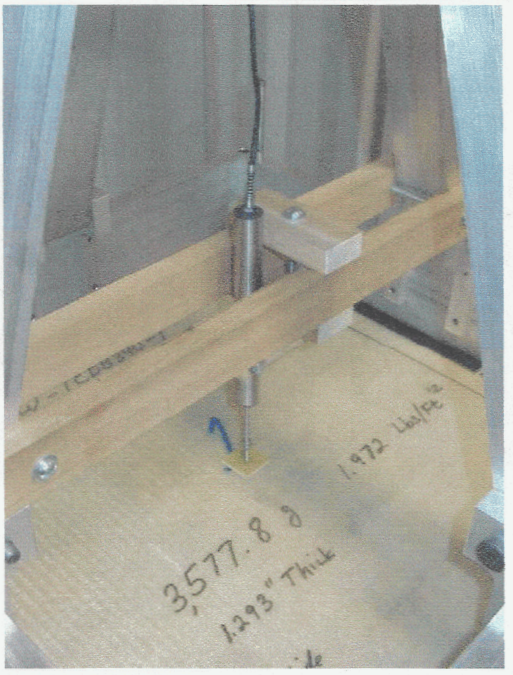
Apparatus



Apparatus



Apparatus



Apparatus

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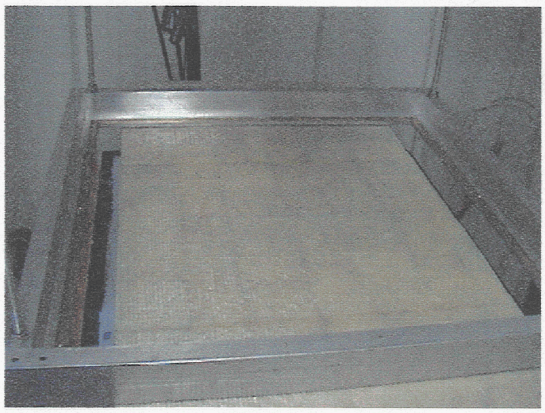
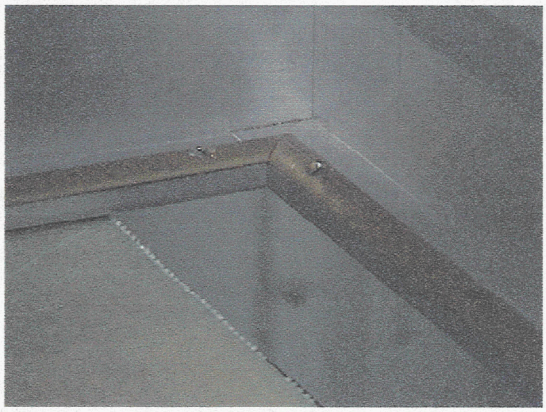


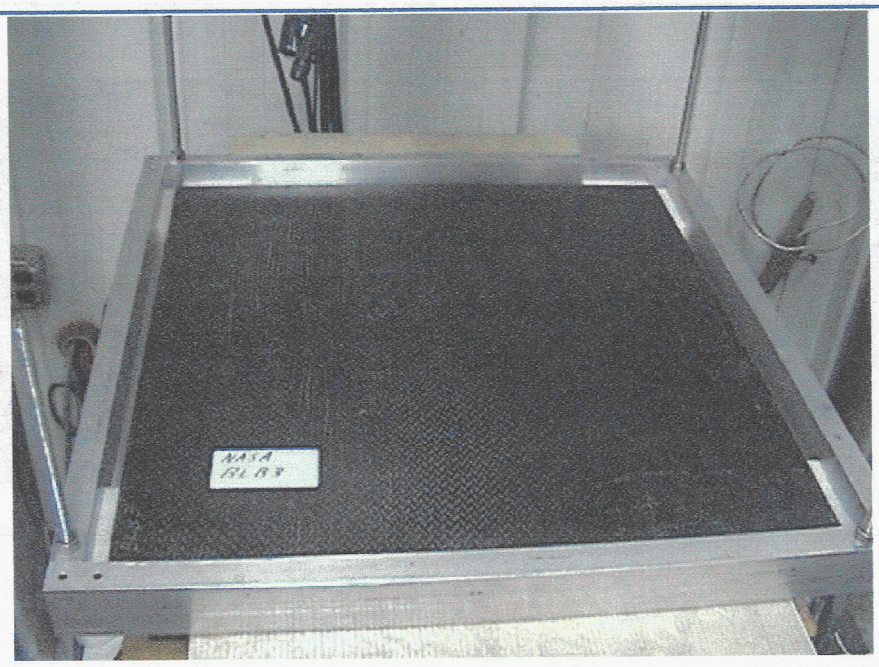


Test Matrix

Date	Tests	Panel BLB3	Panel BLB2
2/20/03	Preliminary Small-Deflection Stroke Ramps	3	
2/24/03	Preliminary Small-Deflection Stroke Ramps		3
2/25/03	Manual Ramp to 25 psi	1	
2/26/03	Fatigue Cycles at 4650 lbf (25 psi)	166	
2/26/03	Stroke Ramp, small-deflection	1	
3/5/03	Strain Gages Installed		Y1, Y2, Z
3/5/03	Manual Ramp to 15 psi		1
3/5/03	Stroke Ramp, small-deflection		1
3/5/03	Fatigue Cycles at 2660 lbf (15 psi)		226
3/6/03	Manual Ramp to 15 psi		1
3/6/03	Stroke Ramp, small-deflection		1
3/6/03	Stroke Ramp, small-deflection		1
3/6/03	Fatigue Cycles at 2660 lbf (15 psi)		227
3/6/03	Manual Ramp to 20 psi		1
3/6/03	Stroke Ramp, small-deflection		1
3/6/03	Fatigue Cycles at 3670 lbf (20 psi)		228
3/6/03	Stroke Ramp, small-deflection		1
3/6/03	Ramp to Failure		1
3/6/03	Stroke Ramp, small-deflection		1

