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# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

(A portion of the study titled “Effects of Moisture Diffusion in Sandwich Composites”)

Hrishikesh (‘Rishi’) Pathak and Mark Tuttle
Department of Mechanical Engineering
University of Washington

2018 Fall AMTAS Meeting
UW Center for Urban Horticulture

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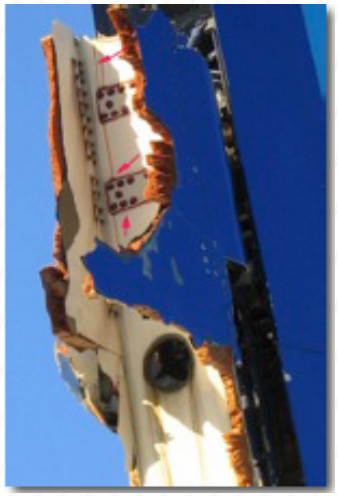
# Background: "Effects of Moisture Diffusion in Sandwich Composites"

## Motivation and Key Issues:

In-service bond failures between composite facesheets and honeycomb cores in sandwich structures have been reported:

Boeing 747 upper skin disbonds


Airbus A-310 Rudder Failure



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# Background: "Effects of Moisture Diffusion in Sandwich Composites"

Motivation and Key Issues:

- Core-to-skin disbond initiation and growth are thought to occur due to combination of factors:
  - Water ingression into core volume, followed by freeze-thaw cycles….water ingression may occur due to:
    - Wicking of liquidous water through facesheet microcracks, along fiber/matrix interfaces, and/or through improper design of edge closeouts
    - Diffusion of water *molecules* through (otherwise undamaged) facesheets, resulting in increased core humidity levels
  - Pressure differences between inside and outside of unvented honeycomb cores (Ground-Air-Ground or 'GAG' pressure cycles)

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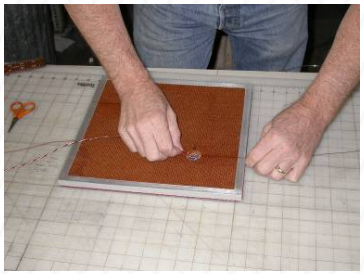
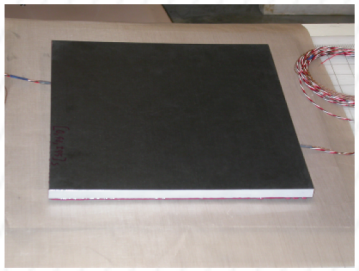
# Background: "Effects of Moisture Diffusion in Sandwich Composites"

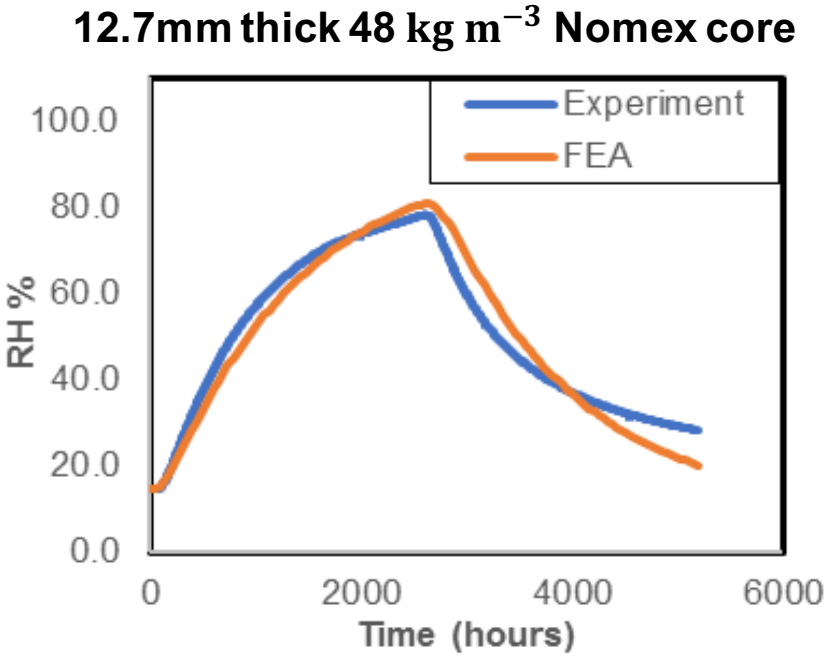
- **Principal Investigator**
  - Mark Tuttle
- **Students**
  - Current: Rohith Jayaram
  - Past Participants: Hrishikesh ("Rishi") Pathak, Anirudh Ashok, Andrew King, Ritika Singh, Karen Harban, Balakumaran ("Bala") Gopalarethinam, Will Smoot, Sun Lin "Jason" Tien, Shuyu "Frank" Xia
- **FAA Technical Monitor**
  - Lynn Pham, Zhi-Ming Chen
- **Industry Participation**
  - Bill Avery, Hamid Razi, and Adam Sawicki/The Boeing Company
  - Dan Holley and Chris Praggastis/3M
  - Bob Fagerlund/Bell Helicopter
  - Kevin Marshall/Hexcel Corporation
  - Shreeram Raj/Solvay Composites
- **Study Initiated in September 2015**

# Background: "Effects of Moisture Diffusion in Sandwich Composites"

- Task 1: Measure humidity increase in sandwich core volume due to diffusion and compare with FE predictions



