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

Terminology-Current Research

Fluid Ingression Damage Tolerance

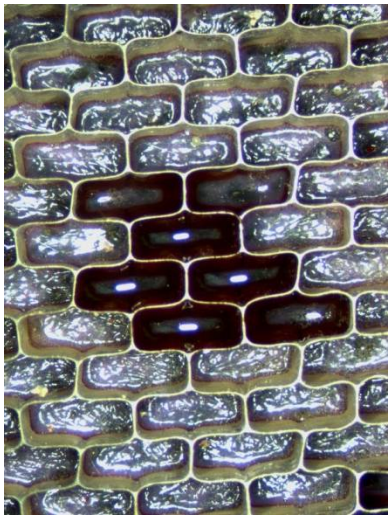
The rate of propagation of damage due to fluid ingression and degradation of structural performance

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

Fluid Ingression Damage Tolerance



STARSHIP fuselage sample with de-ionized water during core permeability test

BASIC ASSUMPTIONS

- Fluid ingression path is established

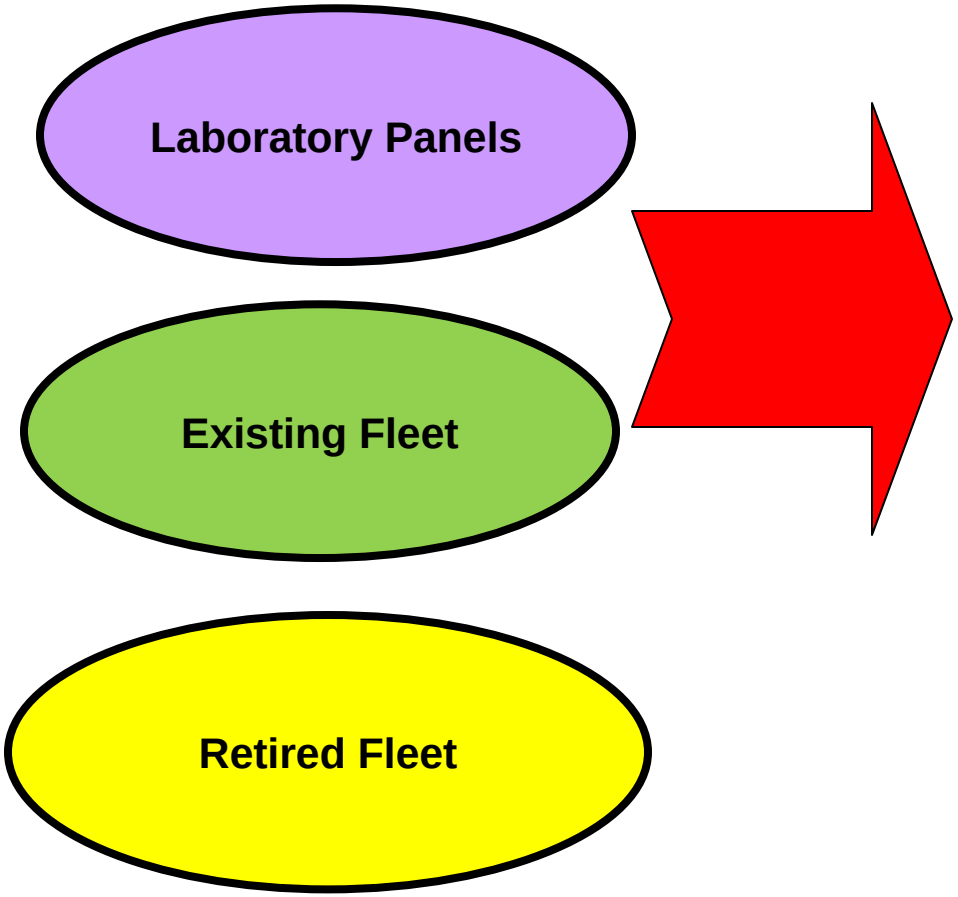
  and

- Ingression **HAS** occurred

GOAL

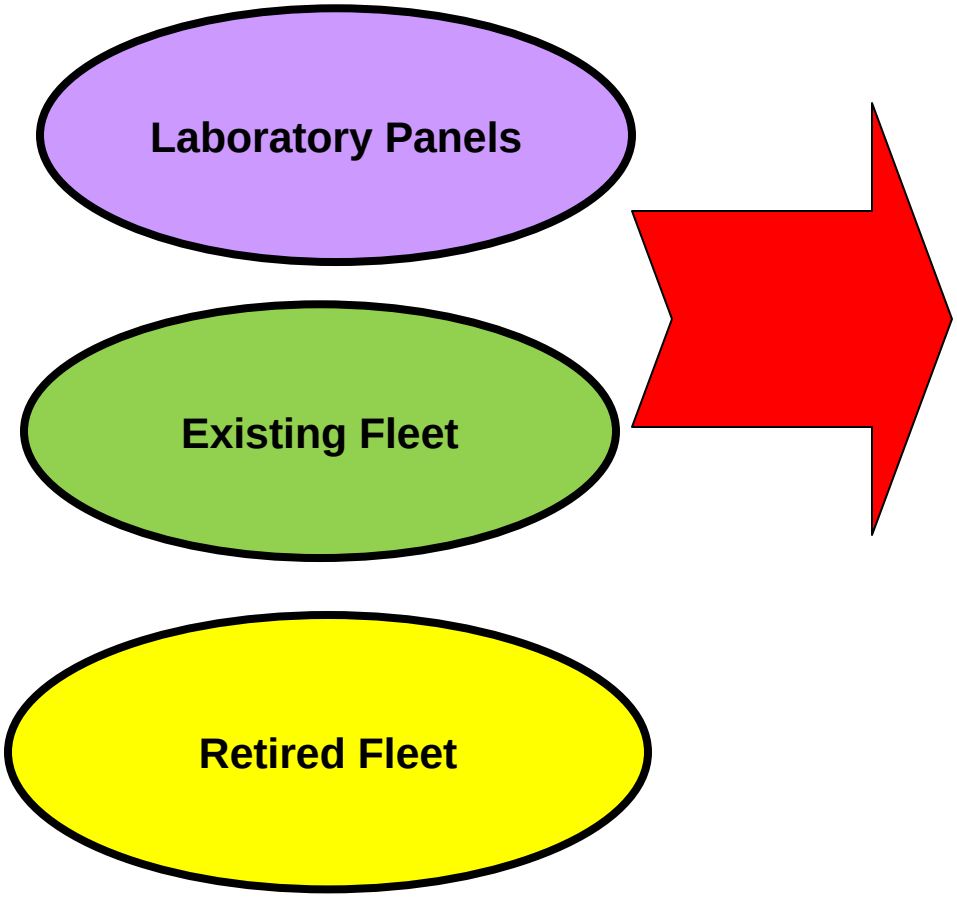
Characterize the fluid ingression growth mechanisms and rates due to hygrothermal exposure based upon a number of variables

Desired Outcomes from current research



- 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

Test Matrix: Phase 1

STAR SHIP FUSELAGE							
Panel Name	Specimen	C-SCAN BEFORE IMPACT	Impact ENERGY IN-LB	C-SCAN AFTER IMPACT	CYCLE COUNT NO LOAD		
					500	1000	2000
Panel B	B5	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	B14	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	B13	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE
	B16	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
Panel C	C14	DONE	600	DONE	COMPLETE	COMPLETE	COMPLETE
	C8	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE
	C10	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
Panel E	E13	DONE	600	DONE	COMPLETE	COMPLETE	COMPLETE
	E18	DONE	600	DONE	COMPLETE	COMPLETE	COMPLETE
	E12	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE
	E3	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
Panel F	F7	DONE	600	DONE	COMPLETE	COMPLETE	COMPLETE
	F14	DONE	600	DONE	COMPLETE	COMPLETE	COMPLETE
	F23	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE

Note: These Adam panels are representative panels of the ADAM AIRCRAFT Fuselage the primary difference is the radius of these panels.

