Fluid Ingression Damage Mechanism in Composite Sandwich Structures

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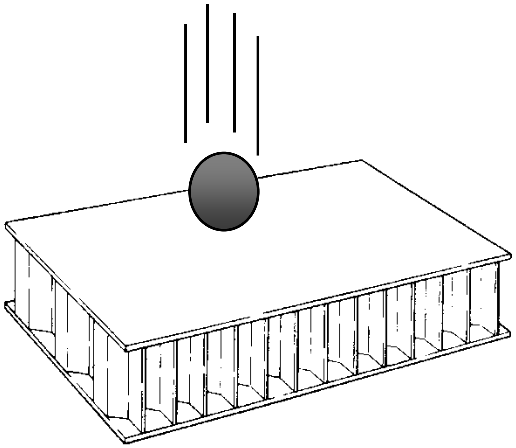
FAA Sponsored Project Information

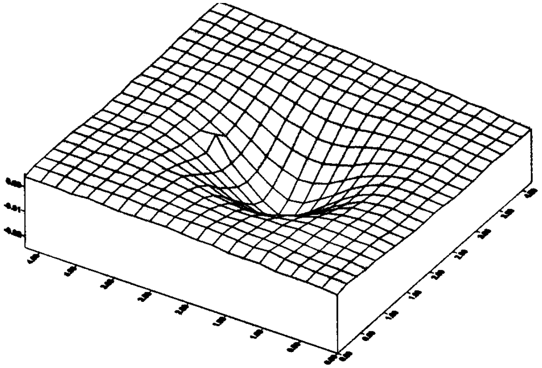
- Principal Investigators & Researchers
  - John Tomblin and Allison Crockett
- FAA Technical Monitor
  - Curt Davies
- Other FAA Personnel Involved
  - Larry Ilcewicz
- Industry Participation
  - Hal Loken, Consultant

FAA Research Investigations

Research Objective

Characterize the fluid ingression phenomenon in composite sandwich structures as well as to document the damage mechanisms which allow the fluid ingression to propagate and potentially degrade the structural performance





Lessons Learned in 1980's

- The trailing edge wedge on a 1970's wide-body transport aircraft was constructed of the following:
  - Woven fabric composite facesheets, solid laminate spar/attachment and aramid honeycomb core.
- The prepreg resin level had been minimized to reduce weight and the facesheet laminate had channels that directed water and Skydrol into the honeycomb core at the ply drop-offs.
- An increase in prepreg resin content solved this problem.
- As new materials and methods come into use, we must research application limits and define good practices.

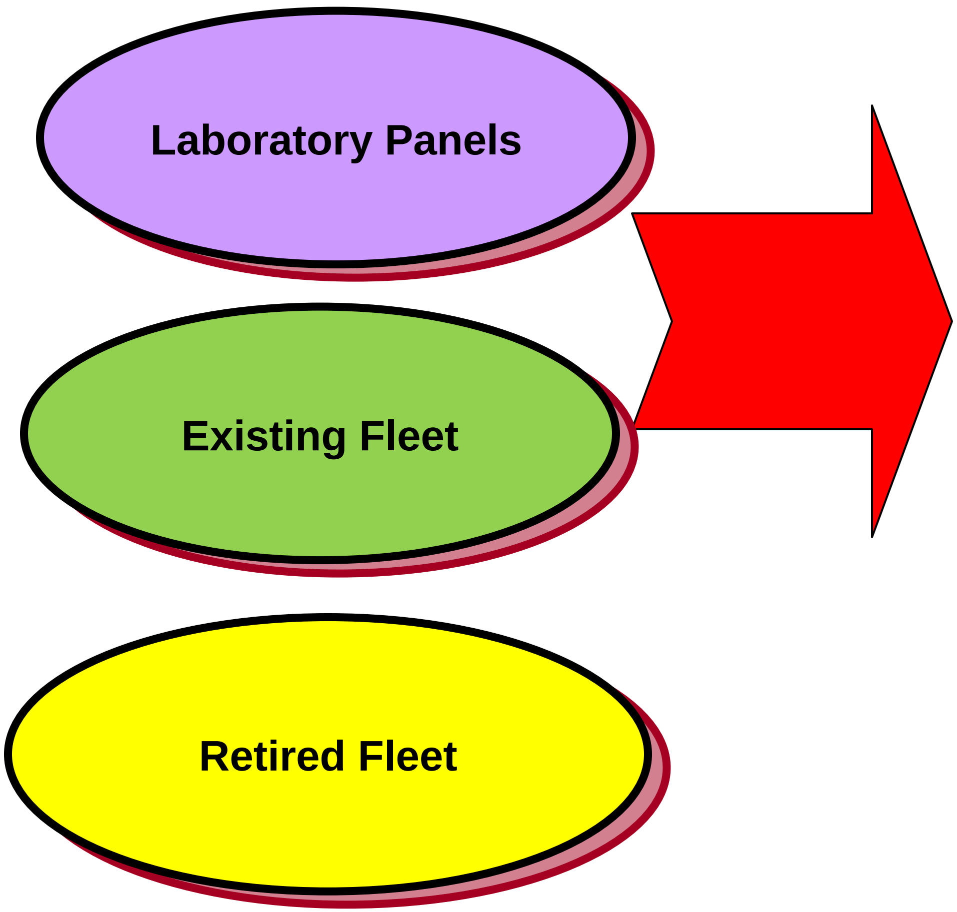
Lessons Learned in 1980's

- One of the biggest problems for an airline operator is when large hailstones strike at a major airport.
- Composite sandwich fixed trailing edge panels are typically damaged by the hailstones
- If not sealed or repaired, these panels will later develop water ingression into the honeycomb core at the spot where each large hailstone struck.
- Research will establish a cost effective standard for hailstone resistance.

What Industry Wants

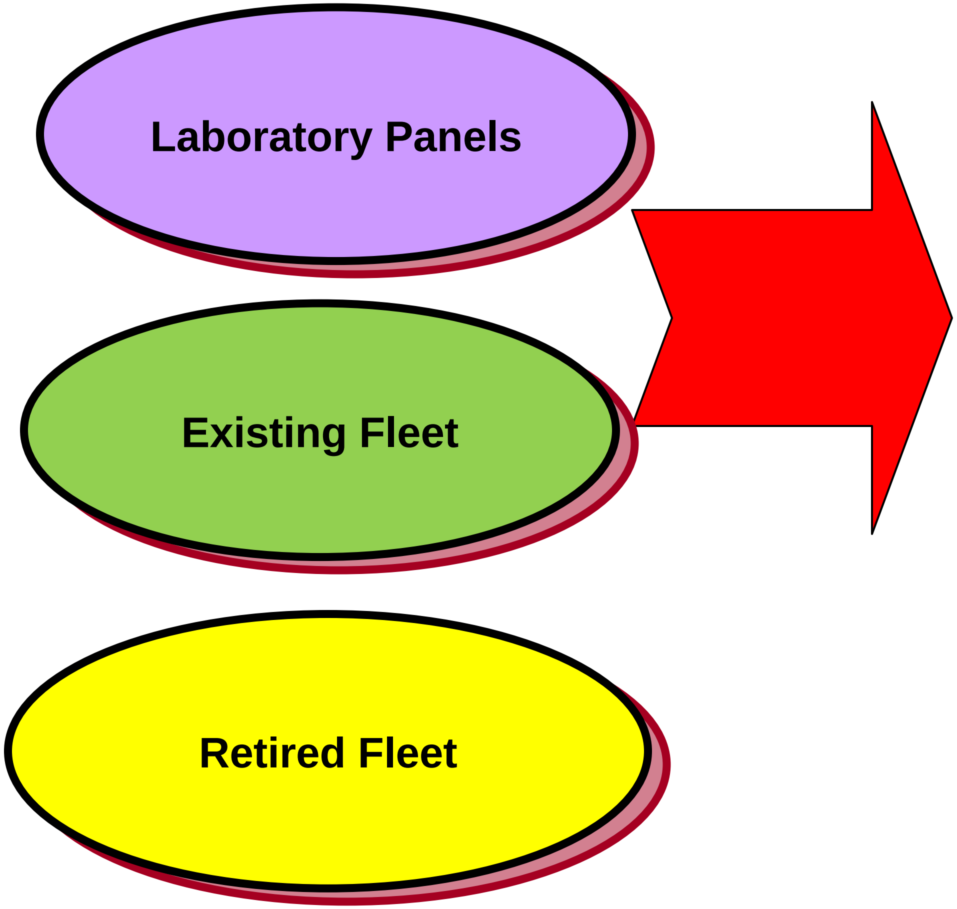
- In May 2007, Fluid Ingression was highlighted at the Damage Tolerance Workshop in Amsterdam.
- As a result Industry wants to know some details about Fluid Ingression before other details.
- From our breakout session the following outcomes where determined to be the most important.