Test Setup

Test Setup



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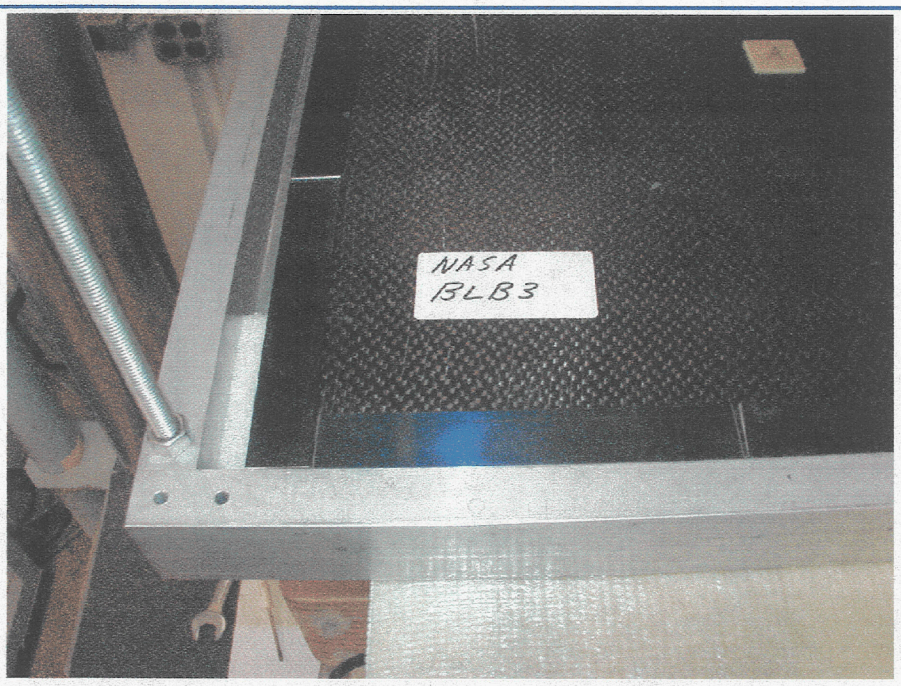
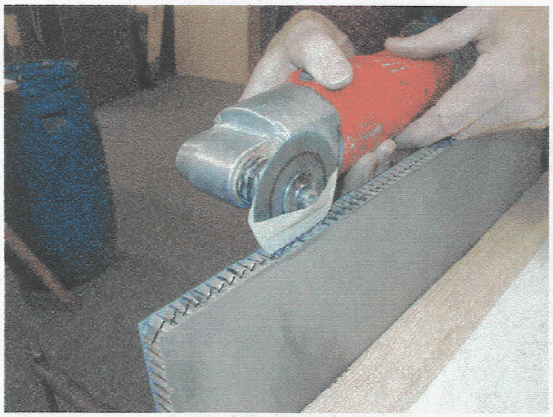
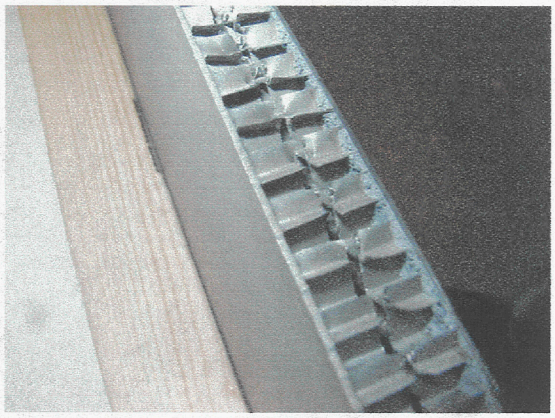
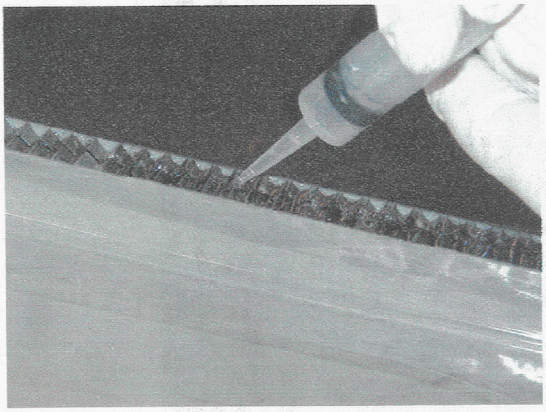


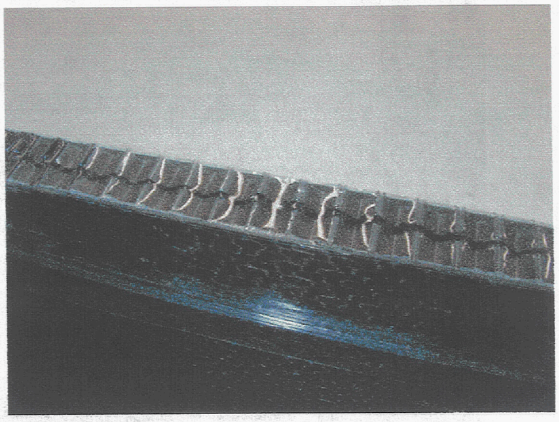
Specimen Edge Prep





Specimen Edge Prep





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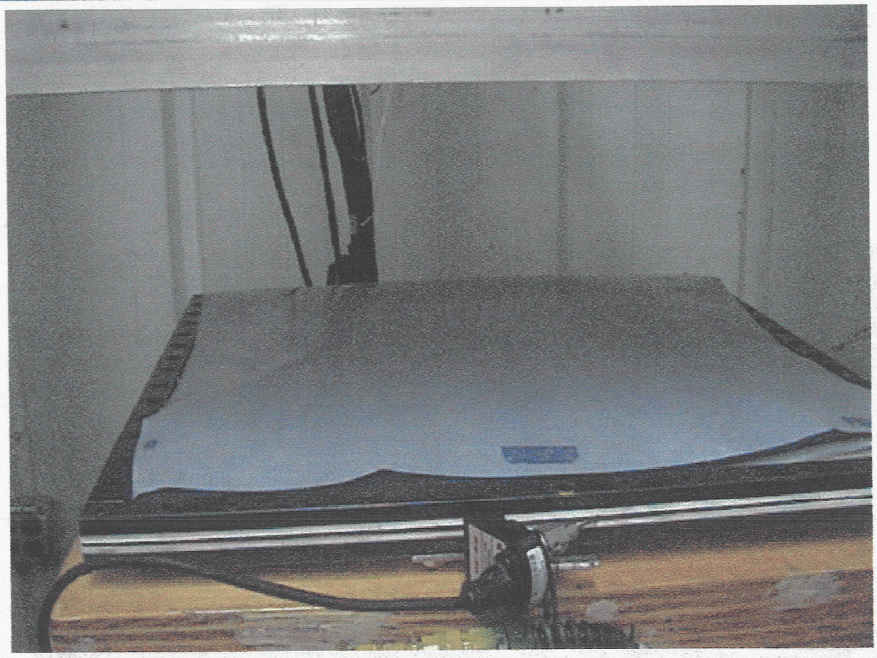