ADAM FUSELAGE REPRESENATIVE PANELS							
Panel Name	Specimen	C-SCAN BEFORE IMPACT	Impact ENERGY IN-LB	C-SCAN AFTER IMPACT	CYCLE COUNT NO LOAD		
					500	1000	2000
CP1B	CP1B 8D	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP1B 7D	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
CP2	CP2 8D	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP2 2C	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE
CP3	CP3 6B	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP3 8D	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
CP4	CP4 8C	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP4 6C	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
CP5	CP4 2D	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
	CP5 7E	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
CP6	CP6 8C	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
	CP6 4D	DONE	1100	DONE	COMPLETE	COMPLETE	COMPLETE
CP7	CP7 C3	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP7 D3	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE
CP8	CP8 2E	DONE	500	DONE	COMPLETE	COMPLETE	COMPLETE
	CP8 4D	DONE	800	DONE	COMPLETE	COMPLETE	COMPLETE

2 Phase Research Program: Including Impact Damage

Phase 1

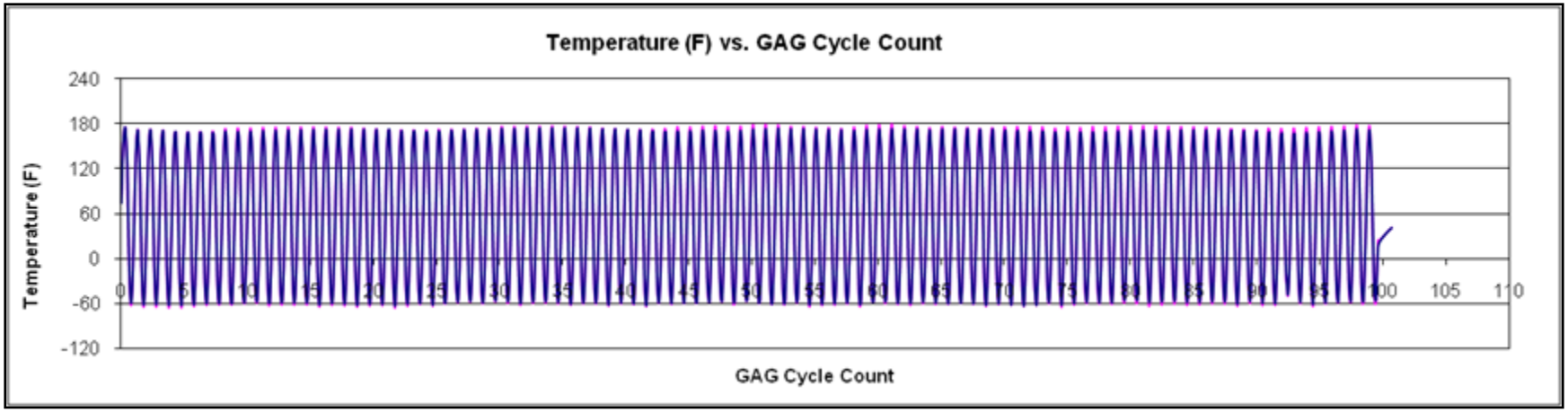
Phase 2