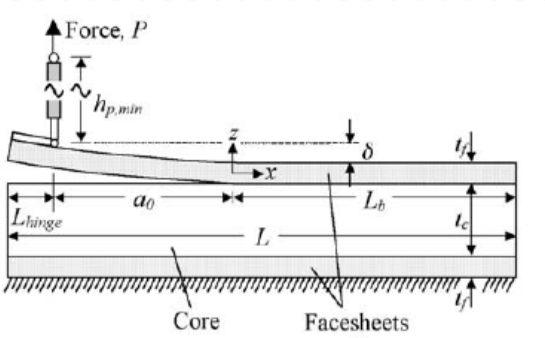


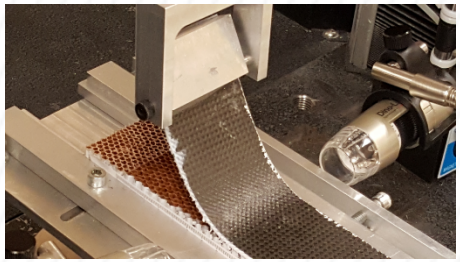


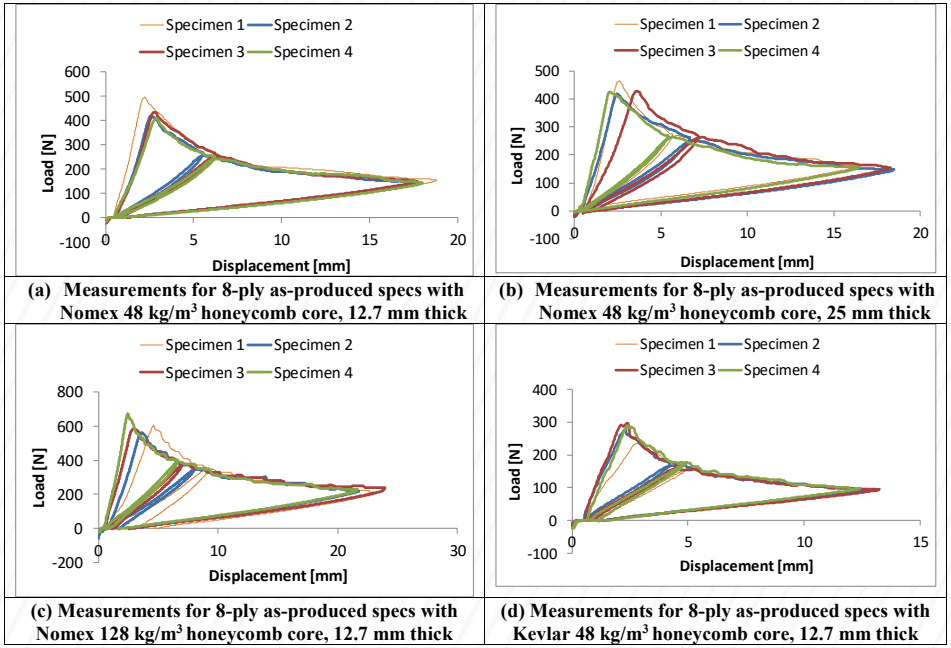

Increase in RH% for panel with 8-ply facesheet
caused by exposure to 65°C and 90%RH
(B. Gopalarethinam and M. Tuttle, ASC Conf, Seattle, Sept 2018)

# Background: "Effects of Moisture Diffusion in Sandwich Composites"

- Task 2: Measure critical strain energy release rate ($G_c$) using SCB specimens subjected to elevated humidity and thermal cycling






(a) Measurements for 8-ply as-produced specs with Nomex 48 kg/m$^3$ honeycomb core, 12.7 mm thick

(b) Measurements for 8-ply as-produced specs with Nomex 48 kg/m$^3$ honeycomb core, 25 mm thick

(c) Measurements for 8-ply as-produced specs with Nomex 128 kg/m$^3$ honeycomb core, 12.7 mm thick

(d) Measurements for 8-ply as-produced specs with Kevlar 48 kg/m$^3$ honeycomb core, 12.7 mm thick

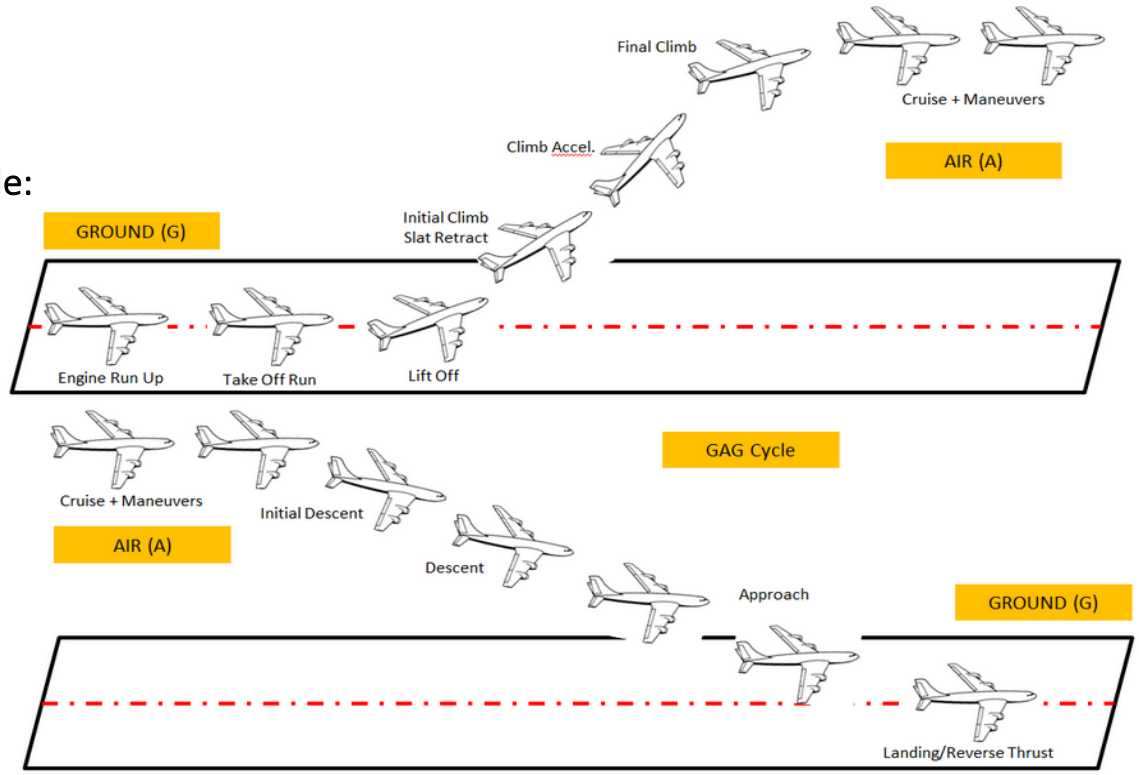
96 SCB tests performed using various facesheet/core combinations, all at room temperature (Rishi Pathak, Anirudh Ashok, Andrew King, Ritika Singh, Karen Harban, Shuyu "Frank" Xia)

# Background: "Effects of Moisture Diffusion in Sandwich Composites"

- Task 3: Develop an experimental setup to simulate ground-air-ground (GAG) pressure cycles, which can be used to study delamination growth due to pressure cycles in the lab

Ground-Air-Ground Pressurization Cycle:

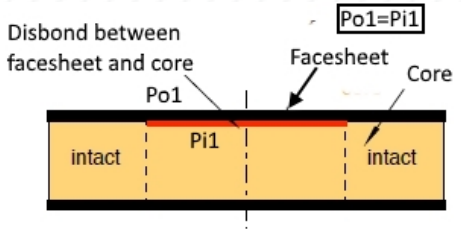
- Take Off
- Cruise + Maneuvers
- Landing



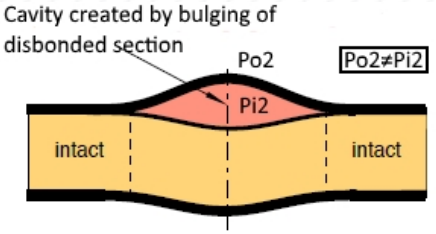
# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

- **External Pressure decreases from 14.7 psi at ground level to 2 psi at cruise altitude (~36000ft)**
- **External Pressure increases from 2 psi to 14.7 psi during descent of aircraft.**
- **Pressure difference between inside and outside of unvented sandwich structures**
  - Caused by alternating changes in external pressure and temperature
  - Results in significant deformations and core volume increase

- **Initial configuration at ground elevation**




- **Deformed configuration at cruising altitude**




*Chen, Z. M., R. Krueger, and M. Rinker. 2015. "Face Sheet/Core Disbond Growth in Honeycomb Sandwich Panels Subjected to Ground-Air-Ground Pressurization and In-Plane Loading," presented at the National Agency for Finite Element Methods and Standards World Congress 2015, June 21-June 24, 2015.*