Desired Outcomes



- Intercellular diffusion (good cell wall)
- Permeable cell wall
- Permeability as a function of age/load sensitivity
- Filleting quality
- Poorly machined honeycomb (poor bond)
- Freeze/thaw
- Porous or discontinuous adhesive (adhesive type/process)

Desired Outcomes



- How resistant is core
- Is fluid migration noticeable without impact damage
- Should there be a process specification on core
- Can foams be added to the test matrix

Current Industry Contributors

Configuration 1

Configuration 2

- Adam Aircraft and Hawker Beechcraft are the current two industry contributors which provided parts for the following research.

Terminology-Current Research

Fluid Ingression Damage Tolerance

Resistance to the propagation of damage due to fluid ingression and degradation of structural performance

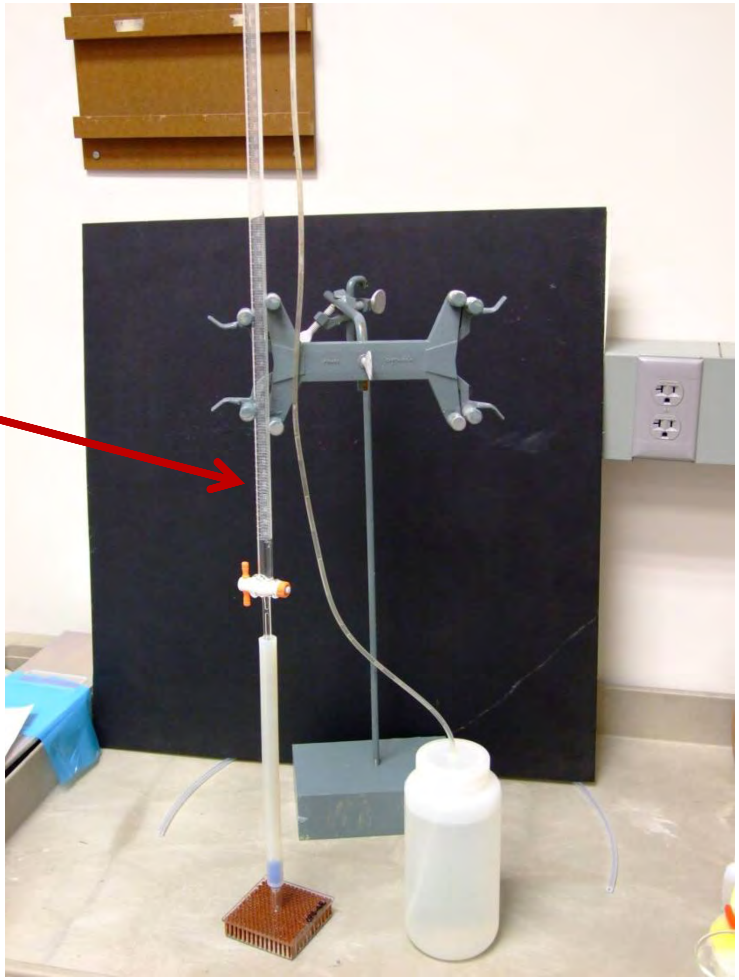
Fluid Ingression Damage Resistance

Material performance, design details and maintenance practices which resist fluid ingression into the core

Proposed research program will focus on *Fluid Ingression Damage Tolerance*

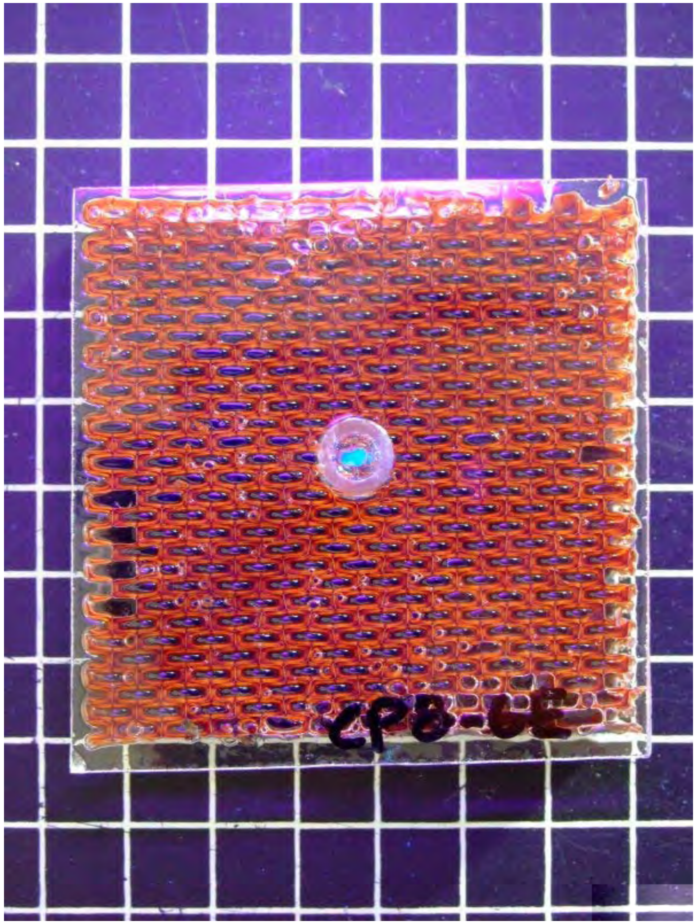
Permeability of Honeycomb Core

- Fluid Migration Test (ASTM F1645-00)
  - 36” tall hydrostatic column providing near-constant pressure within primary core cell wall.
  - Fluid is applied to honeycomb cell through column for 24 hrs.



Permeability of Honeycomb Core

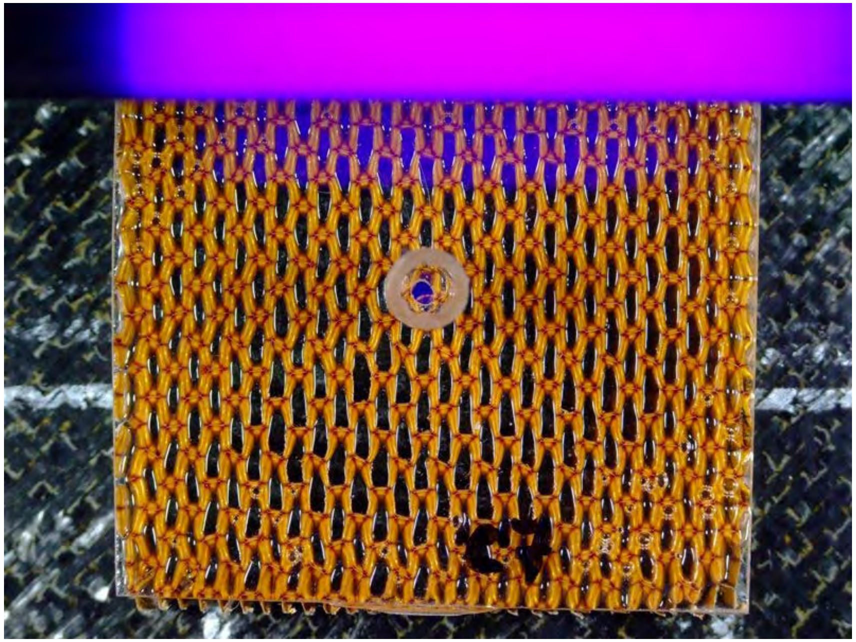
- Test Set-up Parameters
  - Three samples from each configuration were tested
  - Color dye/UV light was used as a visual aide to see the fluid migrating.
  - Deionized water was the initial fluid used
  - Sample size was 3.0”length x 3.0” width



CONFIGURATION 2 PANEL

Permeability of Honeycomb Core

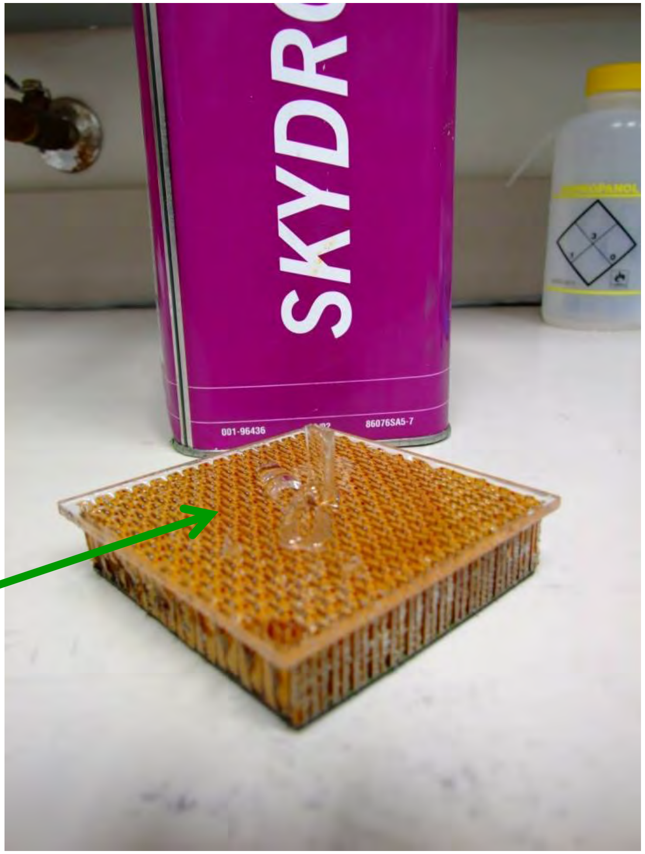
- Test Set-up Parameters
  - Honeycomb core was bonded to an impermeable transparent facing
  - Adhesive to bond the facing is water resistant and applied heavily to form strong fillets between the core and facing.
  - Water did not migrate beyond the single honeycomb cell the fluid was placed in for any sample from configuration 1 or 2.