GAG
No Load Applied

Repeat Under Load

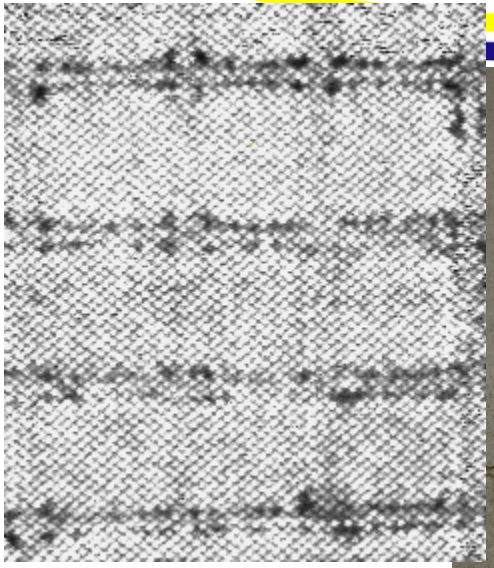
GAG
Load Applied

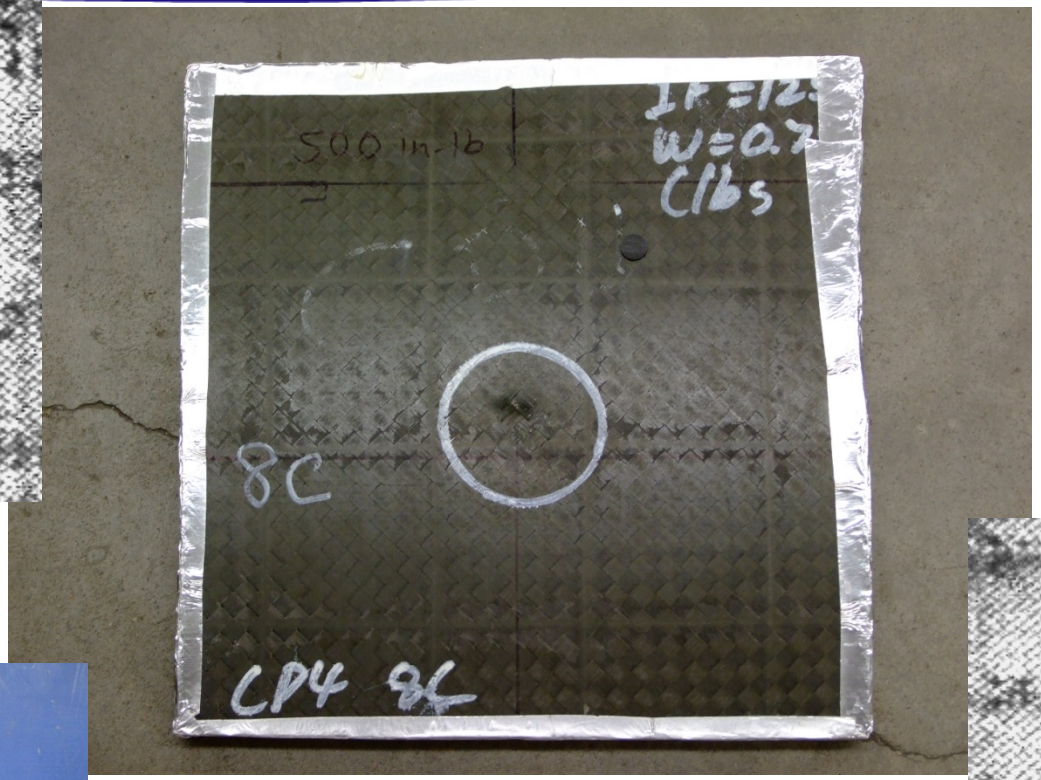
ASTM F1645
Water Migration Test



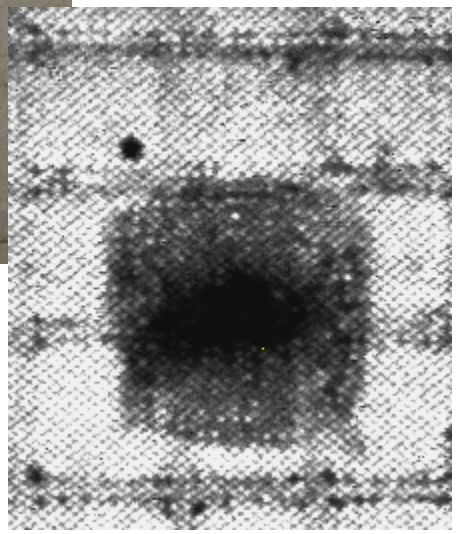
Impacting for Phase 1 & 2 Panels

Before Impact





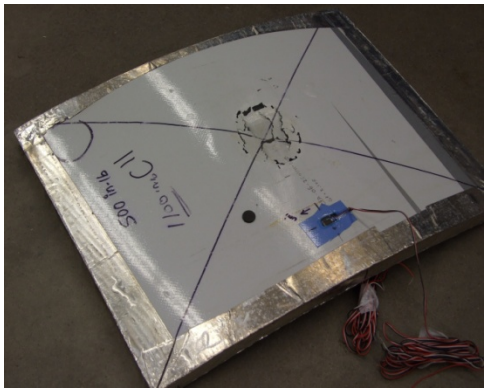
After Impact

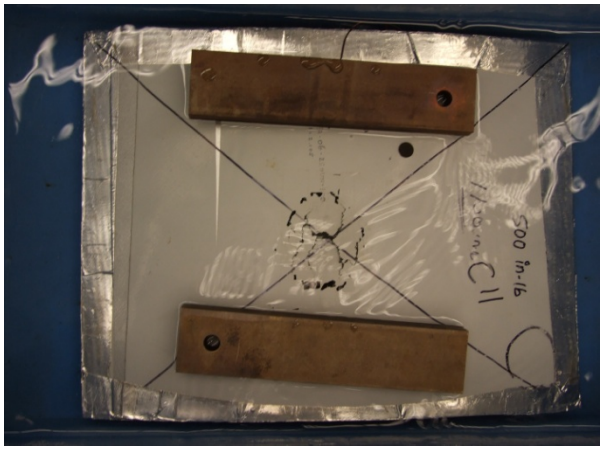


GAG Cycle & panel preparation instructions

- After Impact Adam and Starship panels were soaked in water bath for 1 hour at 180ºF~ resembling worst case humidity condition.
- Panels were then cycled in in an environmental chamber from -65°F Dry to 180°F Dry to -65F Dry.
- After Cycle milestone was met panels were NDI inspected

Damaged panel sealed and ready for pre-soak





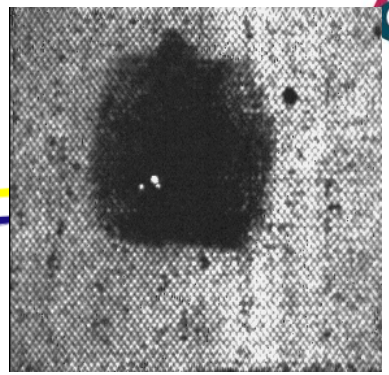
Damaged panel soaking with weights to keep panel submerged

Panel soaking in chamber 180ºF

Phase 1 Results:

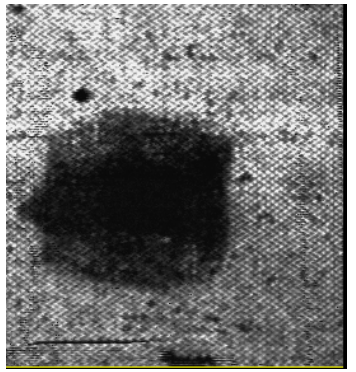
ADAM Panel:CP2-2C

Before Impact

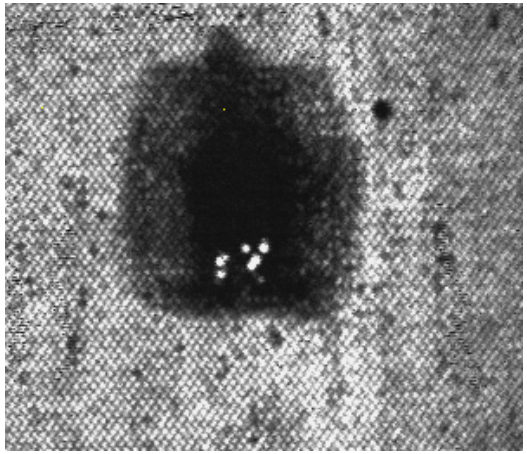


500 Cycles

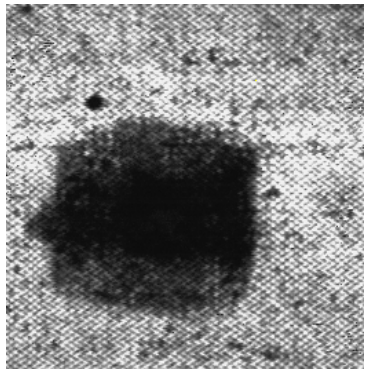
NDI Results GAG - no LOAD



1000 Cycles



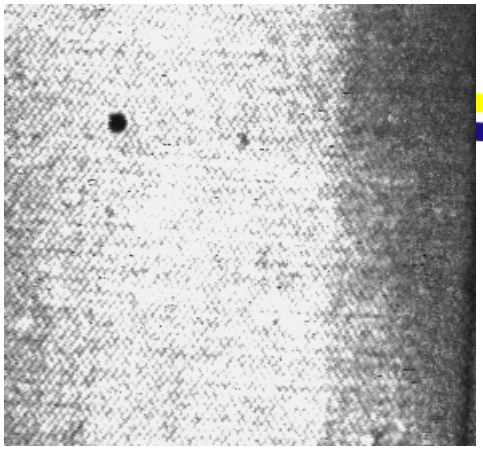
After Impact



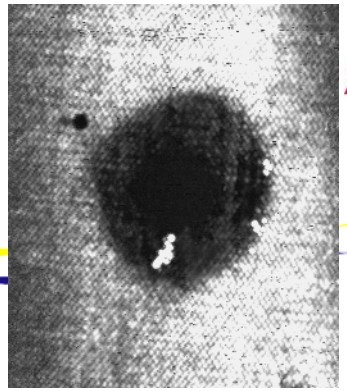
2000 Cycles

Phase 1 Results:

STARSHIP Panel: B 13

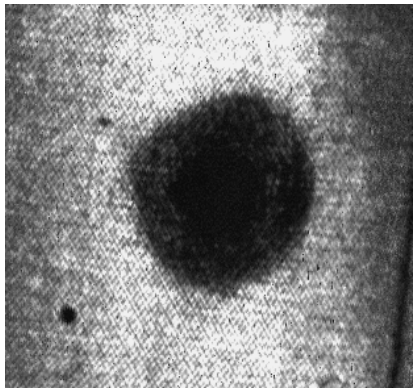


Before Impact

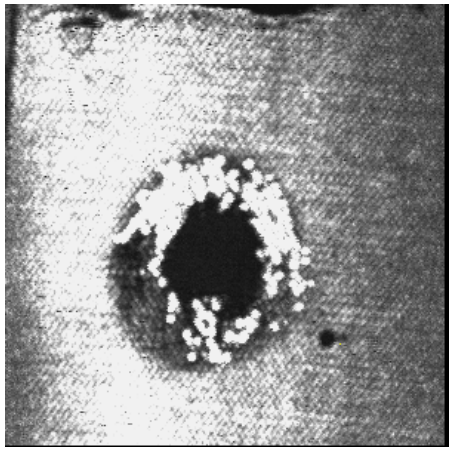


500 Cycles

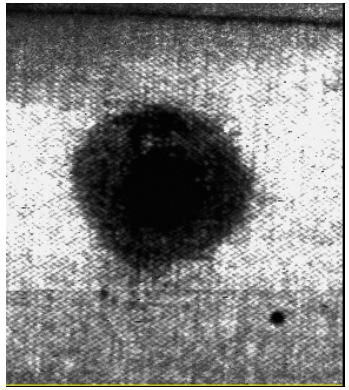
NDI Results GAG - no LOAD



1000 Cycles

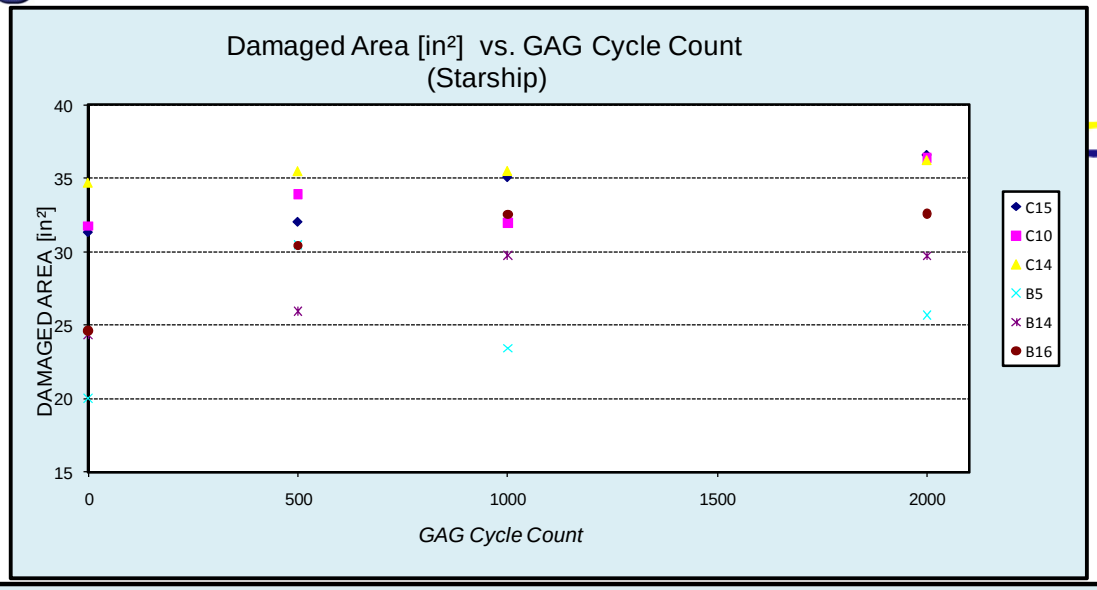


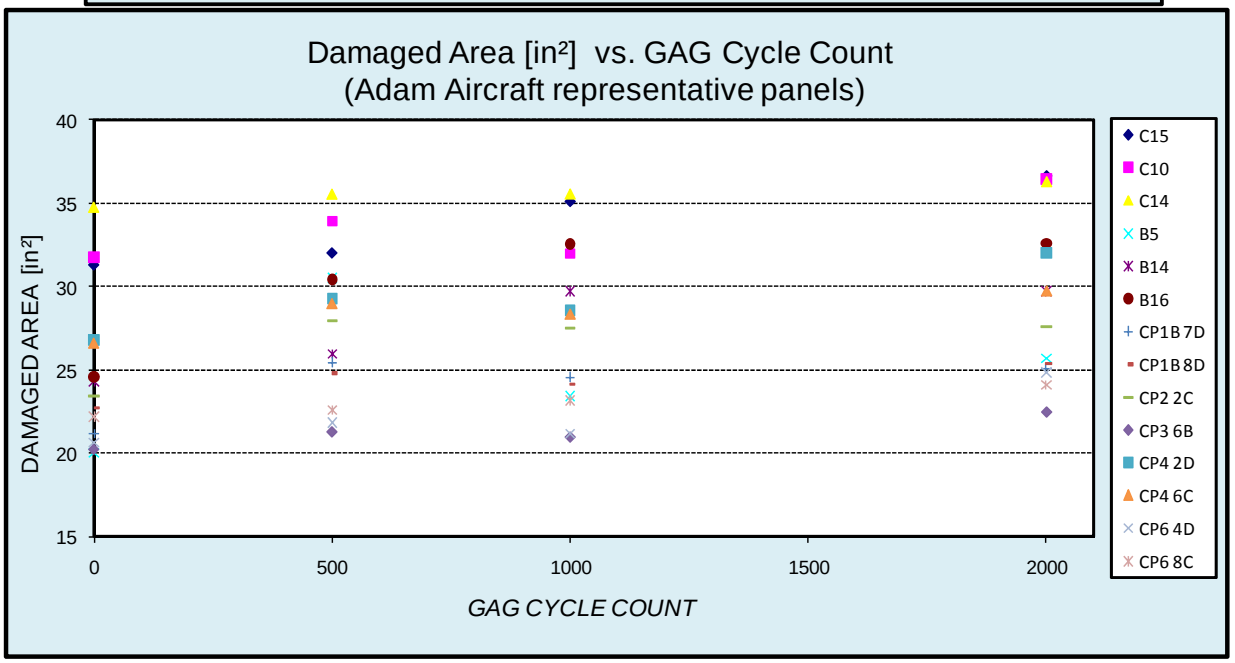
After Impact



2000 Cycles

PHASE 1:GAG-No Loading Results





- Milestones completed:
  - 500 cycles
  - 1000 cycles
  - 2000 cycles
- No growth was detected on any of the milestones completed.
- Graphs represent a sample of the panels actually cycled without loading.