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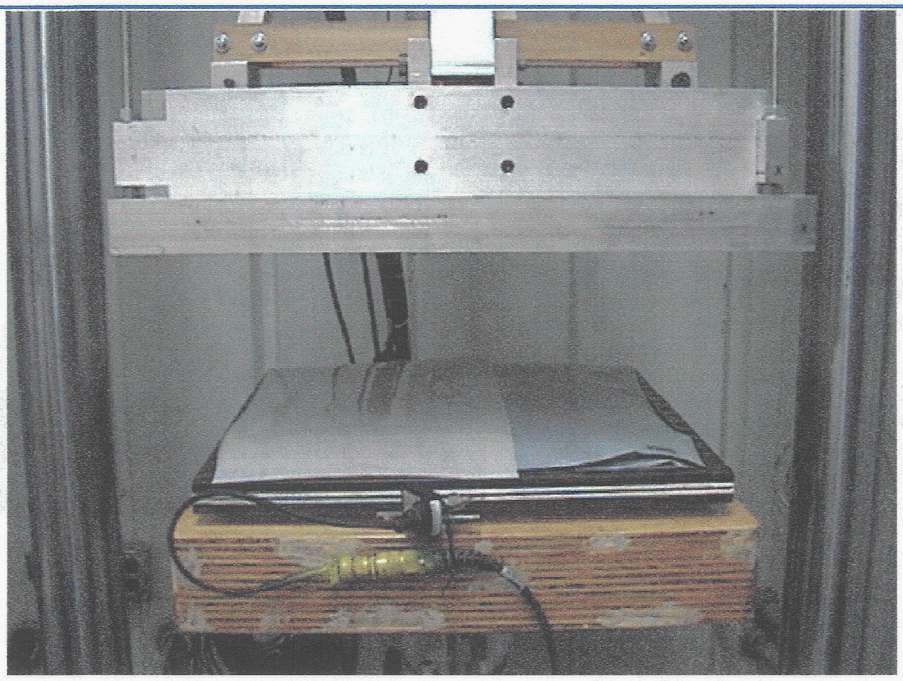

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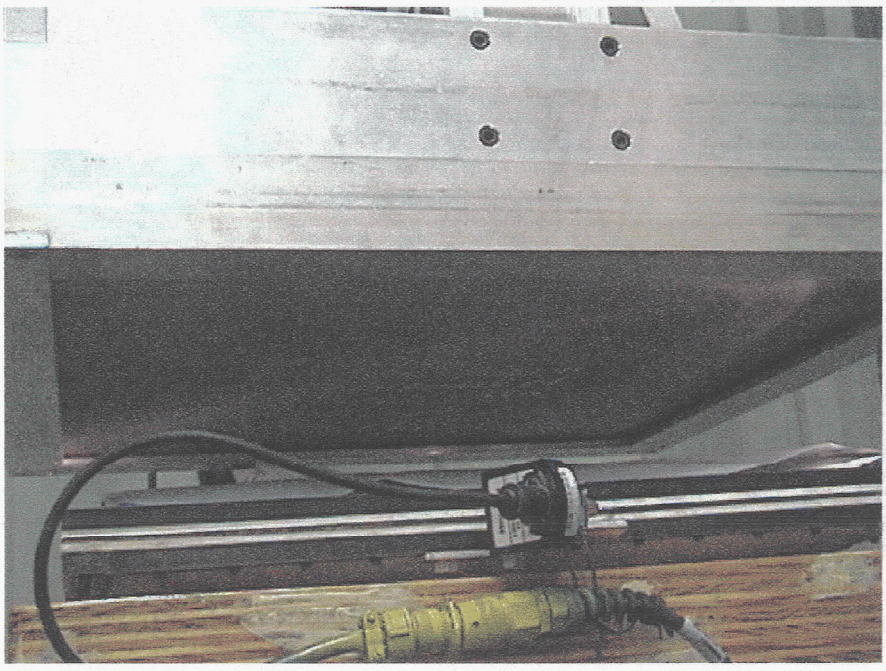
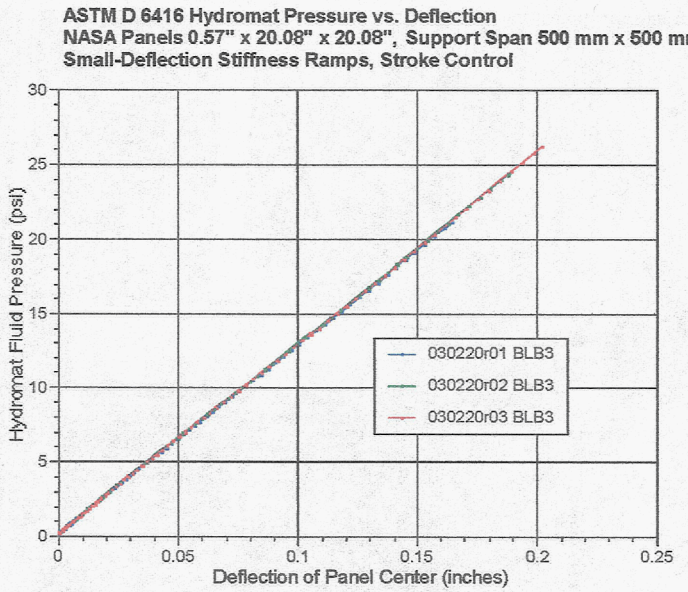