CONFIGURATION 1 PANEL

Fluid Migration Testing continued…..

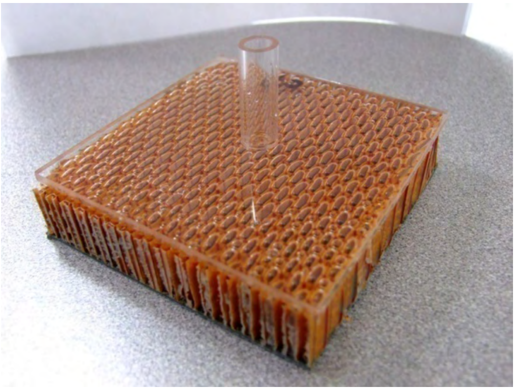
- Additional fluids were also used for the Water Migration Test using ASTM F1645-00
- Skydrol, JP-8, Hydraulic Fluid Royco 756
  - Skydrol made plexiglas brittle causing it to fracture



Water Migration Results

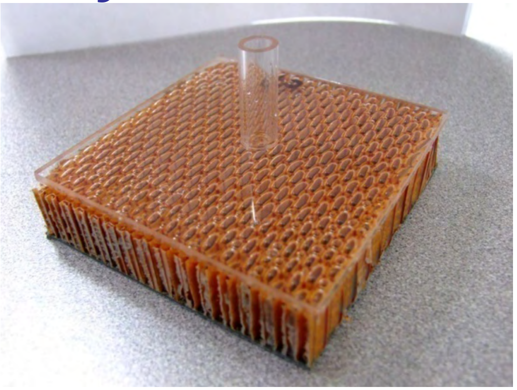
SPECIMEN NAME	Dry Weight (g)	Weight with Single Cell Filled with Water (g)	After 24 Hrs Specimen weight (g)	Single Cell Water Weight (g)	Water Migrated After 24 hrs (g)	No. of Cells Water Migrated to	Comments
CP8-6E	40.34	40.64	40.69	0.30	0.05	0.2 cell	NO MIGRATION
CP6-3D	54.56	54.81	54.82	0.25	0.01	0.0 cell	NO MIGRATION
C7	44.76	45.01	45.21	0.27	0.20	0.7 cell	NO MIGRATION

- Amount of water that is calculated as migrating cell-to-cell is negligible, due to nature of ASTM standard.
- Nomex Honeycomb cores tested from configuration 1 and 2 exhibit a water-proof cell wall.

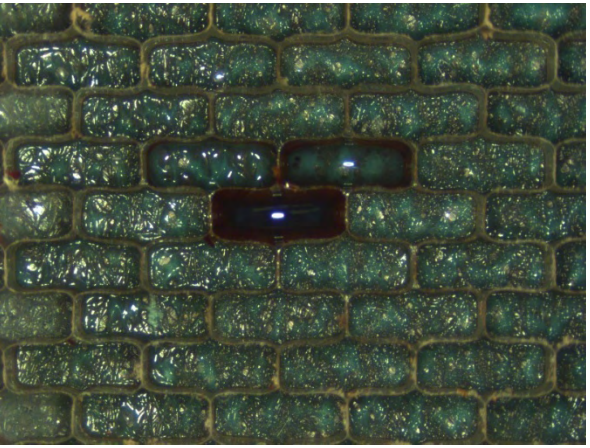


Water Migration Results

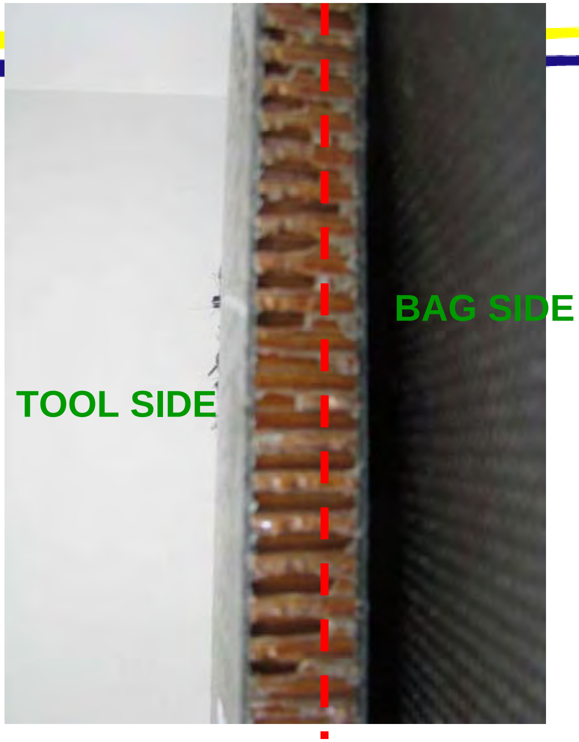
- ASTM F1645 test results can be affected by three things:
  - the permeability of the adhesive, the adhesive thickness and the thickness uniformity of the adhesive.
  - Voids, cracks and other defects may also affect the fluid migration results.