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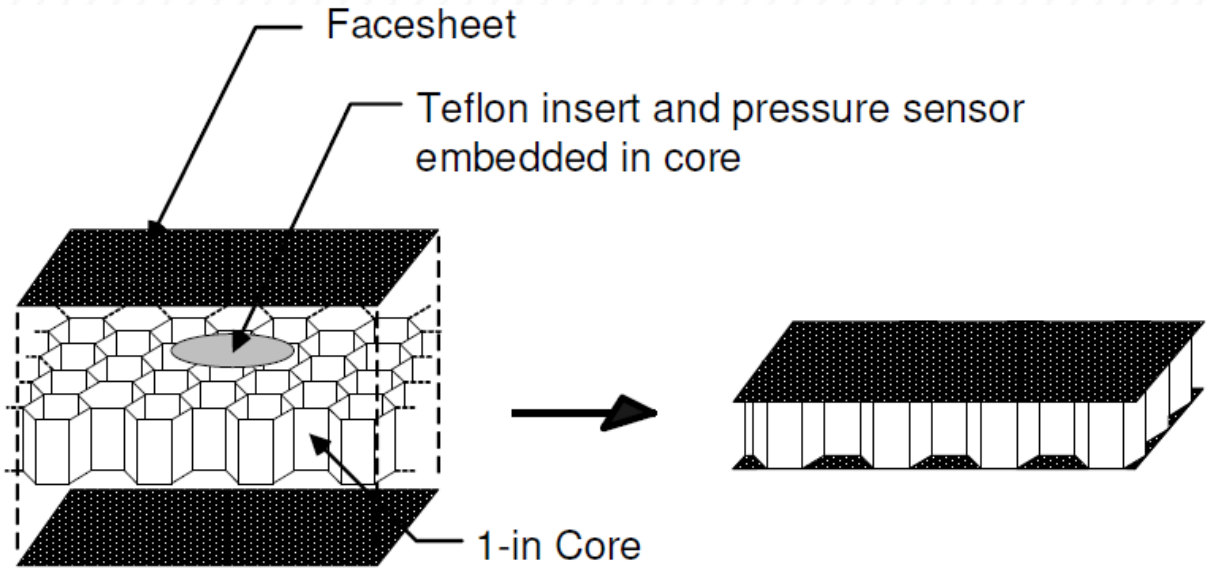
# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

- GAG Specimens



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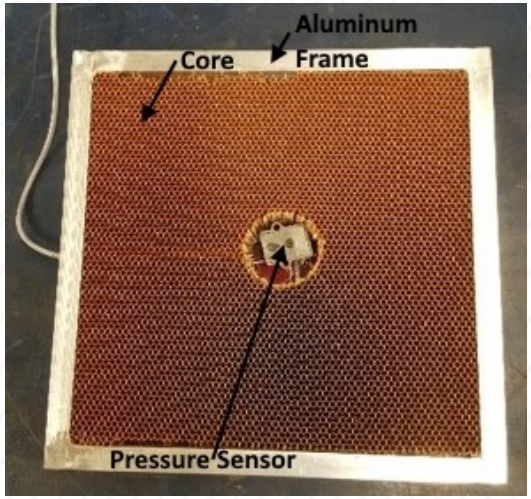


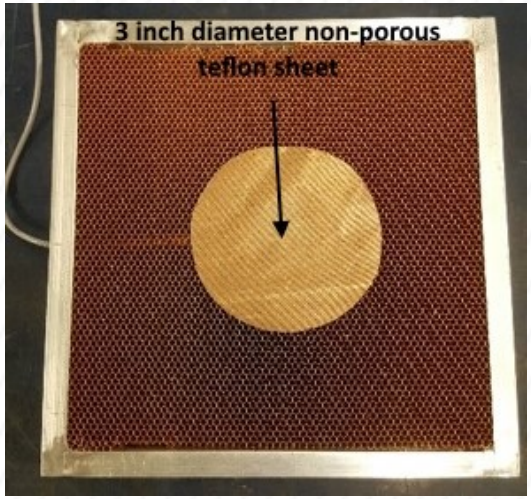


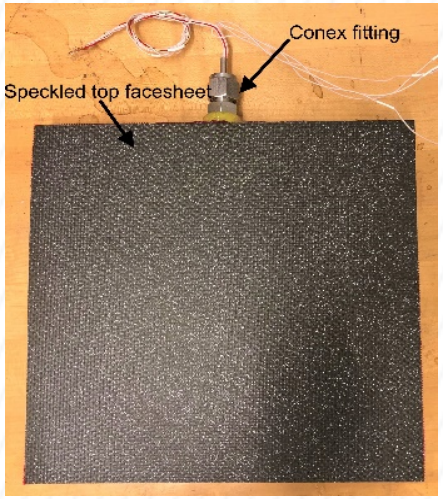

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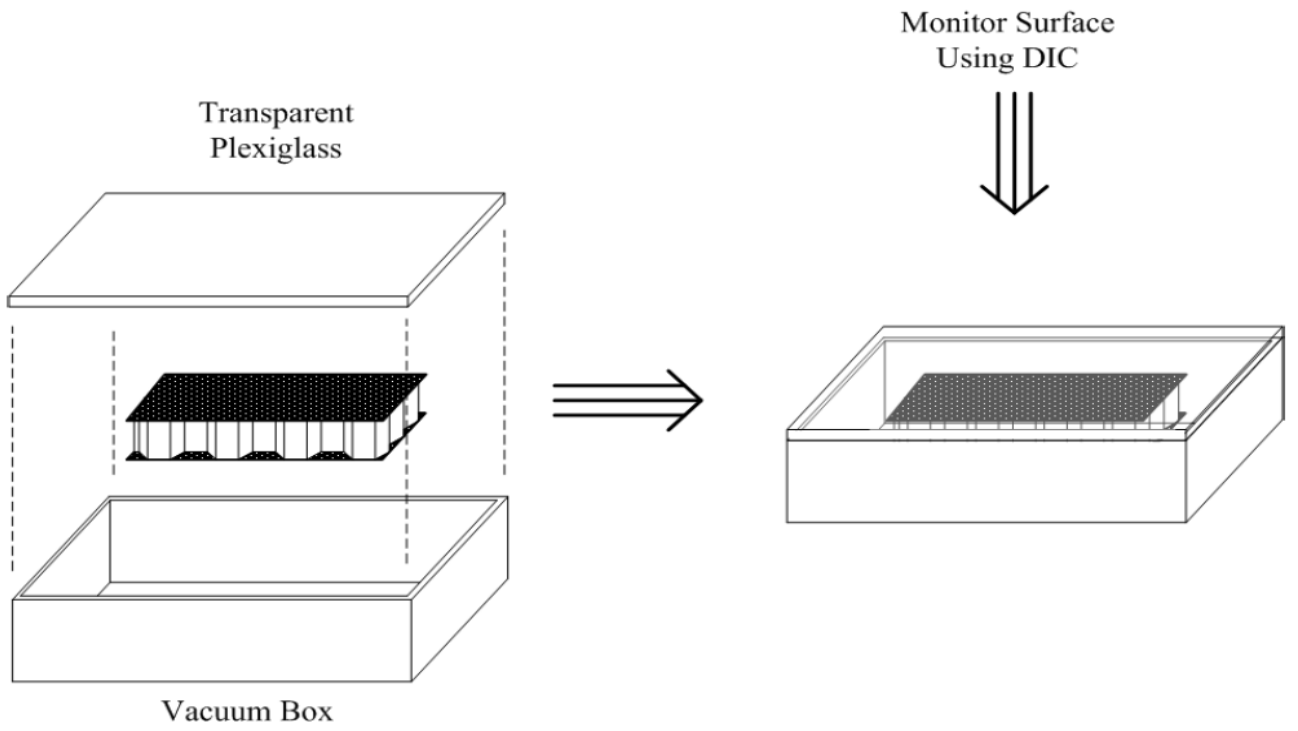