Test Setup

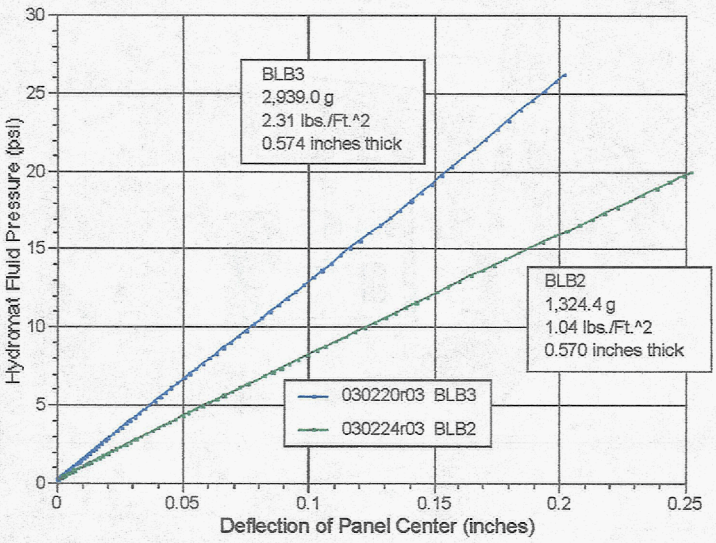
Data Acquisition

Static Deflection Data

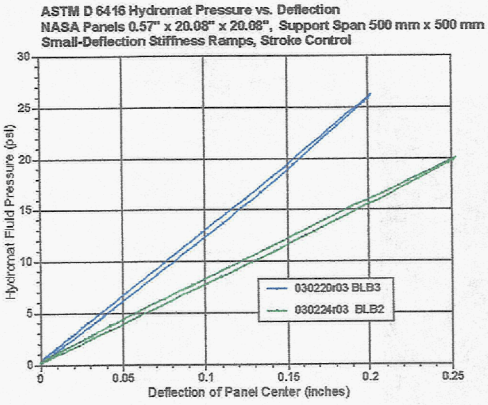


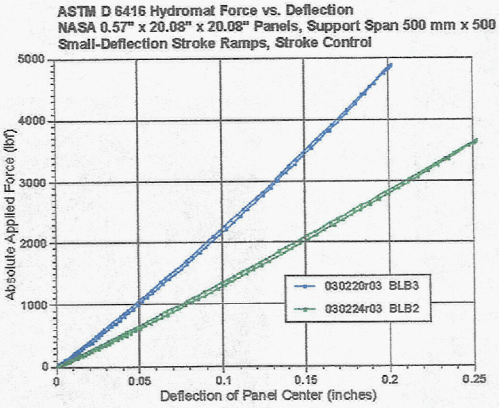
Actuator speed: 0.1 inches per minute. Data sampling interval: 3 seconds. Corner nut torque: 32 inch lbf

Static Deflection Data

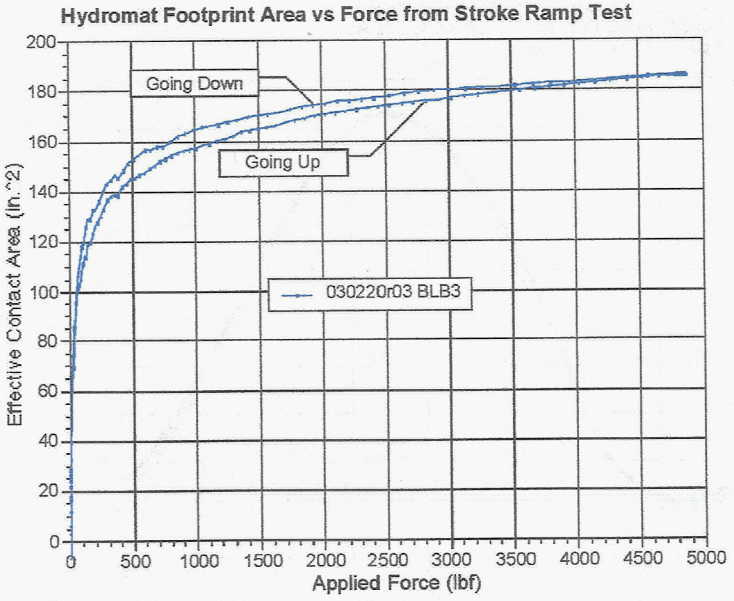


Static Deflection Data

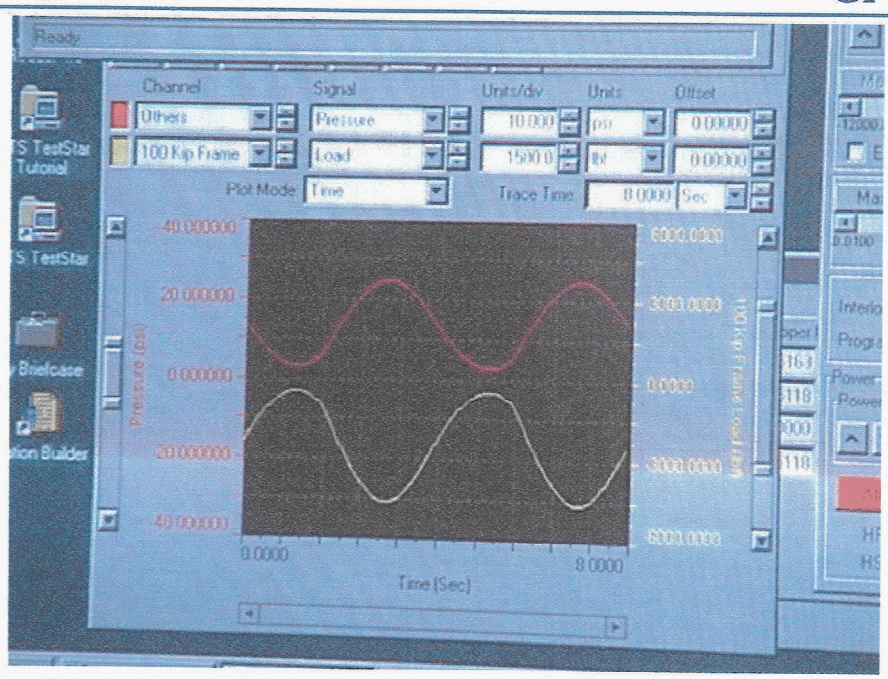




Effective Contact Area

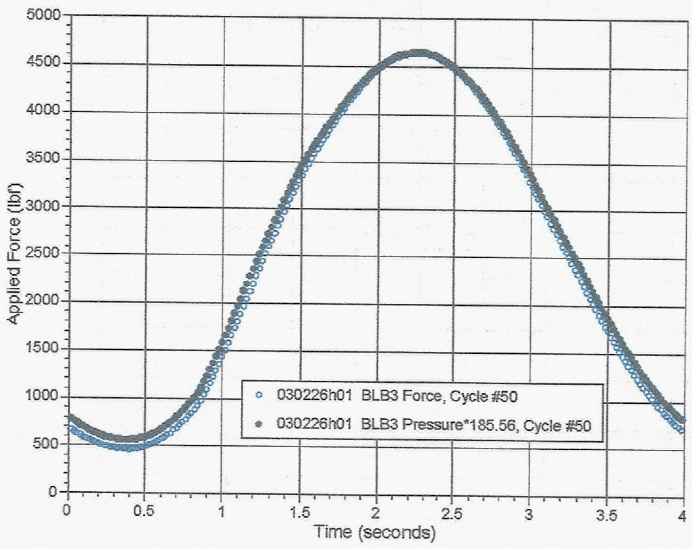


Fatigue Tests



Fatigue Sinusoid

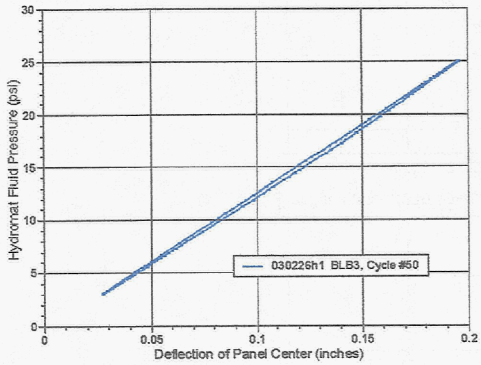
Hydromat Low-Cycle Fatigue
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load Control, 4,650 lbf Peak, R = 0.1, 0.25 Hz
Applied Force vs. Time