Current Research

1. ~~Cycle damaged sandwich panels from two aircraft – GAG cycle with no loading~~

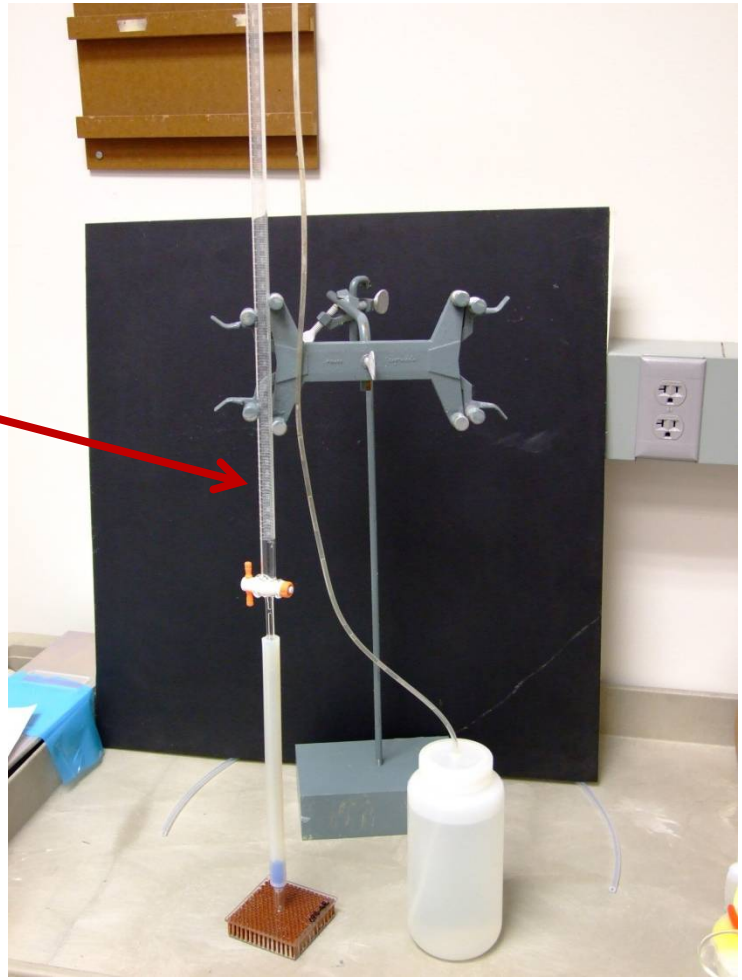
   NO Fluid Migration

☆ 1a. Investigate water migration of panels from Adam and Starship cores using ASTMF1645-00

2. Cycle impact damaged sandwich panels from two aircraft – GAG cycle with loading

Phase 1a: Water Migration Review

- 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.
  - Skydrol, JP-8, Hydraulic Fluid Royco 756

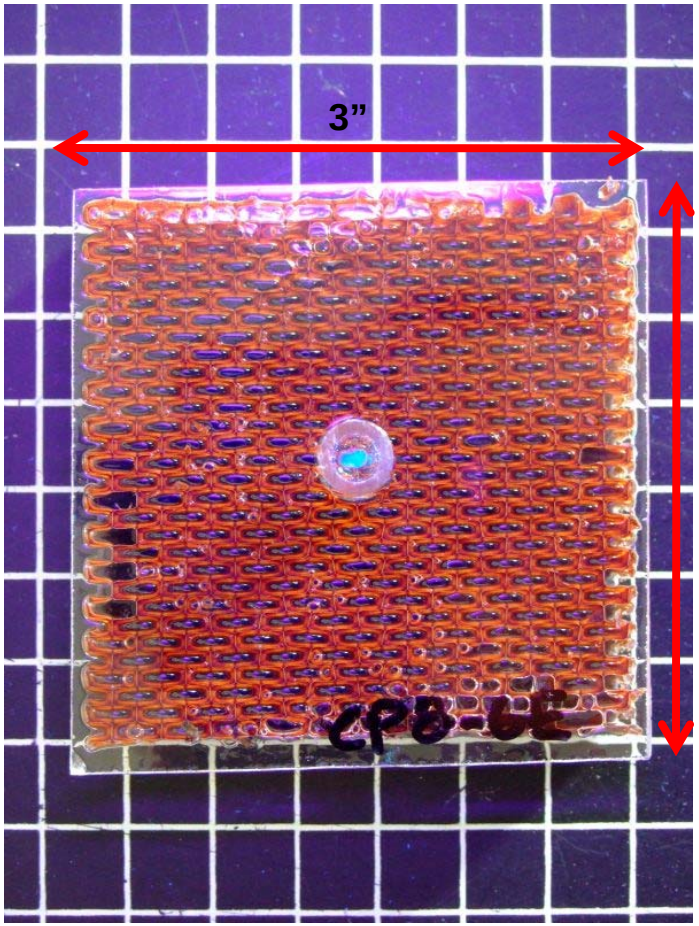


Phase 1a: ASTM F1645-00 Test Matrix

Panel Name	Specimen	ASTM F1645-00	Core Permeability Test-ROBUST
STAR SHIP PANELS			
Panel B	B4	X	X
	B1	X	X
	B3	X	X
Panel C	C11	X	X
	C13	X	X
	C7	X	X
	C5	X	X
Panel E	E1	X	X
	E2	X	X
	E26	X	X
	E10	X	X
	E11	X	X
Panel F	F8	X	X
	F19	X	X
	F17	X	X
	F16	X	X
	F13	X	X
ADAM FUSELAGE REPRESENTATIVE PANELS			
CP1B	CP1B2C	X	X
	CP1B3C	X	X
CP2	CP23C	X	X
	CP37E	X	X
CP3	CP37C	X	X
	CP38C	X	X
CP5	CP52D	X	X
	CP33D	X	X
CP6	CP63D	X	X
	CP86E	X	X
CP7	CP74E	X	X
	CP73E	X	X
CP8	CP83D	X	X
	CP86D	X	X

ASTM F1645-00 Test Matrix

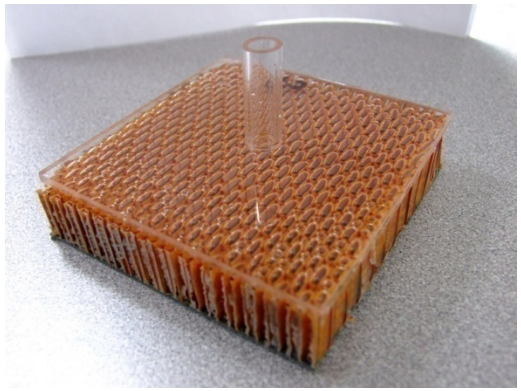
Test specimen



Phase 1a: 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

- Water did not migrate beyond the single honeycomb cell the fluid was placed in for any sample from configuration 1 or 2.
- Water migration calculated is negligible, due to nature of ASTM standard.
- ASTM F1645-00 affected by 3 things:
  - Core permeability, Adhesive thickness and thickness uniformity.
- Voids, cracks and other defects will affect fluid migration results.