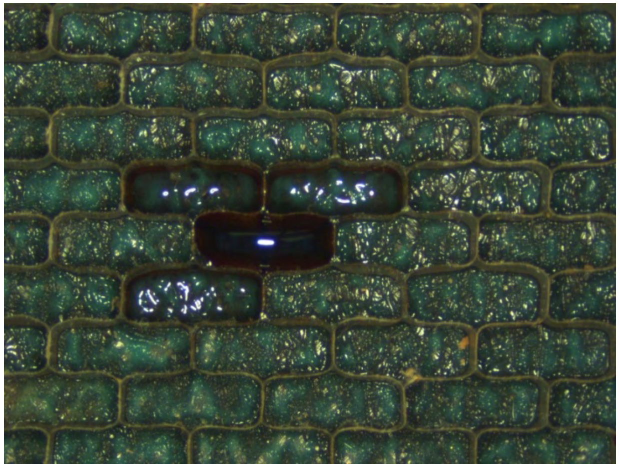


Permeability of Honeycomb Core



CP1B-3C TOOL SIDE



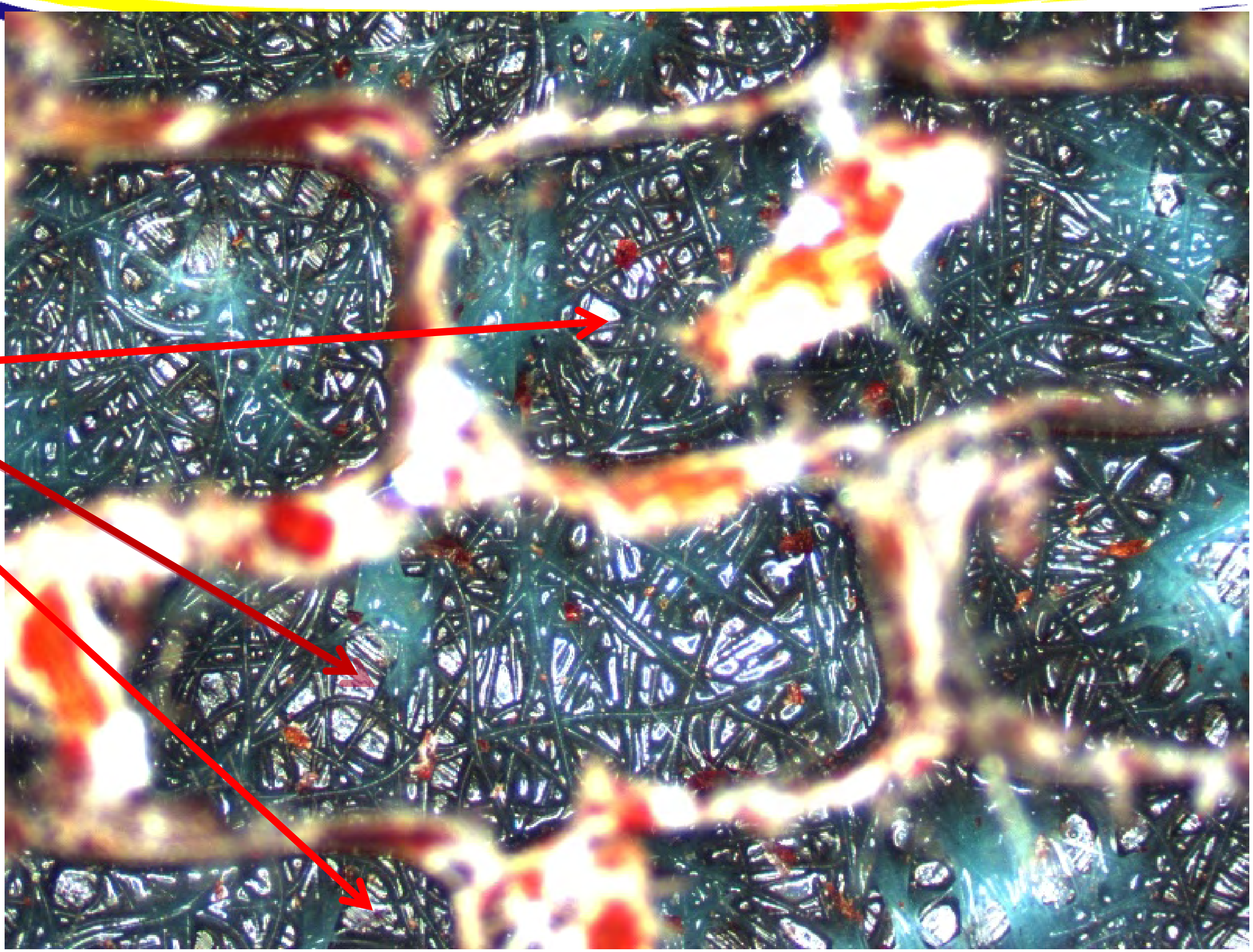


CP1B-3C BAG SIDE

- Consequently a more robust approach was taken so visibility of the cells and quality of the cell to facesheet bond was visible. The core was sliced in half as seen above, and a similar fluid test was repeated.

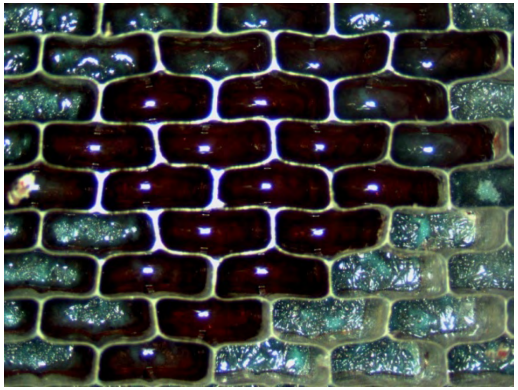
Problem between Facesheet and Core contributing to Fluid migration

Several Dry Spots

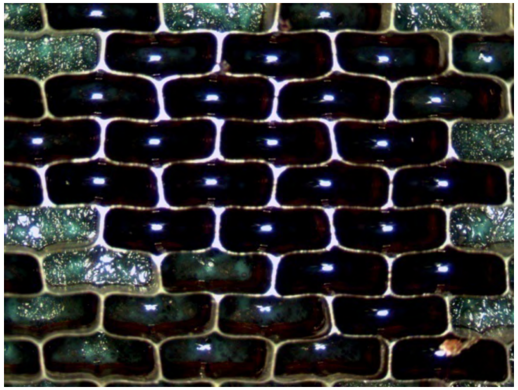


CONFIGURATION 2 PANEL

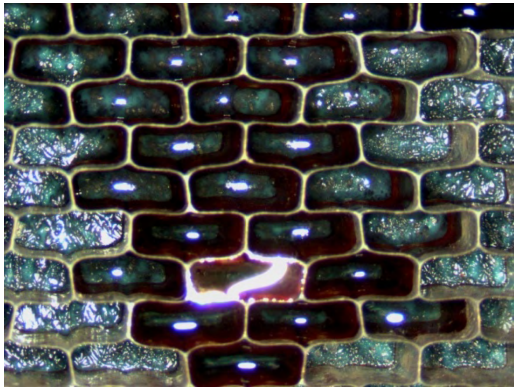
Problem between Facesheet and Core contributing to Fluid migration



Hydraulic Fluid



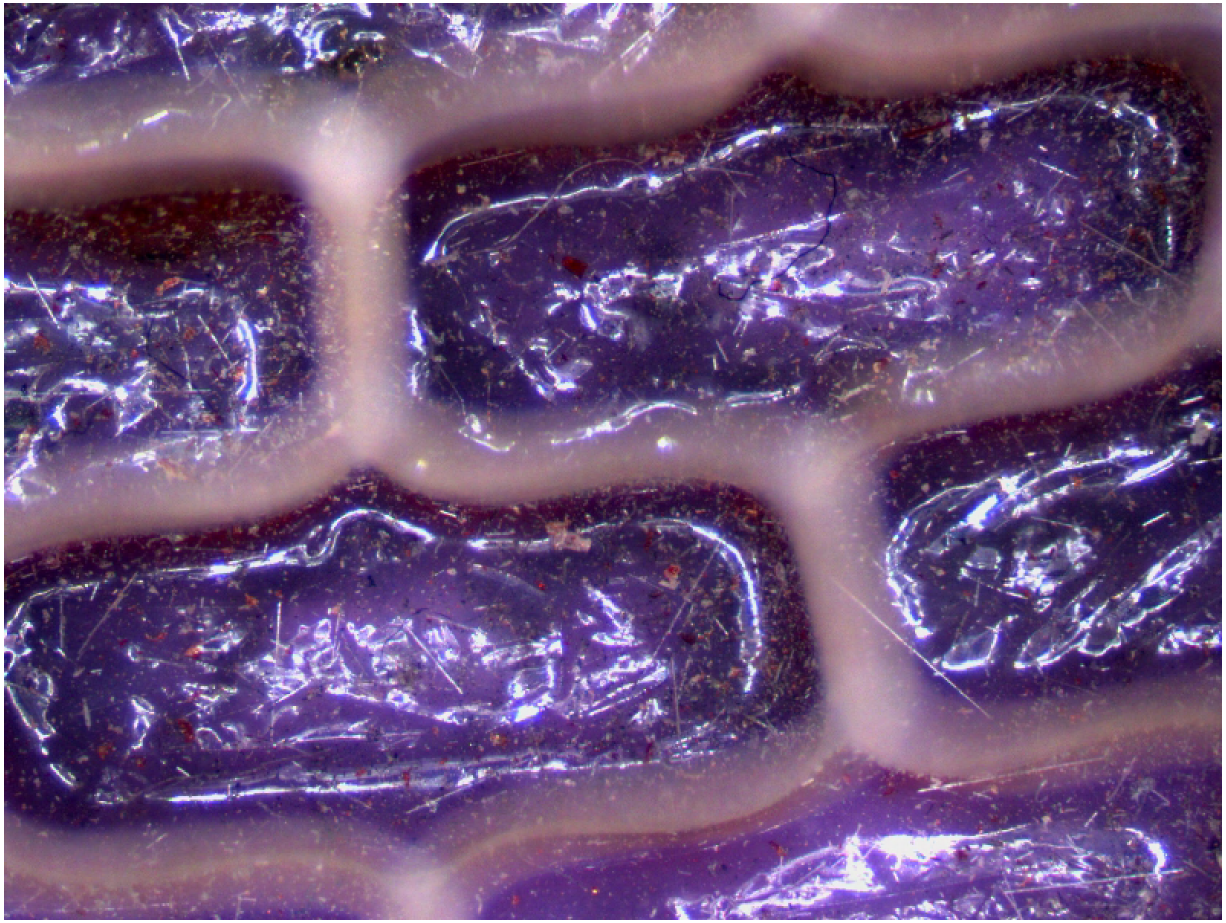
Skydrol



Water

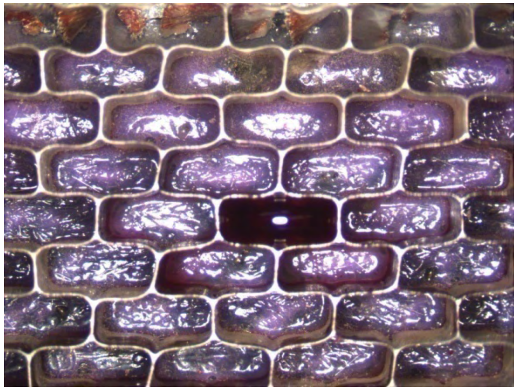
- Samples taken from the same Configuration 2 panel seen previously with dry spots.
- Three different fluids were added to one single cell.
- Migration between cells occurred after fifteen minutes, in all cases three cells filled with fluid immediately.
- No Configuration 1 panels displayed dry spots and therefore showed migration, half of the Configuration 2 panels tested showed migration.