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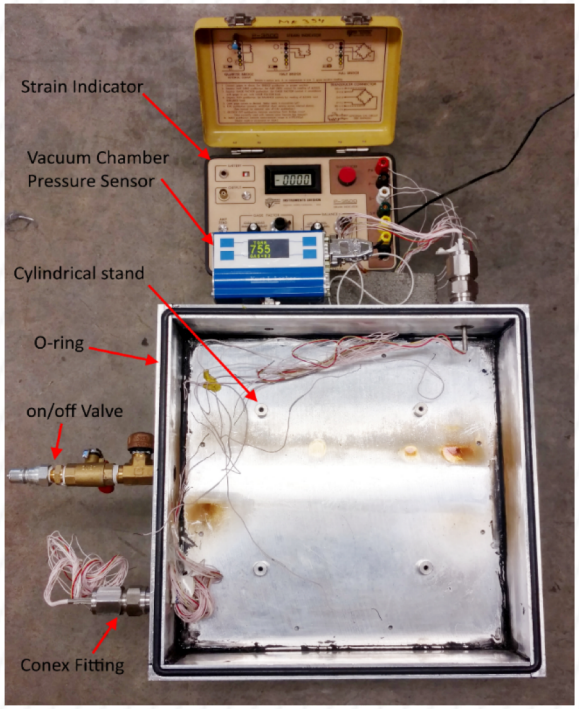


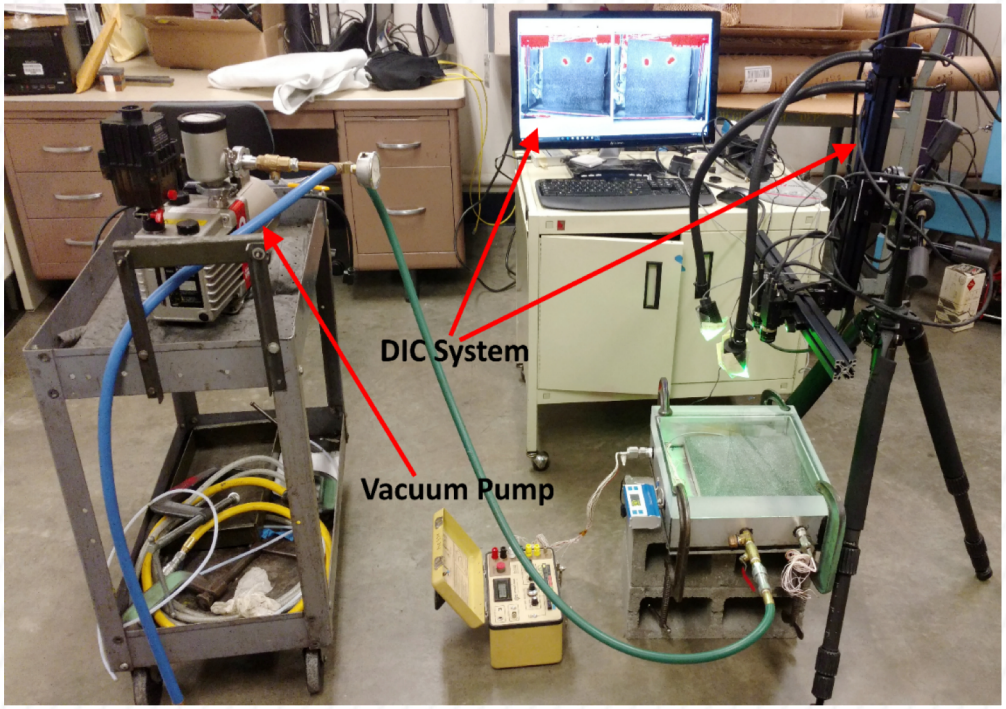

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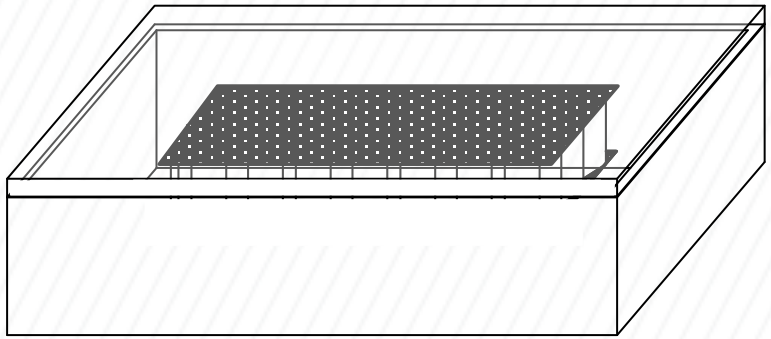
# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

- Modifications of test setup as experience gained:
  - Increased thickness of transparent plexiglass plate from 0.5 in to 2 in, to minimize optical distortions due to plate deflection



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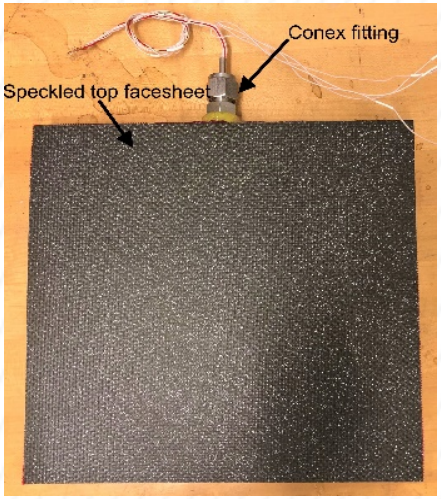
  - Added Nomex fitting to GAG specimen aluminum frame, to eliminate pressure loss from core volume