Current Research

1. ~~Cycle damaged sandwich panels from two aircraft – GAG cycle with no loading~~

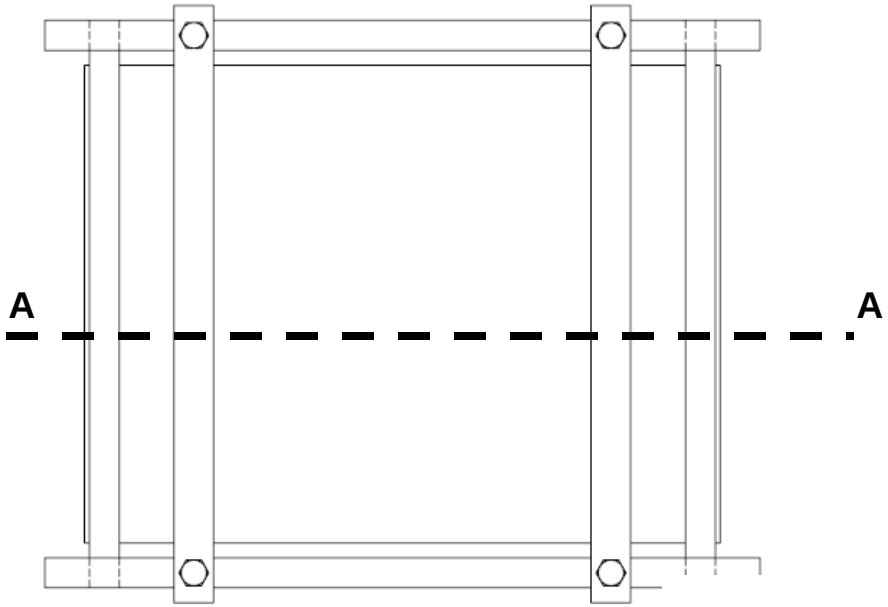
   NO Fluid Migration

1a. ~~Investigate water migration of panels from Adam and Starship cores using ASTMF1645~~

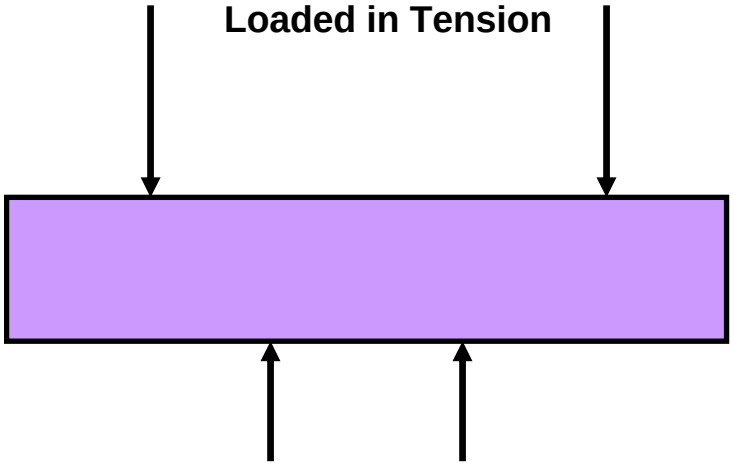
   NO Fluid Migration

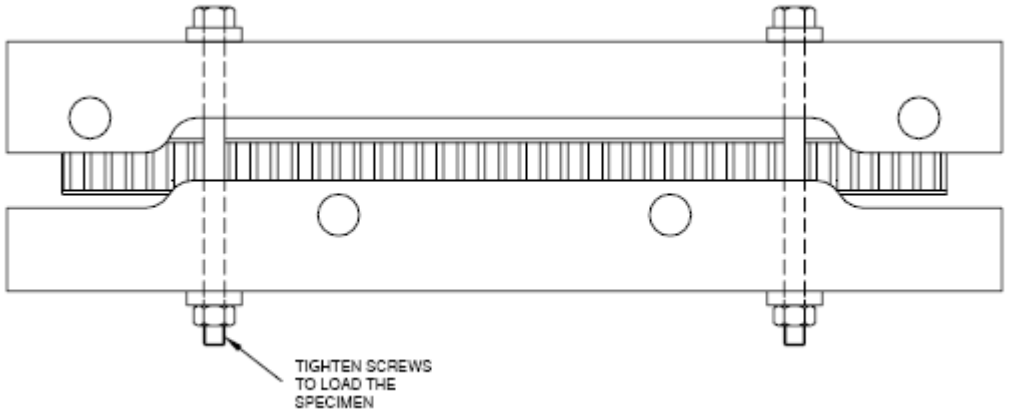
☆ 2. Cycle impact damaged sandwich panels from two aircraft – GAG cycle with loading