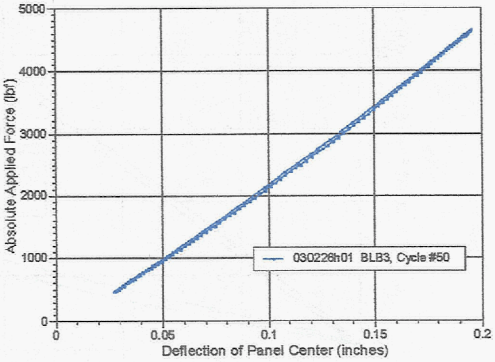
Data sampling interval: 0.02 seconds

Hysteresis Data

Hydromat Pressure vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load-Controlled Fatigue, 4,650 lbf Peak, R = 0.1, 0.25 Hz



Hydromat Force vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load-Controlled Fatigue, 4,650 lbf Peak, R = 0.1, 0.25 Hz



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Hysteresis Data

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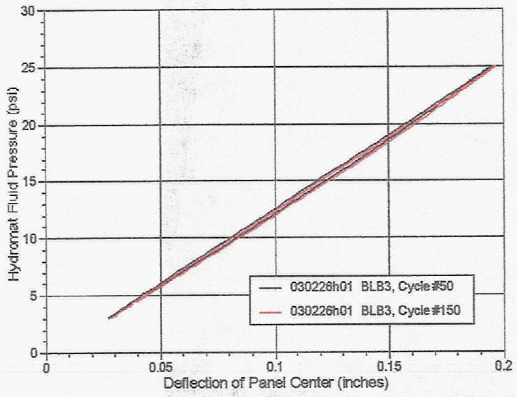
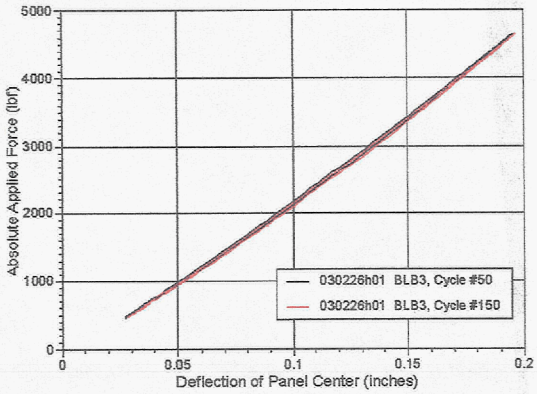
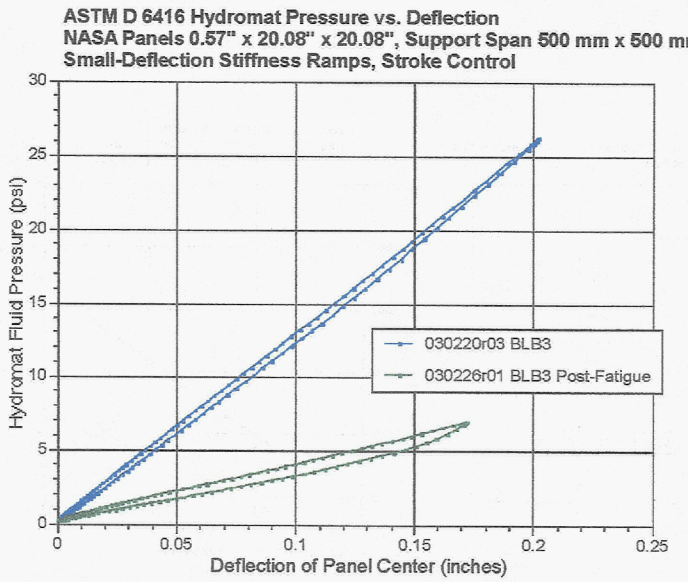
Load-Controlled Fatigue, 4,650 lbf Peak, R = 0.1, 0.25 Hz



Hydromat Force vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load-Controlled Fatigue, 4,650 lbf Peak, R = 0.1, 0.25 Hz

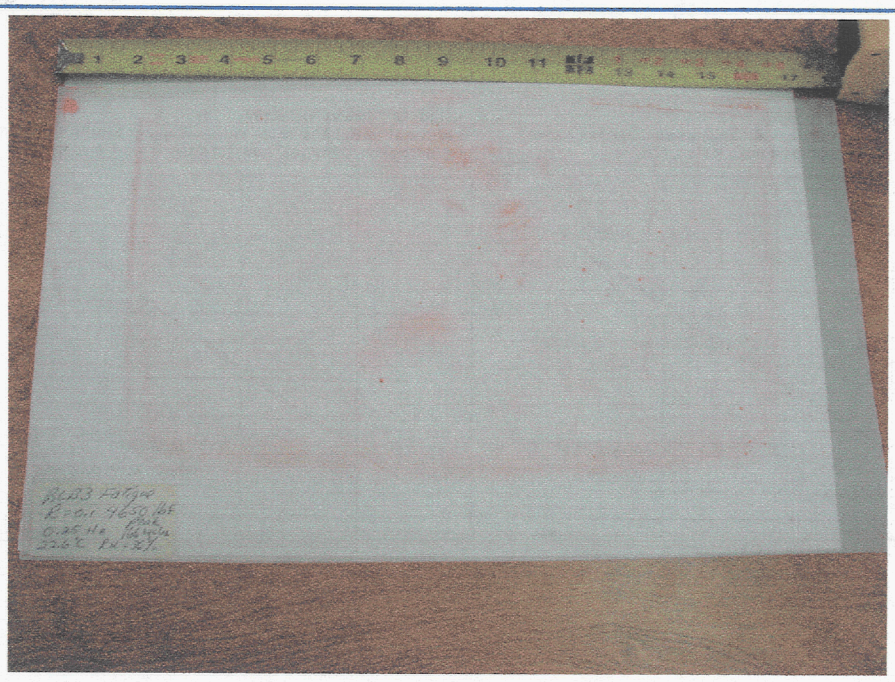


Residual Stiffness



Actuator speed: 0.1 inches per minute. Data sampling interval: 3 seconds. Corner nut torque: 32 inch lbf