No Dry Spots between facesheet and core visible

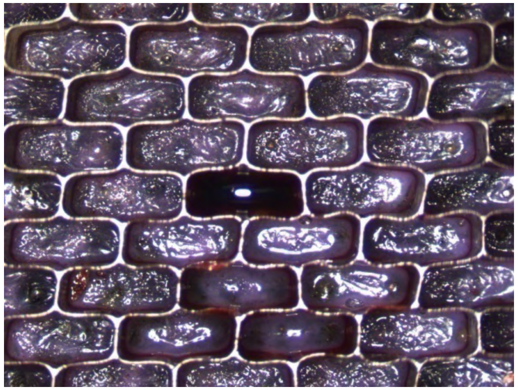


CONFIGURATION 2 PANEL

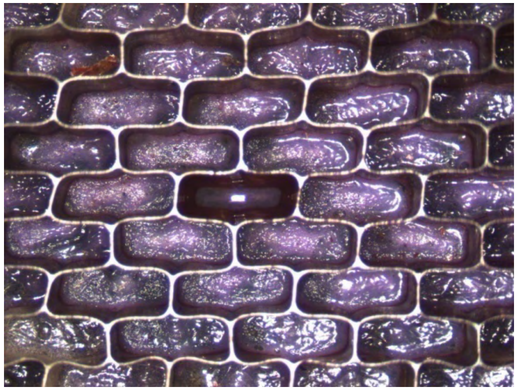
No Dry Spots-Spacing between Honeycomb core and Facesheet fully Filled



Hydraulic Fluid



Skydrol

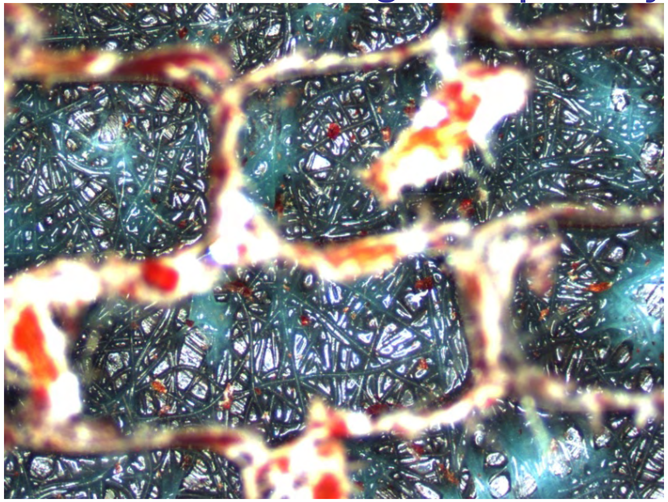


JP8

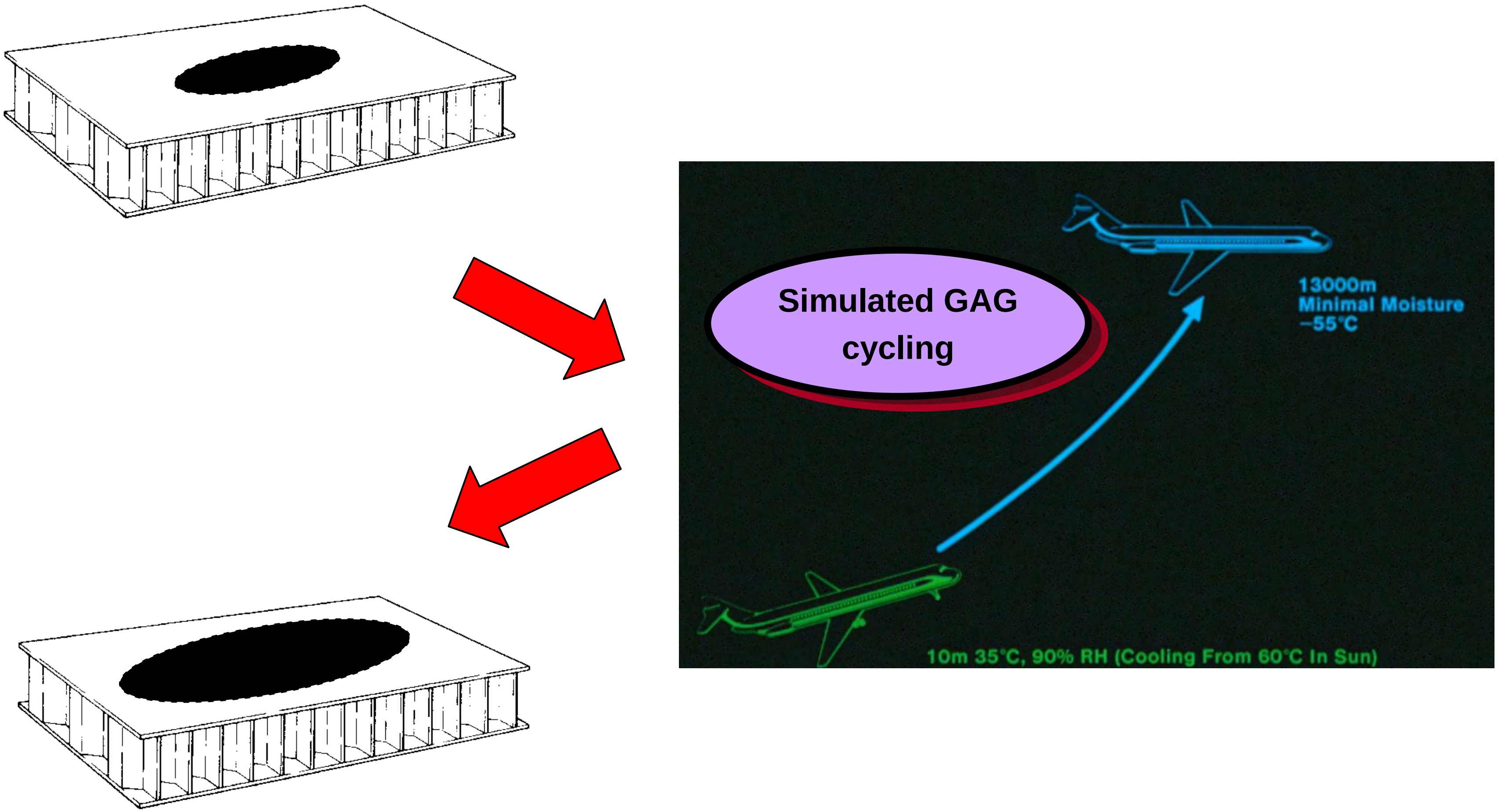
- Samples taken from same Configuration 2 panel seen previously with no dry spots.
- Three different fluids were added to one single cell.
- After fifteen Minutes-No Migration Occurred.
- All Configuration 1 panels tested had no migration present from cell-to-cell about half the configuration 2 panels had no migration.

Preliminary Results from Permeability Testing

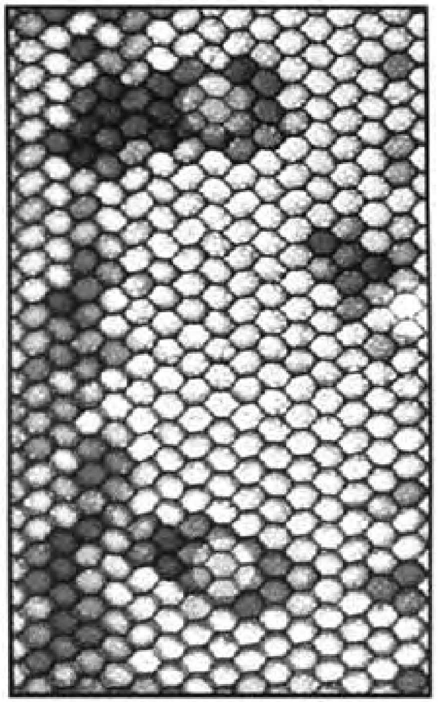
- No evidence of fluid migration was present through undamaged Nomex Honeycomb Core Cell walls.
- With an adequate bond present between the facing and the core the Nomex Honeycomb core appears to be fluid resistant to the following:
  - Deionized water, Skydrol, JP8 and Hydraulic fluid.
- Fluid will migrate through the spacing located between facesheet and the honeycomb core, a result of the facesheet not being completely filled with adhesive.
- This could be improved through manufacturing process improvements.



Looking at Thermal Cycling Effects on Damage Panels



Proposed Program Outline



BASIC ASSUMPTIONS

- Fluid ingression path is established

  and

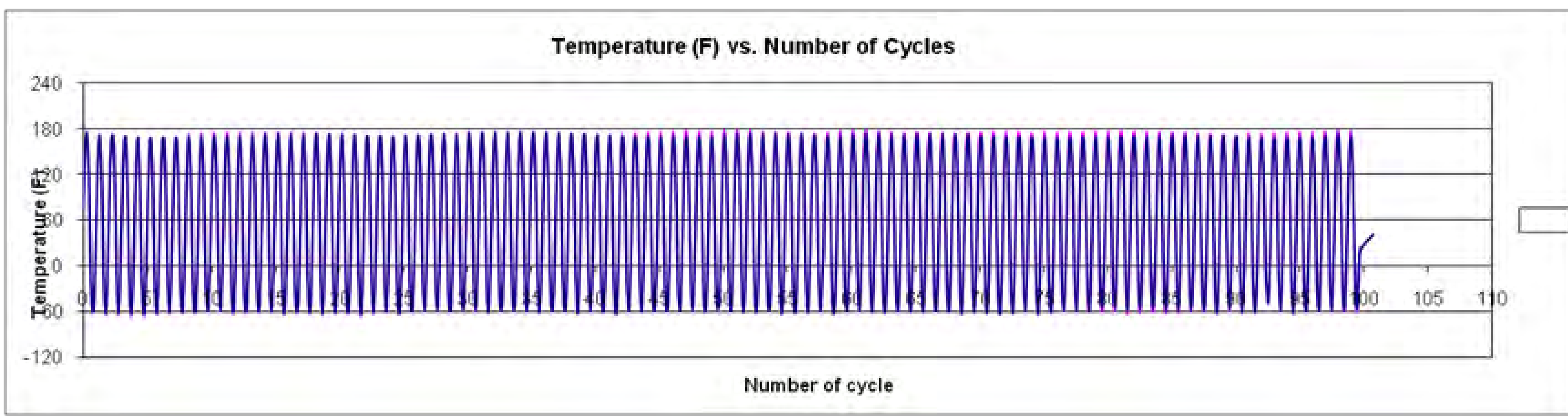
- Ingression **HAS** occurred

GOAL

Characterize the fluid ingression growth mechanisms and rates due to hygrothermal exposure based upon a number of variables