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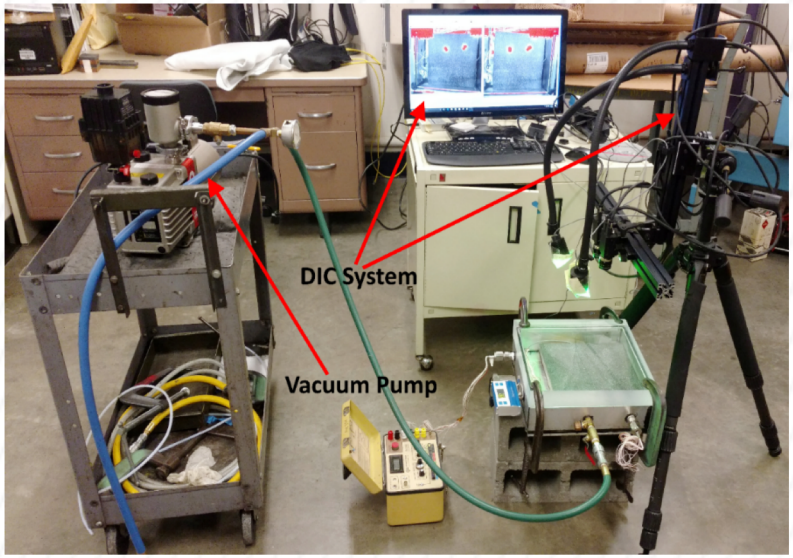
  - Adjusted camera angles used in 3D DIC measurements to improve accuracies



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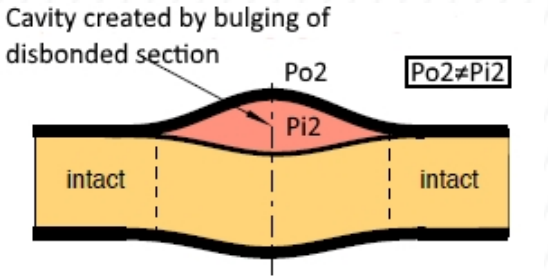
  - Added Nomex fitting to GAG specimen aluminum frame, to eliminate pressure loss from core volume
  - Adjusted camera angles used in 3D DIC measurements to improve accuracies
  - Increased thickness of backside (non-delaminated) facesheet, such that distortions due to pressure differential occurs primarily on delaminated side



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# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

Facesheet/core combinations tested to date:

| Component | Description | Product Designation |
|---|---|---|
| Facesheet Panels | Carbon/Epoxy plane woven prepreg | Cytec (Solvay) Facesheet panels T300/970 3k PW |
| | Three-ply: $[0/45/0]_T$ | |
| | Four-ply: $[0/90]_S$ | |
| | Eight-ply: $[0/45/90/45]_S$ | |
| Core Material | Nomex 48 kg/m$^3$ honeycomb core, 25.4 mm thick (3 lb/ft$^3$; 1.0 in thick) | Hexcel HRH-10-3-1inch |
| Adhesive | Thin film adhesive | 3M Scotch-Weld AF 163-2k |

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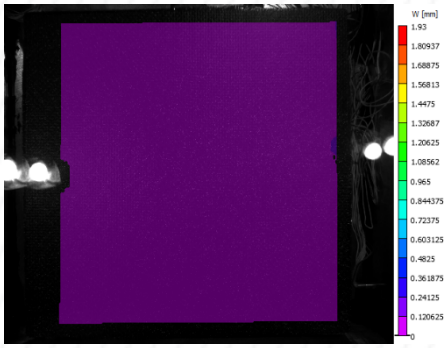
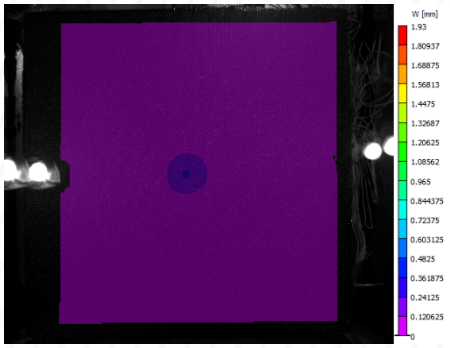
# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

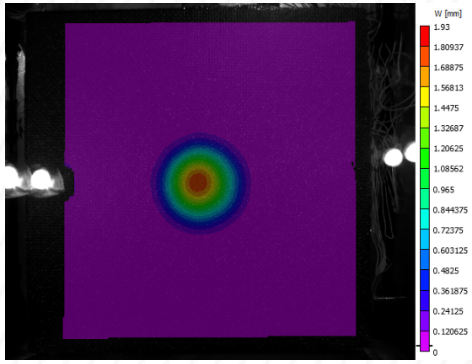
*Typical Measurements for Panel w/3-ply facesheets*