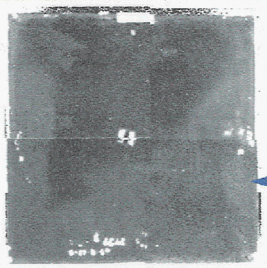
Fatigue Footprint



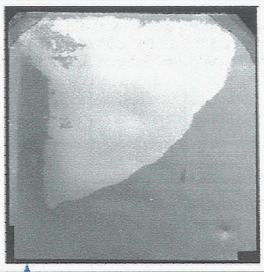
NDE Results

- Panel Type II (BLB3)

Loading Side (A286)



Darker areas indicate skin-core separation

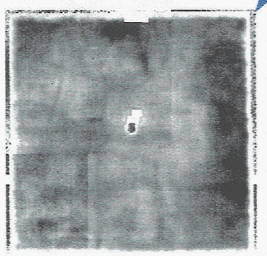


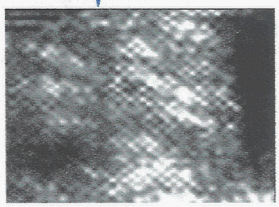
20 MHz Pulse-Echo ultrasonic c-scan; Lighter areas indicate skin-core separation

Thermograph

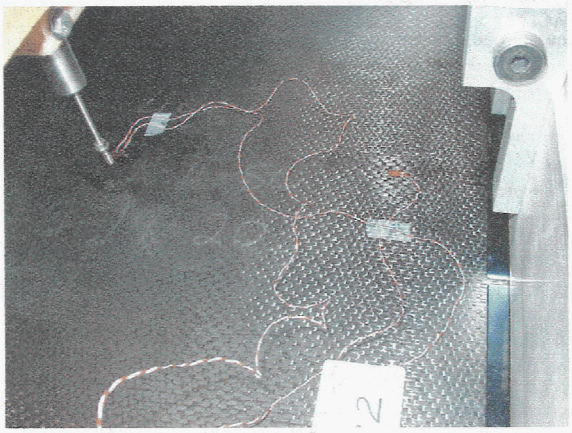
Guided Wave Scan (M0)

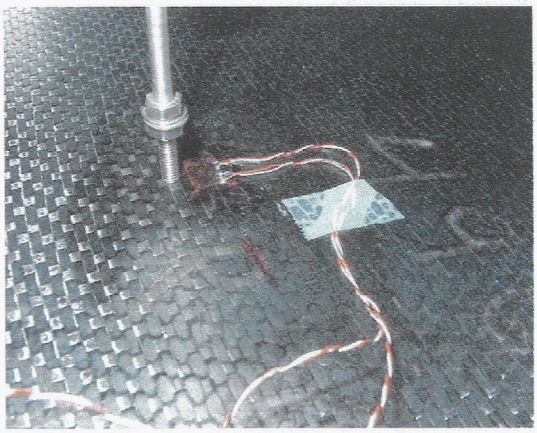
Tension Side (PMC)





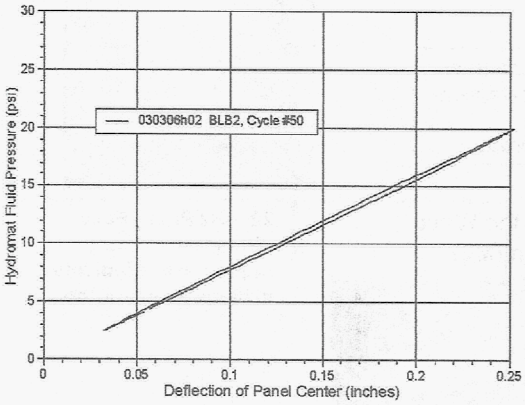
Strain Gaging



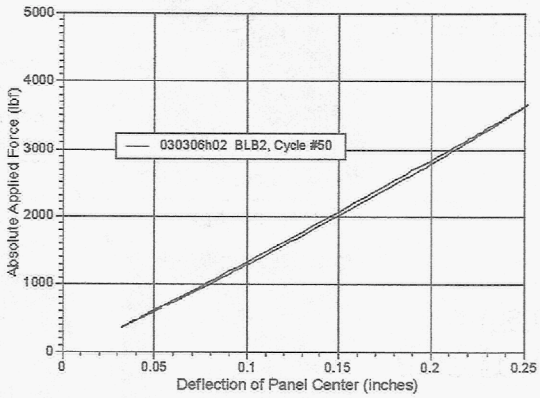


Hysteresis Data

Hydromat Pressure vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load-Controlled Fatigue, 3,670 lbf Peak, R = 0.1, 0.25 Hz



Hydromat Force vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 m
Load-Controlled Fatigue, 3,670 lbf Peak, R = 0.1, 0.25 Hz



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Hydromat Pressure vs. Deflection
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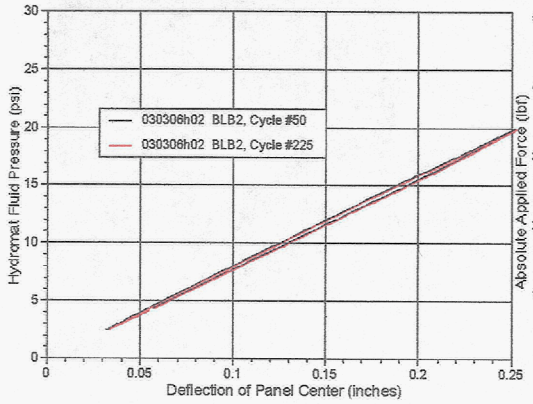
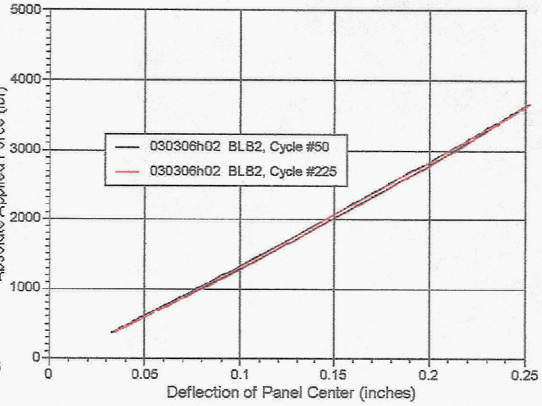
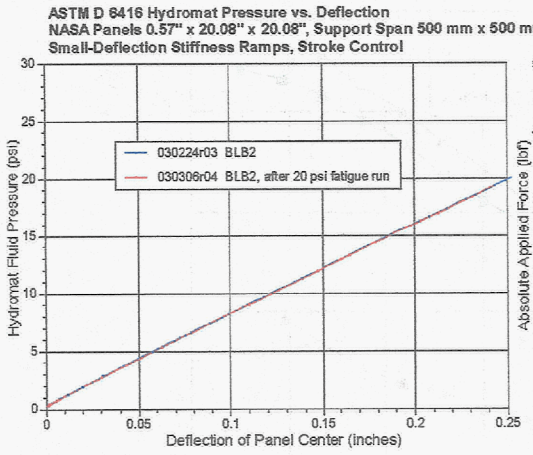
Load-Controlled Fatigue, 3,670 lbf Peak, R = 0.1, 0.25 Hz