Thermal Cycling Instructions

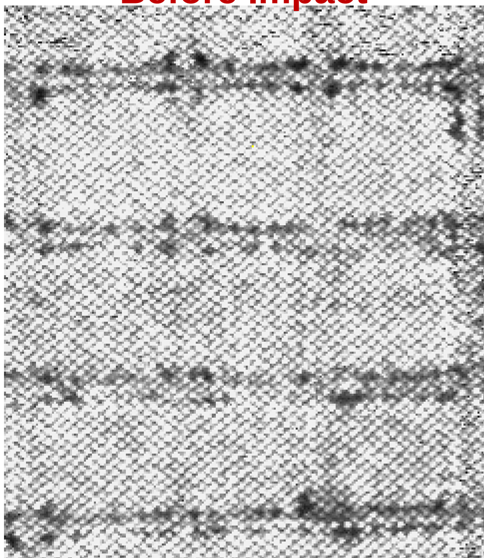
- After Impact Adam and Starship panels were soaked in water bath for 2 hours at 180F~ resembling worst case humidity condition.
- Panels were then cycled in in an environmental chamber from -65°F Dry to 180°F Dry.
- The samples were subject to 123 cycles prior to NDI inspection for damage growth.

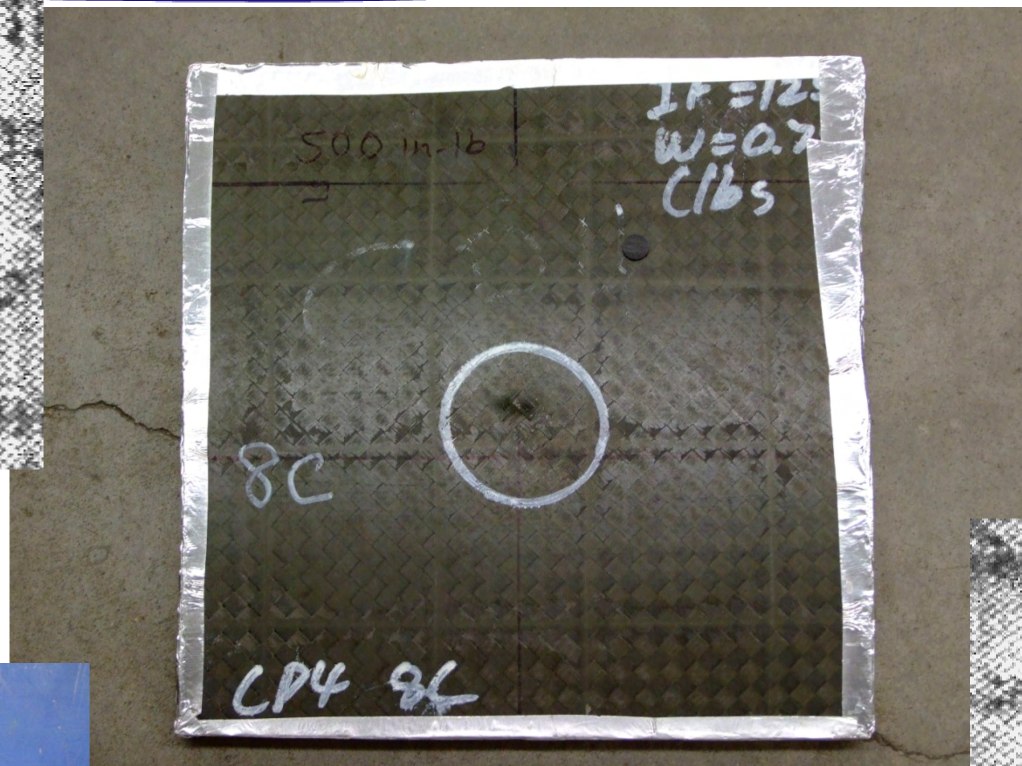


Impacting Configuration 2 Panels

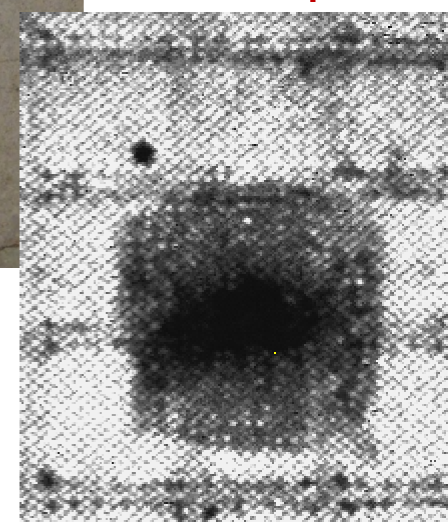
Panel CP4-8C

Before Impact





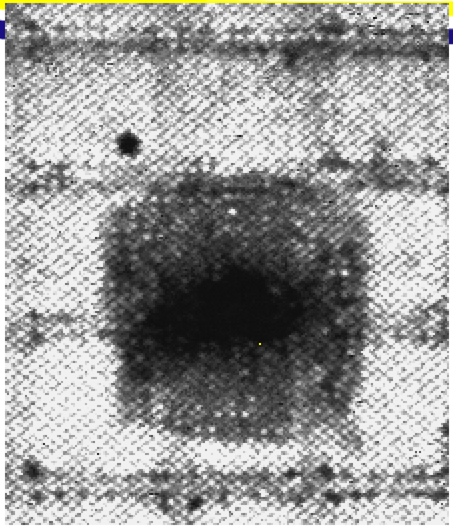
After Impact



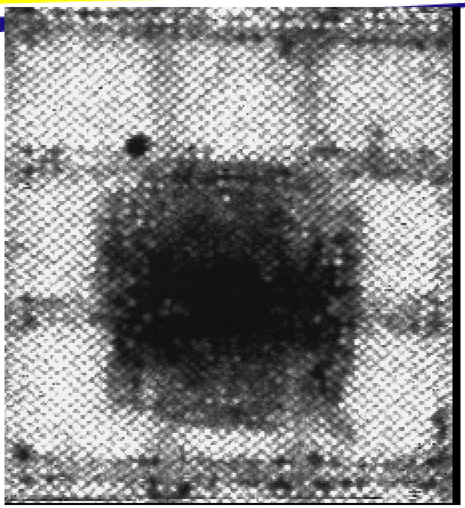
3" Impactor

Configuration 2 Panels Thermal Cycling

Panel CP4-8C



After Impact Before Thermal Cycling



After Impact After 7 Days Thermal Cycling

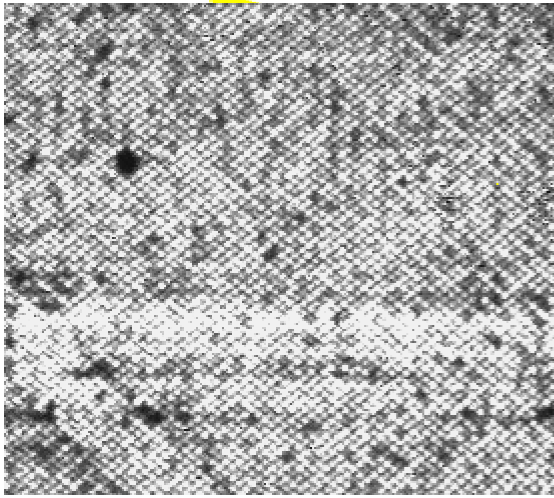
- Impact Energy: 500 in-lb
- Dry Weight: 450.17 g
- Weight After Water Bath: 479.49g
- Weight After Thermal Cycle: 471.28 g