Phase 2:
GAG cycle Load applied



4-pt Bending Fixture
17-4 PH Stainless Steal





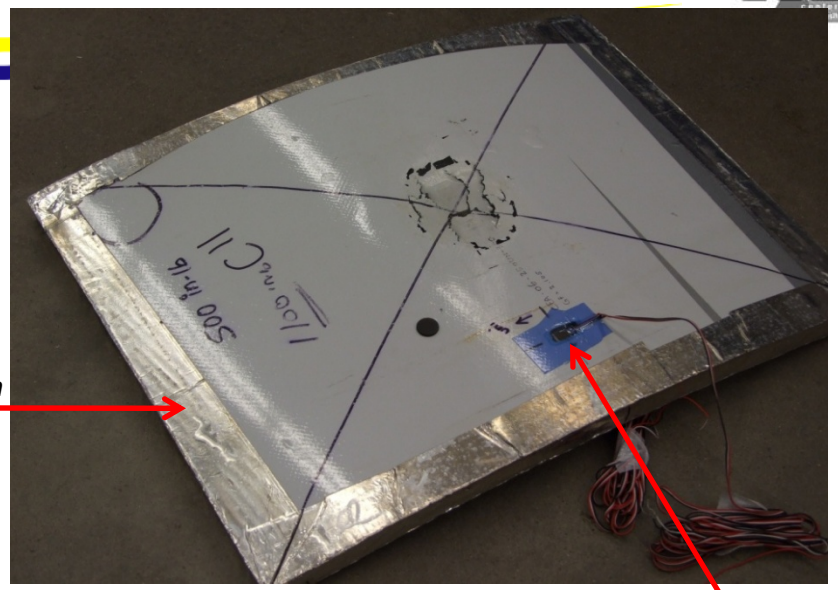
Test Matrix: Phase 2

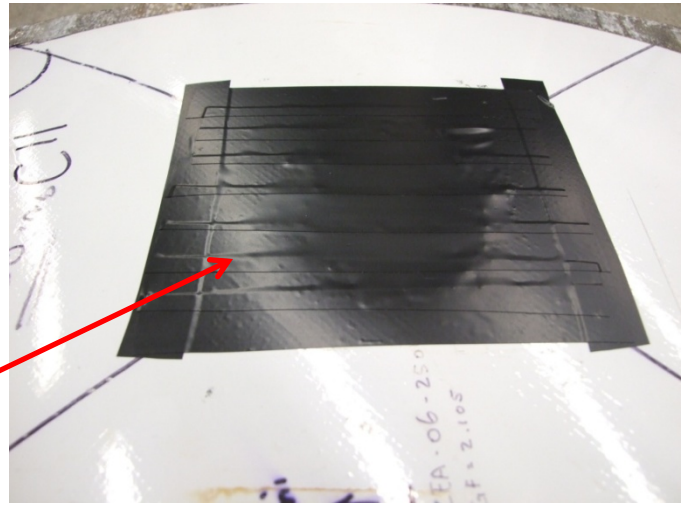
STARSHIP FUSELAGE				
PANEL NAME	B	C	E	F
Specimen	B4 B1 B3	C11 C13 C7 C5	E1 E2 E26 E10 E11	F8 F19 F17 F16 F13
C-SCAN	X	X	X	X
IMPACT PANEL/ C-SCAN	X	X	X	X
GAG CYCLE UNDER LOAD, AFTER EACH MILESTONE NDI INSPECT IMPACT				
500 CYCLES	X	X	X	X
1000 CYCLES	X	X	X	X
2000 CYCLES	X	X	X	X

ADAM FUSELAGE REPRESENATIVE PANELS								
PANEL NAME	CP1B	CP23C	CP3	CP4	CP5	CP6	CP7	CP8
Specimen	CP1B2C CP1B3C	CP23C CP37E	CP37C CP38C	CP42C CP74C	CP52D CP33D	CP63D CP86E	CP74E CP73E	CP83D CP86D
C-SCAN	X	X	X	X	X	X	X	X
IMPACT PANEL/ C-SCAN	X	X	X	X	X	X	X	X
GAG CYCLE UNDER LOAD, AFTER EACH MILESTONE NDI INSPECT IMPACT DAMAGED AREA								
500 CYCLES	X	X	X	X	X	X	X	X
1000 CYCLES	X	X	X	X	X	X	X	X
2000 CYCLES	X	X	X	X	X	X	X	X

Phase 2:
GAG cycle Load applied

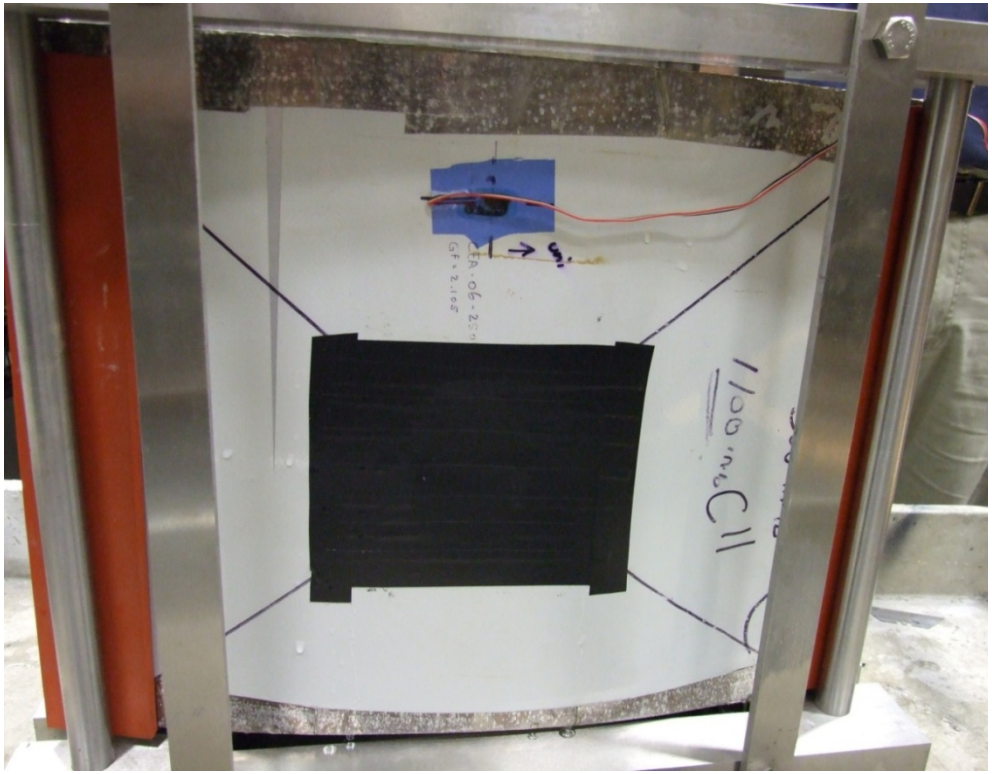
- Impacted sandwich panel (Starship C-11, 1100 in-lb).
- Aluminum tape used to seal exposed core around edges.
- Vishay Strain Gauge so preloading can be measured
- Impact energies, same as panels cycled without load, Phase 1.
- Damaged panels soaked in 180°F water bath before GAG cycle.
- Weights recorded before water bath, GAG cycle and After.





Phase 2:
GAG cycle Load applied

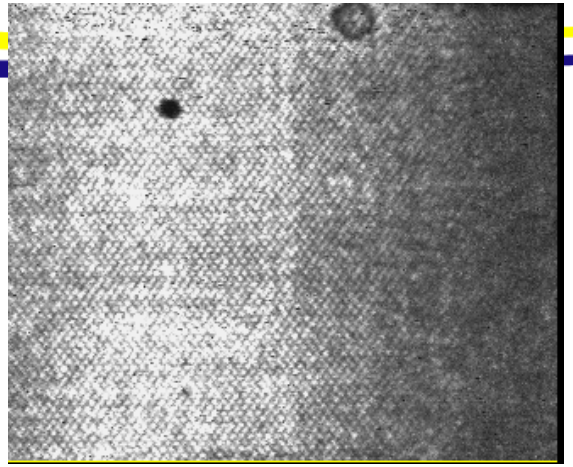
Starship Panel C11,1100 in-lb



Preloaded panel ready to begin water bath and GAG cycling

- Sandwich panel loaded in fixture with strain gage attached while screws are tightened so load applied to panel in known.
- Load applied until 800 microstrains is obtained
- 800 microstrains was used because of fixture constraints, cracking and popping was heard past this point during loading.
- More damage was avoided before cycling