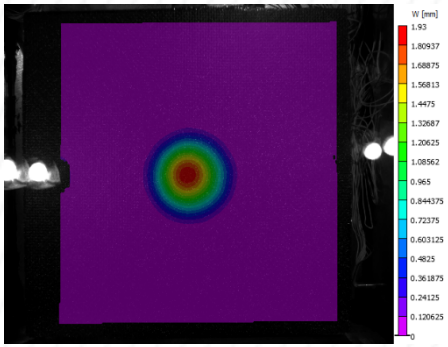

External pressure = 14.7 psi
Core pressure = 14.7 psi



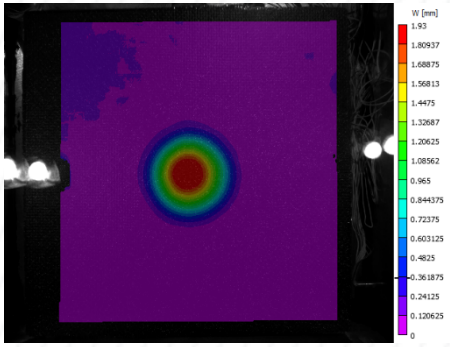

External pressure = 14 psi
Core pressure = 14.65 psi



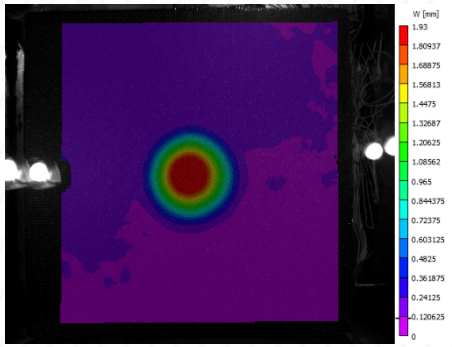

External pressure = 10.2 psi
Core pressure = 14.61 psi




External pressure = 8.5 psi
Core pressure = 14.56 psi




External pressure = 4.3 psi
Core pressure = 14.50 psi




External pressure = 2 psi
Core pressure = 14.45 psi

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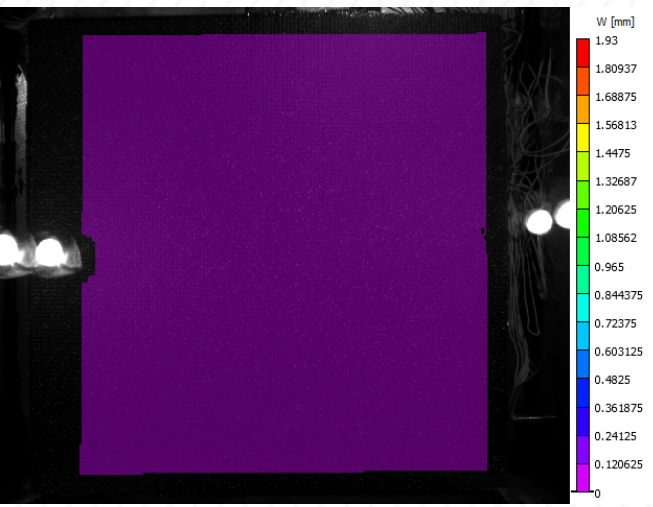
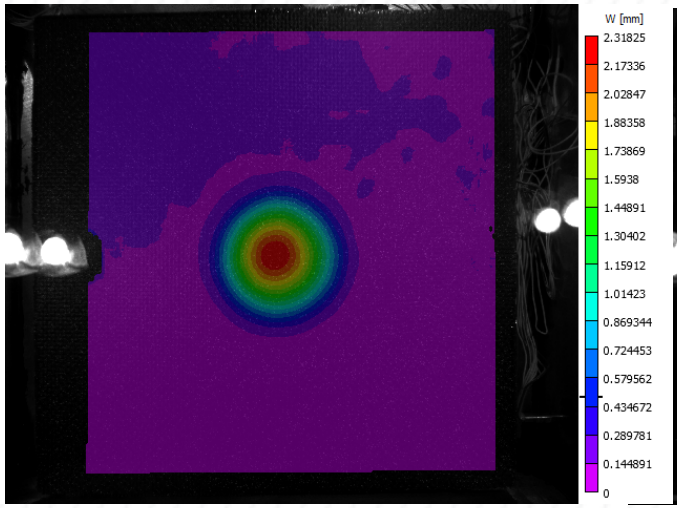
# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

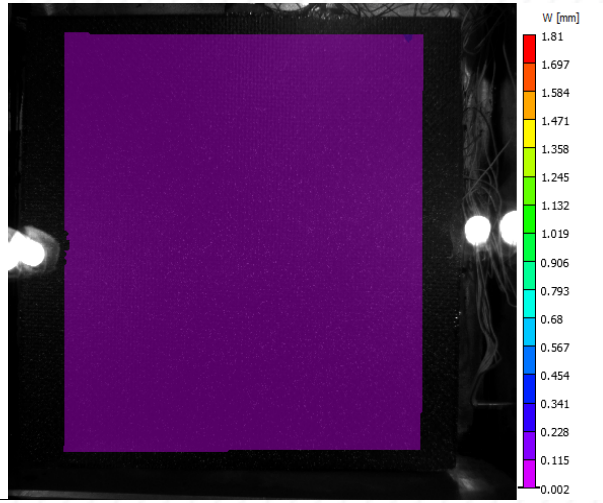
**3 Plies Facesheet GAG Specimen – $[0/45/0]_T$: ($1^{st}$ Run)**




Before starting the vacuum pump
Pressure in Vacuum Box = 14.67 psi
Pressure in specimen core = 14.68 psi




After pressurization
Pressure in Vacuum Box = 1.99 psi
Pressure in specimen core = 14.44 psi
Max W(mm) = 2.318mm

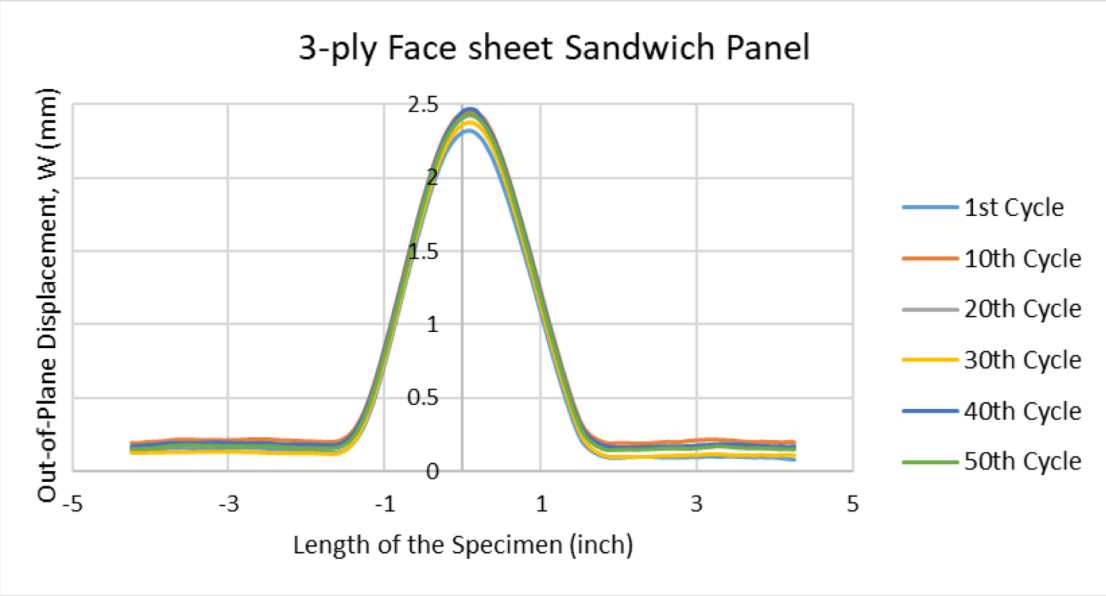



After depressurization
Pressure in Vacuum Box = 14.66 psi
Pressure in specimen core = 14.65 psi

# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

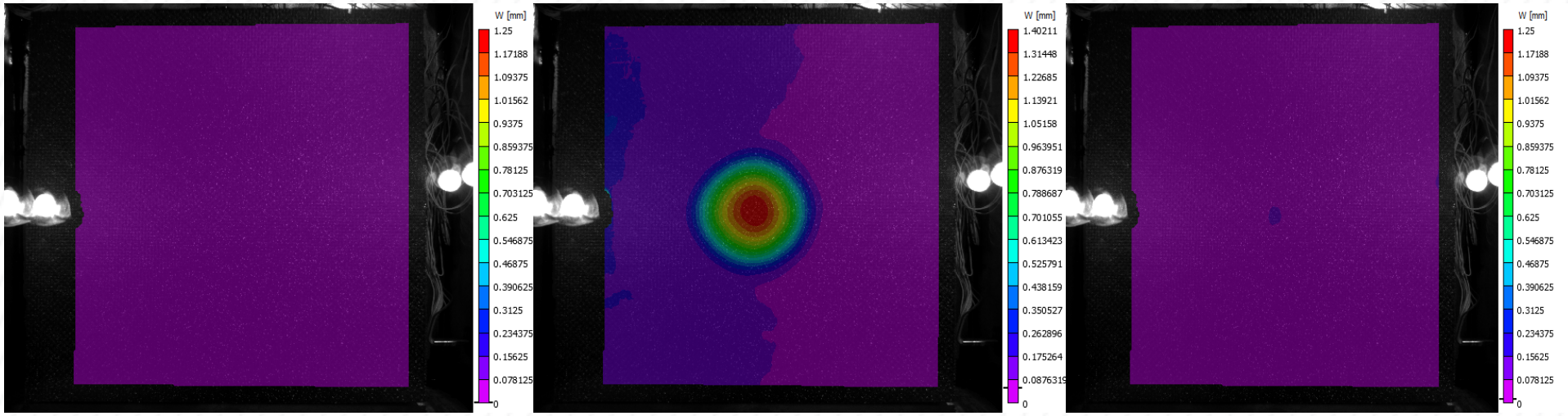
**3 Plies Facesheet GAG Specimen – $[0/45/0]_T$: ($1^{st}$ Run to $50^{th}$ Run)**

| Cycle | Out-of-Plane Displacement "W(mm)" |
|---|---|
| $1^{st}$ cycle | 2.31825 |
| $10^{th}$ cycle | 2.45095 |
| $20^{th}$ cycle | 2.42351 |
| $30^{th}$ cycle | 2.3788 |
| $40^{th}$ cycle | 2.46649 |
| $50^{th}$ cycle | 2.42939 |



# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

**4 Plies Facesheet GAG Specimen – $[0/90]_S$: (1st Run)**




Before starting the vacuum pump
Pressure in Vacuum Box = 14.67 psi
Pressure in specimen core = 14.69 psi

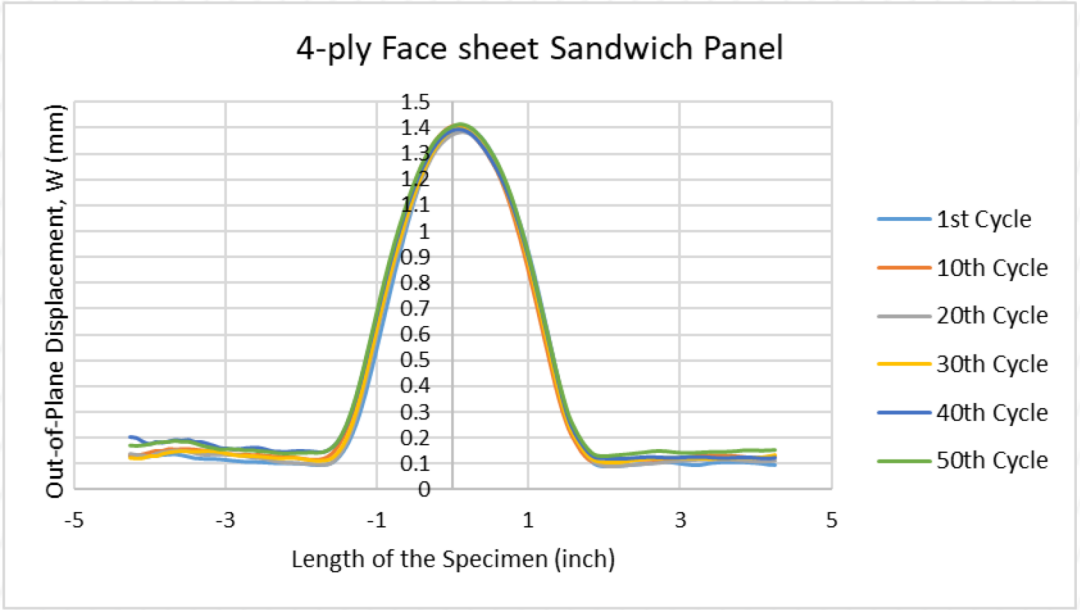
After pressurization
Pressure in Vacuum Box = 2.01 psi
Pressure in specimen core = 14.51 psi
Max W(mm) = 1.402mm

After depressurization
Pressure in Vacuum Box = 14.66 psi
Pressure in specimen core = 14.67 psi

# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

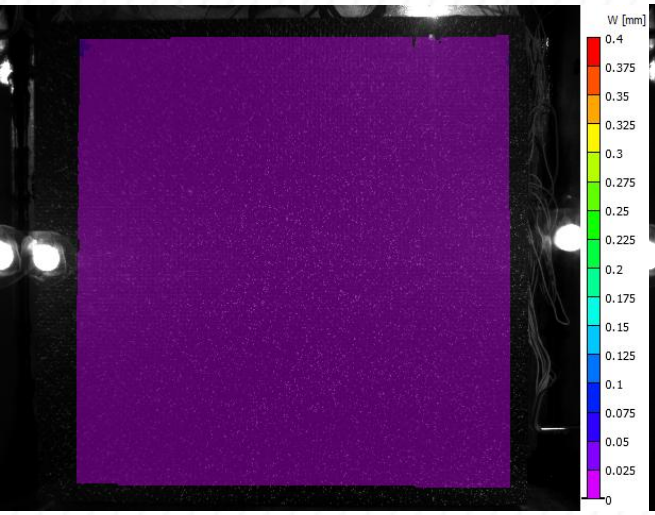
**4 Plies Facesheet GAG Specimen – $[0/90]_S$: ($1^{st}$ Run to $50^{th}$ Run)**

| Cycle | Out-of-Plane Displacement "W(mm)" |
|---|---|
| $1^{st}$ cycle | 1.40211 |
| $10^{th}$ cycle | 1.40727 |
| $20^{th}$ cycle | 1.38378 |
| $30^{th}$ cycle | 1.3966 |
| $40^{th}$ cycle | 1.39539 |
| $50^{th}$ cycle | 1.41601 |

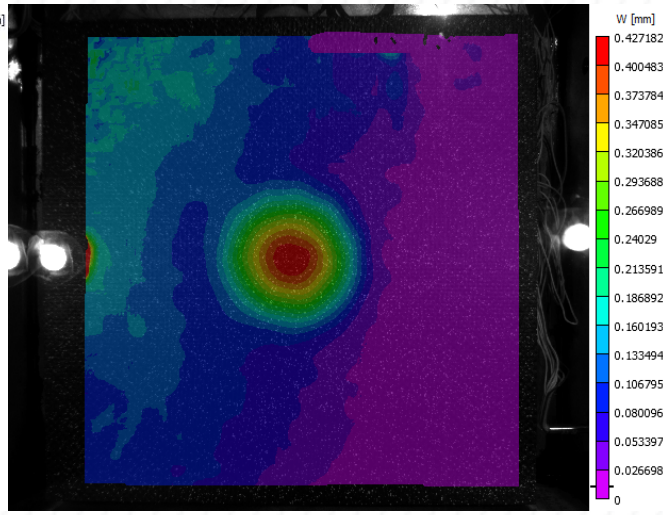


# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

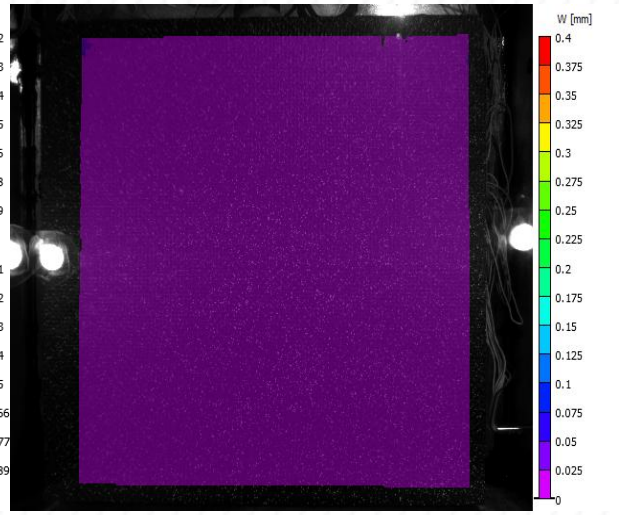
**8 Plies Facesheet GAG Specimen – $[0/45/90/45]_S$: (1st Run)**