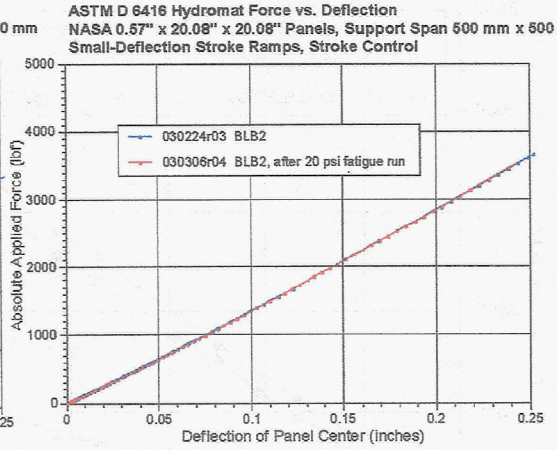


Hydromat Force vs. Deflection
NASA 0.57" x 20.08" x 20.08" Panels, Support Span 500 mm x 500 mm
Load-Controlled Fatigue, 3,670 lbf Peak, R = 0.1, 0.25 Hz

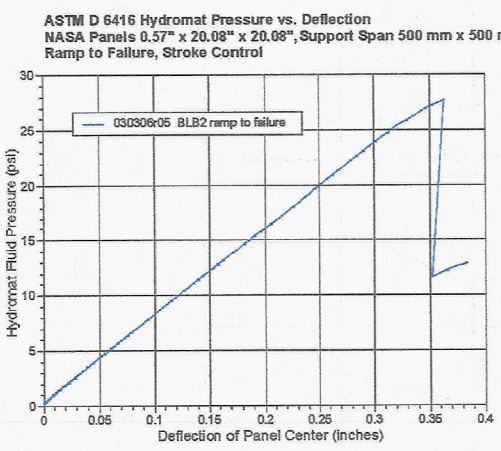


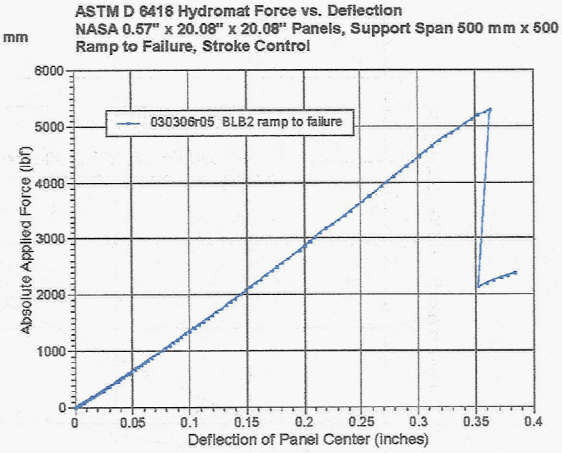
Residual Stiffness



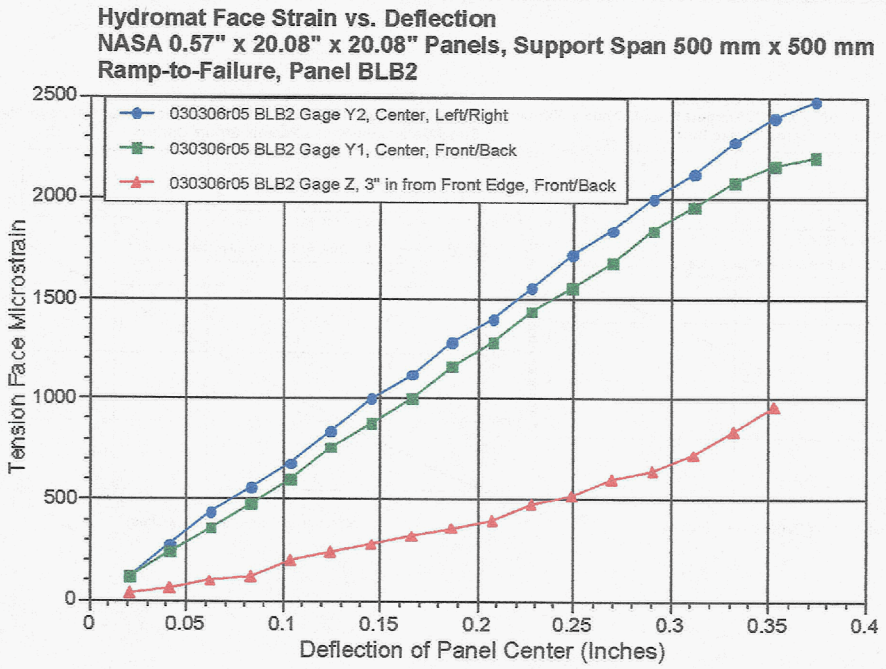


Static Ramp to Failure

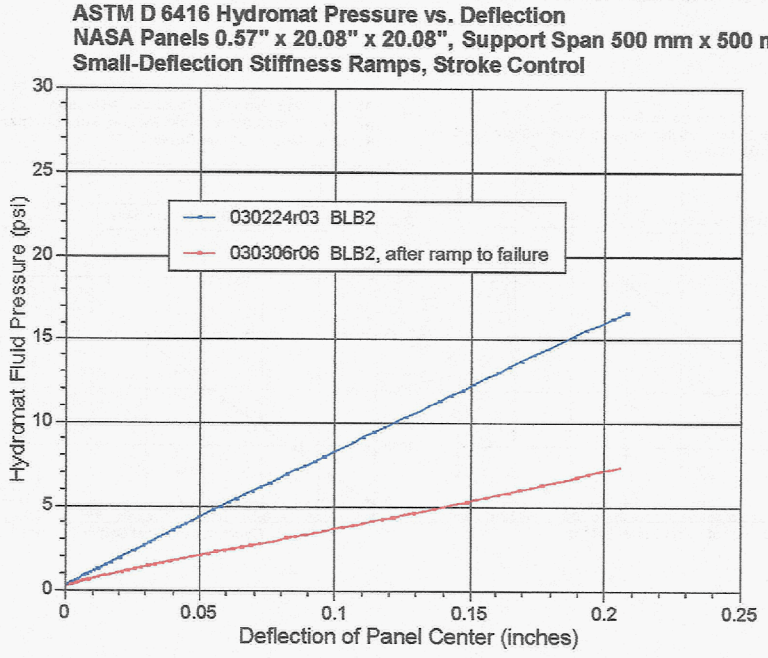




Static Strain Data



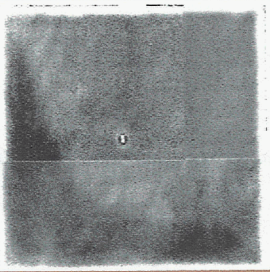
Residual Stiffness

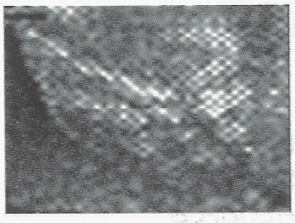


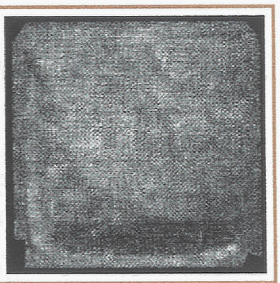
NDE Results

- Panel Type I (BLB2)

Loading Side





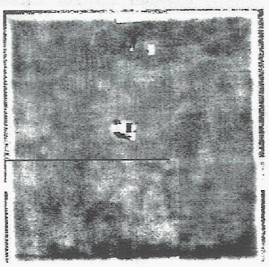


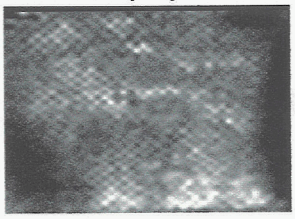
Thermograph

Guided Wave Scan (M0)

5MHz Pulse-Echo ultrasonic c-scan

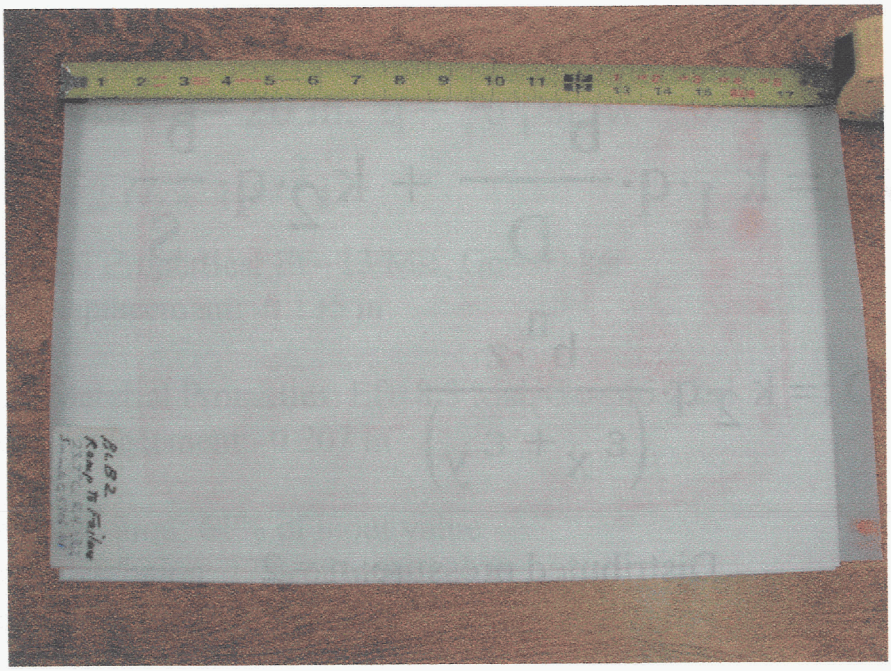
Tension Side





Darker areas indicate skin-core separation

Static Footprint



Navier solution for a simply supported panel

$$k_1 := \frac{16}{\pi^6} \cdot \left[\sum_m \sum_n \frac{\cos\left(m \cdot \pi \cdot \frac{\phi}{a}\right) \cdot \cos\left(n \cdot \pi \cdot \frac{\phi}{a}\right) \cdot \sin\left(m \cdot \frac{\pi}{2}\right) \cdot \sin\left(n \cdot \frac{\pi}{2}\right)}{m \cdot n \cdot \left(\left(m^2 + n^2\right)\right)^2} \right]$$