- No Dramatic Growth present After 7 Days of Cycling.
- Continue Thermal Cycling

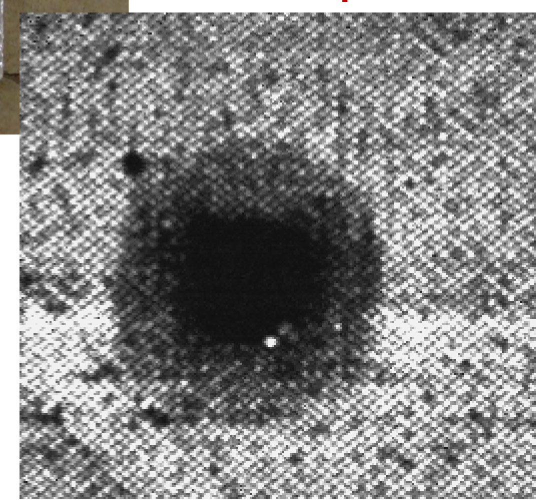
Impacting Configuration 2 Panels

Panel CP7-D3

Before Impact

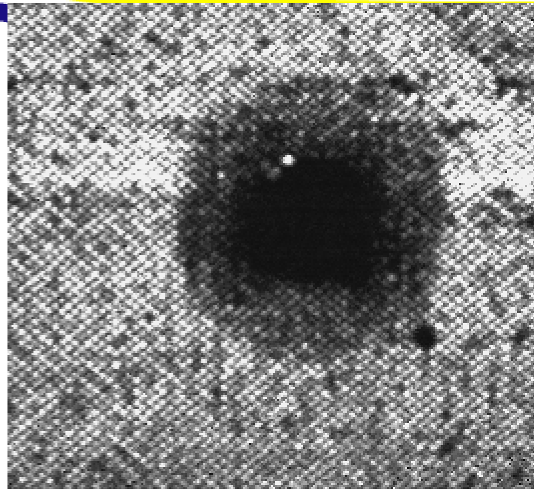


After Impact

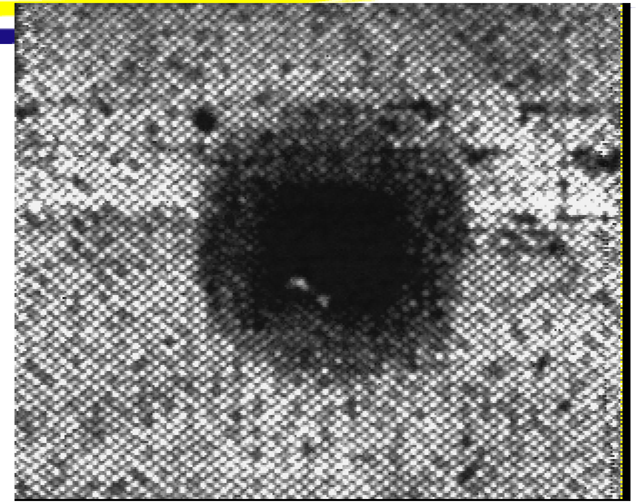


Configuration 2 Panels Thermal Cycling

Panel CP7-D3



After Impact Before Thermal Cycling



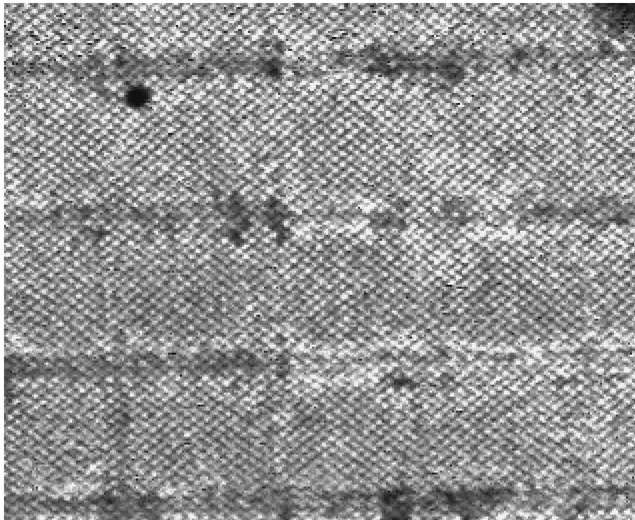
After Impact After 7 Days Thermal Cycling

- Impact Energy: 800 in-lb
- Dry Weight: 442.82 g
- Weight After Water Bath: 482.8 g
- Weight After Thermal Cycle: 435.48 g

- No Dramatic Growth present After 7 Days of Cycling.
- Continue Thermal Cycling

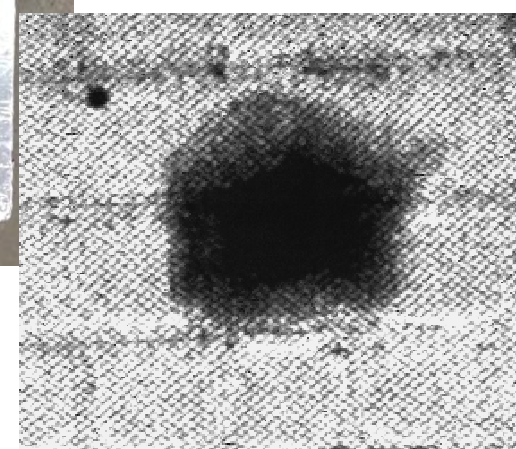
Impacting Configuration 2 Panels

Panel CP6-4D

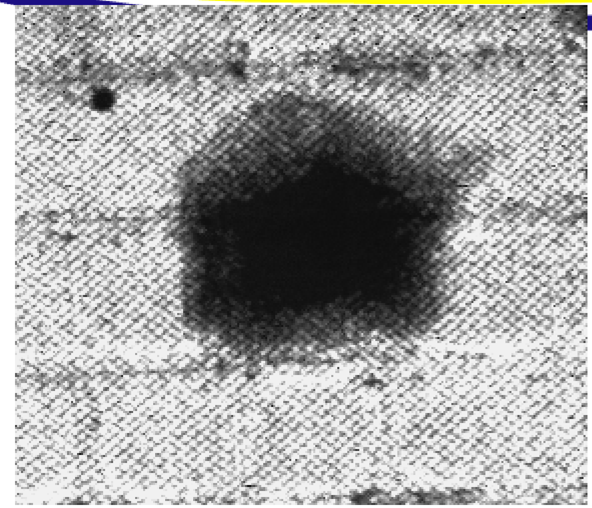


Before Impact

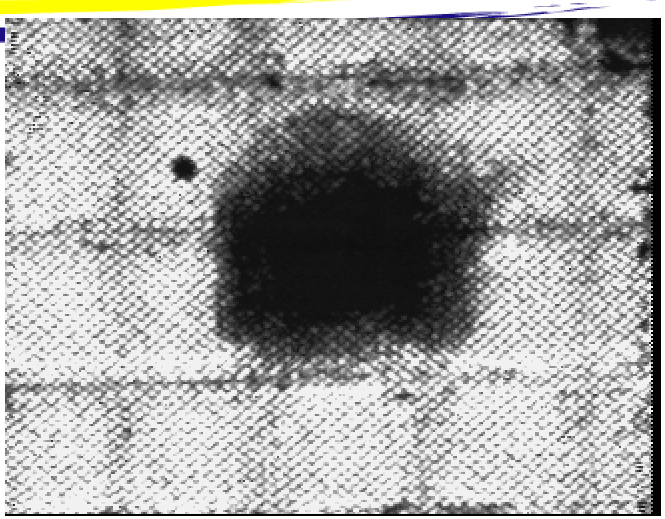
After Impact



Configuration 2 panels Thermal Cycling
Panel CP6-4D



After Impact Before Thermal Cycling



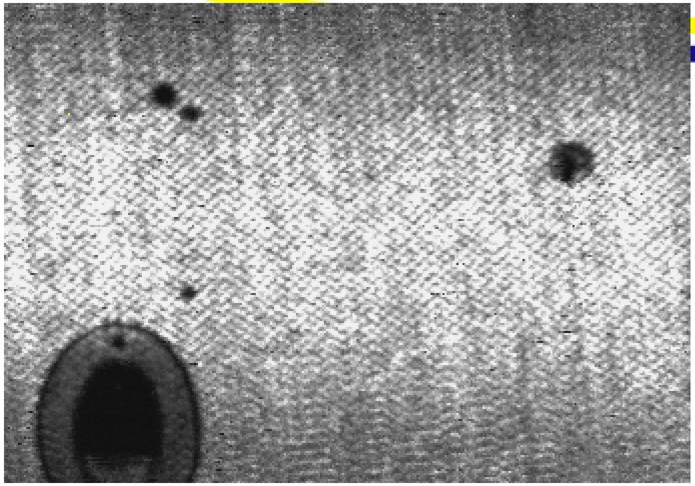
After Impact After 7 Days Thermal Cycling

- Impact Energy: 1100 in-lb
- Dry Weight: 531.61 g
- Weight After Water Bath: 577.19 g
- Weight After Thermal Cycle: 552.36 g