Before starting the vacuum pump
Pressure in Vacuum Box = 14.68 psi
Pressure in specimen core = 14.69 psi




After pressurization
Pressure in Vacuum Box = 1.98 psi
Pressure in specimen core = 14.57 psi
Max W(mm) = 0.427mm

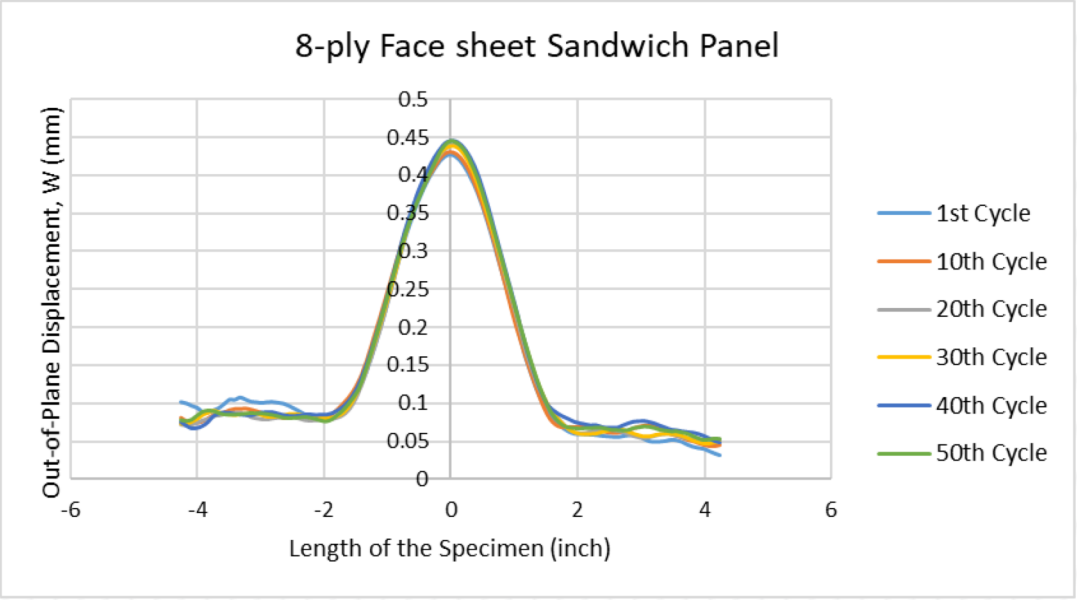



After depressurization
Pressure in Vacuum Box = 14.66 psi
Pressure in specimen core = 14.68 psi

# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

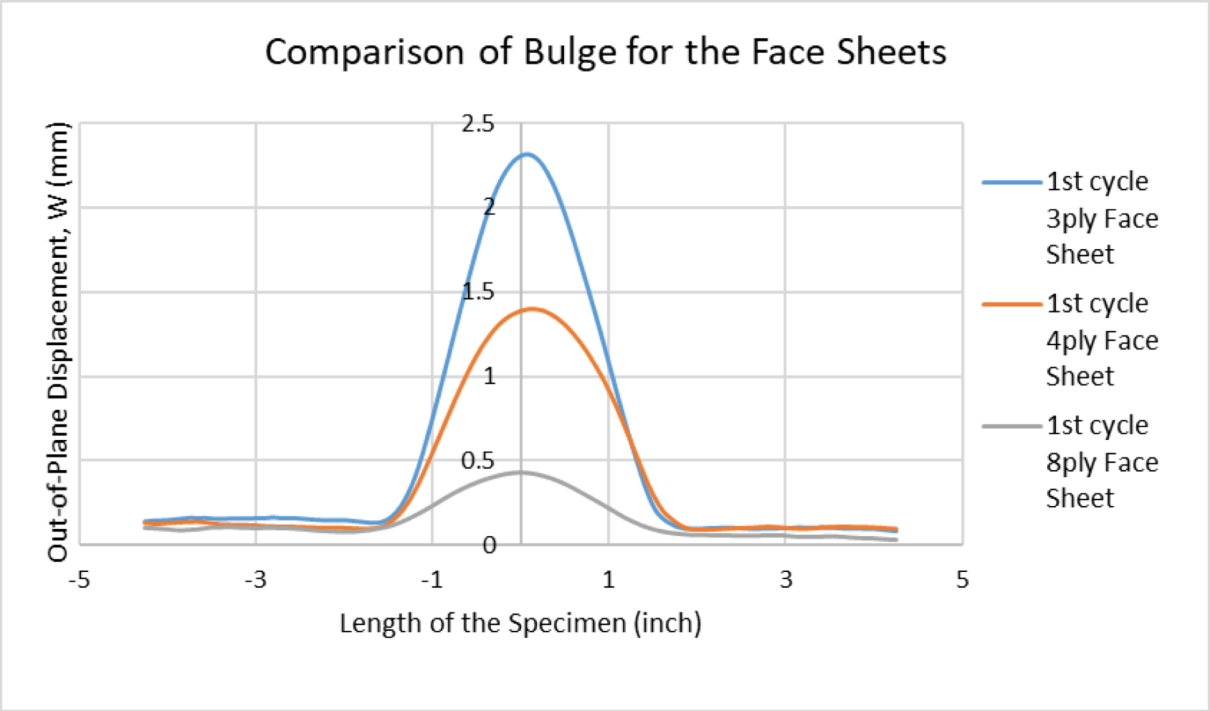
**8 Plies Facesheet GAG Specimen – $[0/45/90/45]_S$: (1st Run to 50th Run)**

| Cycle | Out-of-Plane Displacement "W(mm)" |
|---|---|
| 1st cycle | 0.427182 |
| 10th cycle | 0.430486 |
| 20th cycle | 0.440891 |
| 30th cycle | 0.43814 |
| 40th cycle | 0.444714 |
| 50th cycle | 0.446042 |



# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

**Comparison of 3 plies, 4 plies and 8 plies facesheet**



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# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

*Summary of Current Status*

- Ground-Air-Ground pressurization has been successfully replicated in the lab; specimens were subjected to external pressures decreasing from 14.7 psi to 2 psi and subsequently increased back to 14.7 psi.
- As expected, out-of-plane displacements due to pressure differentials decrease as facesheet thickness is increased
- Preliminary fatigue tests performed “manually” for 50 cycles…slight increases in displacement observed after ~ 40 cycles

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# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

*Work Planned for 2018-19*

- Modify pressure system to allow automated GAG cycles.
  - Conduct experiments for higher number of cycles/runs (e.g., 10k cycles)
  - Conduct experiments using different combinations of core densities and facesheet thickness.
- Introduce thermal chamber to allow tests at -50$^{o}$C
- Perform FEA modeling

# Laboratory Simulation of Ground-Air-Ground Pressurization of Sandwich Panels

## Thank You!

Questions, Comments, Suggestions?