$$k_2 := \frac{16}{\pi^4} \cdot \left[\sum_m \sum_n \frac{\cos\left(m \cdot \pi \cdot \frac{\phi}{a}\right) \cdot \cos\left(n \cdot \pi \cdot \frac{\phi}{a}\right) \cdot \sin\left(m \cdot \frac{\pi}{2}\right) \cdot \sin\left(n \cdot \frac{\pi}{2}\right)}{m \cdot n \cdot \left(\left(m^2 + n^2\right)\right)} \right]$$

$n = 1,3,5....$

$m = 1,3,5....$

$$\phi := \frac{a - \sqrt{A_{eff}}}{2}$$

Analysis Calibration

$A_{eff} = 178\ in^2$, $a = 20\ in$, $q = 16\ psi$, $w = 0.207$

$\varepsilon_x + \varepsilon_y = 2.66 \times 10^{-3}$

Input Material Properties: Ef= 13 Msi, Gc= 60 ksi
Predicted Displacement: 0.135 in

Computed Material Properties: Ef= 8.3 Msi, Gc= 46.2 ksi
Measured Displacement: 0.207 in

Face sheet variation: 64% of input value
Honeycomb variation: 77% of input value
Displacement variation: 53% greater than predicted

Experimental Conclusions:

Simulation testing was successful in terms of:

- Test panel preparation
- Test control. ASTM D6416 can be extended to fatigue testing.
- Repeatability

Analysis Conclusions

- Panel Flexural and Shear Stiffness are lower than predicted
- Valuable estimate of the predictive accuracy for sandwich plates
- Sources of discrepancy:
  - Isotropic Assumption/Sandwich Model
  - Boundary Conditions
  - Load Foot Print

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