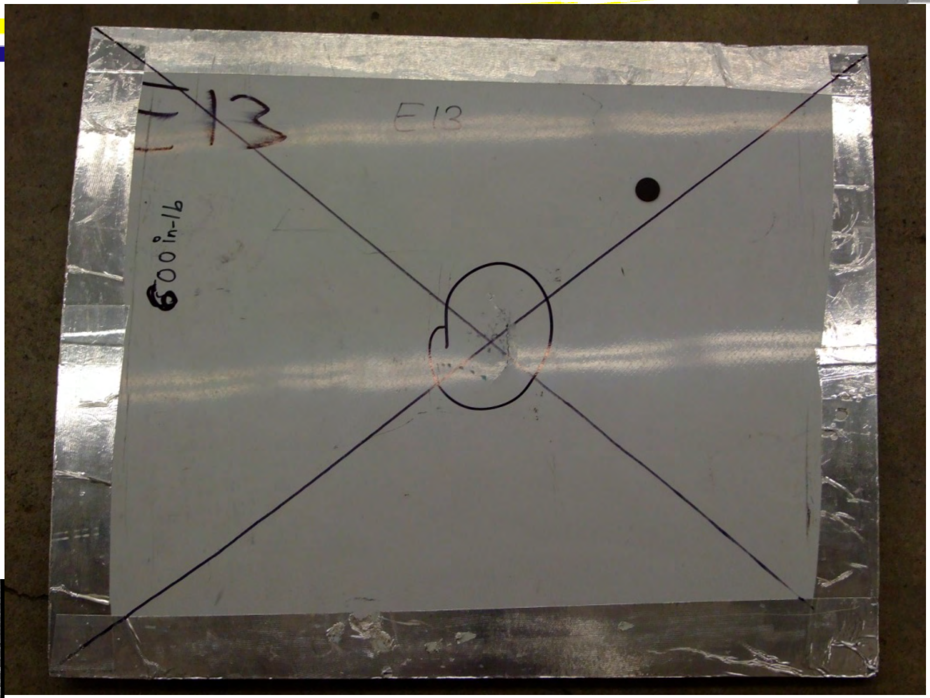
- No Dramatic Growth present After 7 Days of Cycling.
- Continue Thermal Cycling

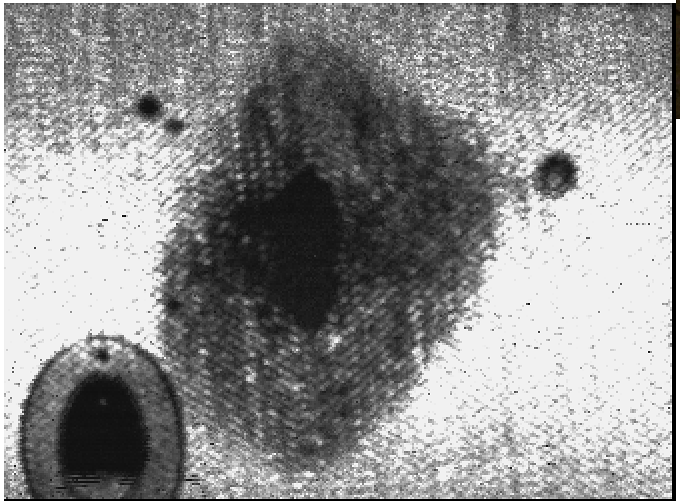
Impacting Configuration 1 Panels

Panel E13



Before Impact

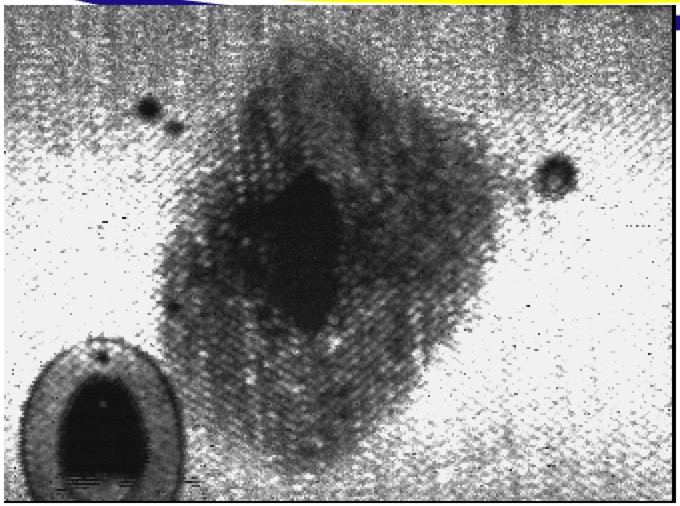




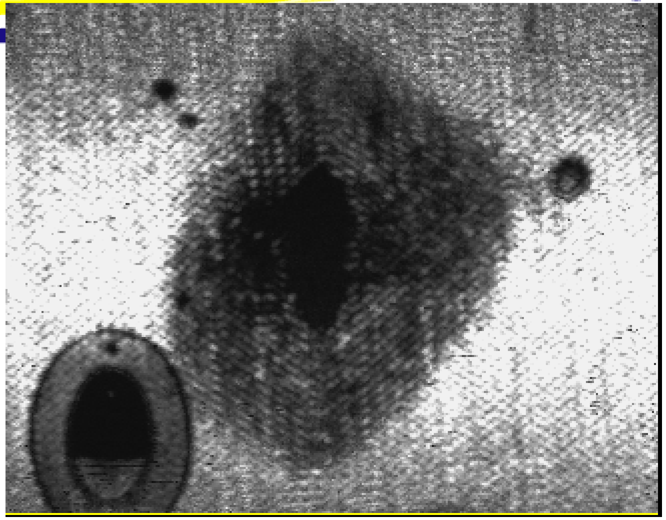
After Impact

Configuration 1 Panel Thermal Cycling

Panel E13



After Impact Before Thermal Cycling



After Impact After 7 Days Thermal Cycling

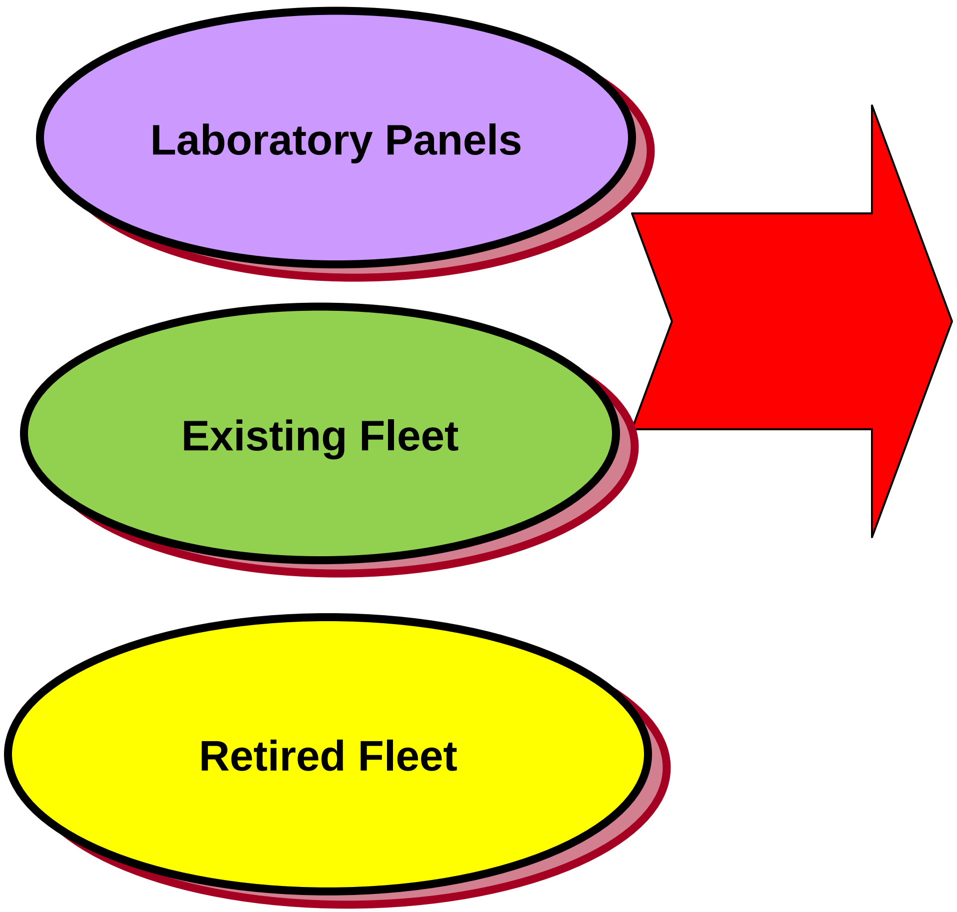
- Impact Energy: 600 in-lb
- Dry Weight: 821.4 g
- Weight After Water Bath: 834.6 g
- Weight After Thermal Cycle: 822 g

- No Dramatic Growth present After 7 Days of Cycling.
- Continue Thermal Cycling

Preliminary Thermal Cycling Results

- Continue with thermal cycling using the same environmental conditions while increasing the number of cycles completed before additional NDI is completed.
- Continued Cycle Plan 500, 1000, and 5000 cycles.
- This will help define what the growth rate is in damaged core with fluid present.

Desired Outcomes



- ☆ Intercellular diffusion (good cell wall)
- ☆ Permeable cell wall
- Permeability as a function of age/load sensitivity
- ☆ Filleting quality
- ☆ Poorly machined honeycomb (poor bond)
- ☆ Freeze/thaw
- ☆ Porous or discontinuous adhesive (adhesive type/process)

A Look Forward

- Benefit to Aviation
  - *Characterize the damage mechanisms which allow the fluid ingression to propagate and potentially degrade the structural performance*
  - *Identify potential areas which should be monitored during routine aircraft service*
  - *Provide awareness of the fluid ingression phenomenon as related to continued airworthiness*
- Future needs
  - *Provide guidance materials for design and maintenance of composite sandwich structures*

Questions?

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