Phase 2:
GAG cycle Load applied

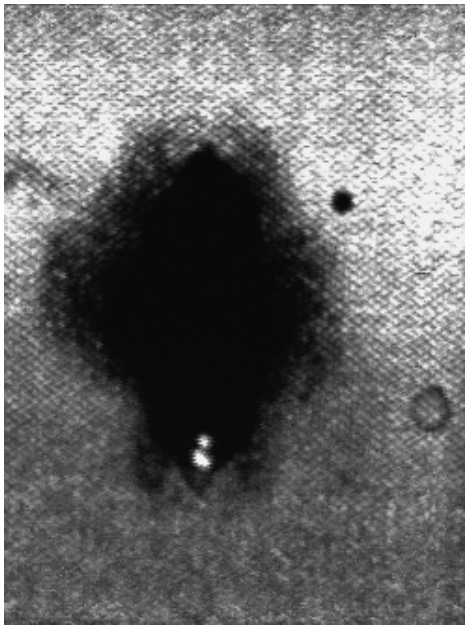


Panel: Starship C11

Impact Energy 1100 in-lb

GAG Cycle Count = 0

Measured Damaged Area = 0 in²



Panel: Starship C11

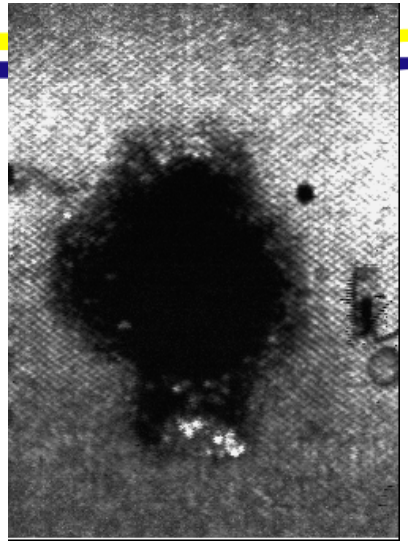
Impact Energy 1100 in-lb

GAG Cycle Count = 0

Measured Damaged Area = 32.75 in²

Phase 2:

GAG cycle Load applied

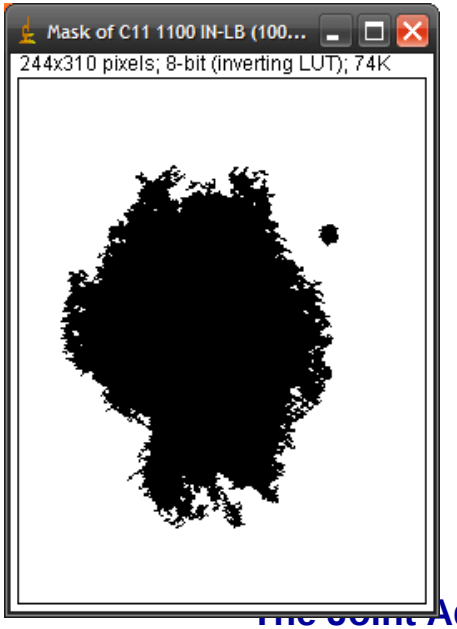


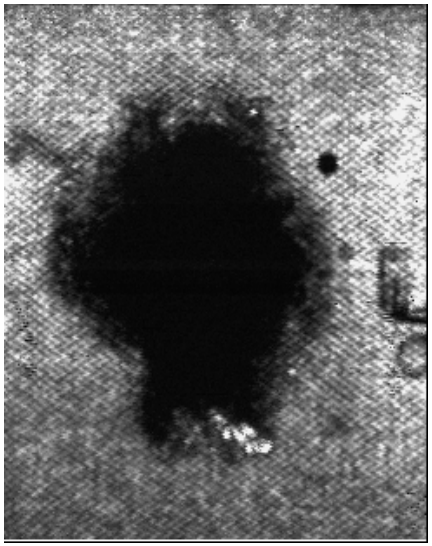
Panel: Starship C11

Impact Energy 1100 in-lb

GAG Cycle Count = 500

Measured Damaged Area = 34.44 in²





Panel: Starship C11

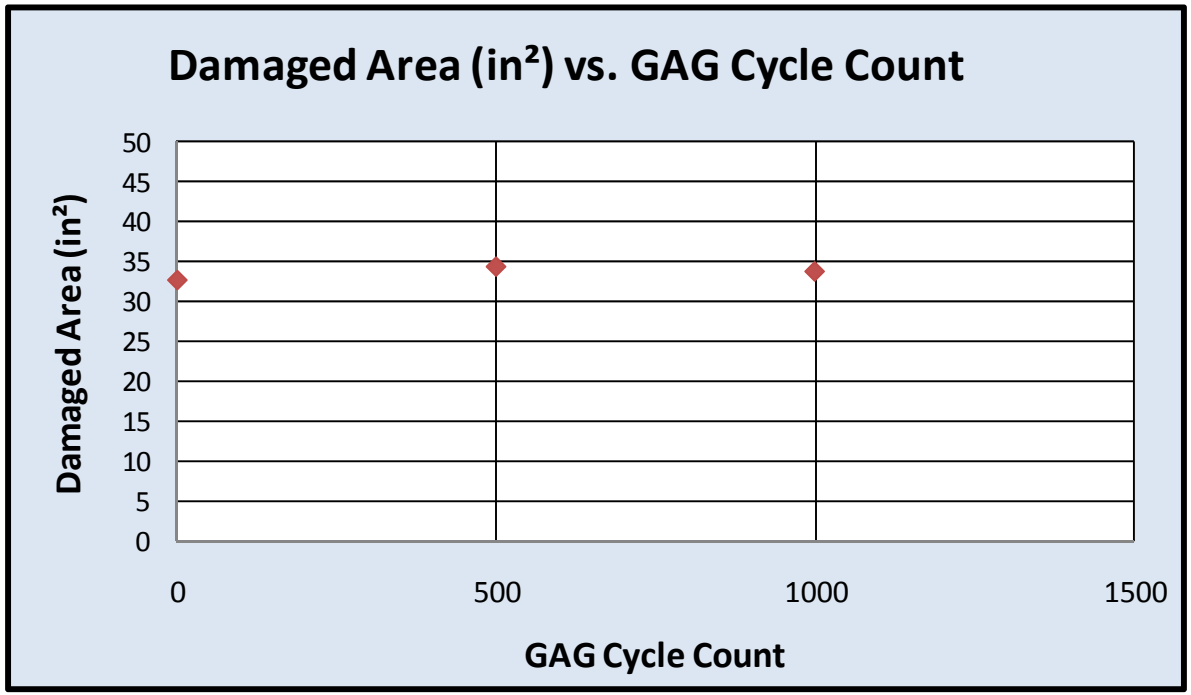
Impact Energy 1100 in-lb

GAG Cycle Count = 1000

Measured Damaged Area = 33.83 in²

Phase 2:

GAG cycle Load applied Results



To Date Growth is not observed under the loading constraints of 800 microstrains in the 4-pt bend fixture, loading the panel in Tension, while completing the1000 GAG cycle count referenced above.

Current Research Summary

1. ~~Cycle damaged sandwich panels from two aircraft – GAG cycle with no loading~~

   NO Fluid Migration

1a. ~~Investigate water migration of panels from Adam and Starship cores using ASTMF1645~~

   NO Fluid Migration

2. ~~Cycle impact damaged sandwich panels from two aircraft – GAG cycle with loading~~

   NO Fluid Migration

A Look Forward

- Benefit to Aviation
  - *Understanding the effects of thermal cycling given a specified impacted damage area both while under load or free standing is beneficial to Aviation when understanding the permeability as a function of age/load sensitivity.*
  - *This research should help continue to provide awareness of the fluid ingression phenomenon as related to continued airworthiness, in other words how quickly does this become a severe problem.*
- Future needs
  - *Additional funding will allocate funds to provide guidance materials for design and maintenance of composite sandwich structures*