Resolution of an Orbital Issue: A Designed Experiment

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Background

- During STS-114, on , an issue came up that required the astronauts to take a space walk visit to the underneath side of the orbiter
- This is story of the "Gap Filler".....and how we used an advanced statistical method to prevent it from happening again....
- So let's see what happened.

http://video.google.com/videoplay?docid=11839295015116342 26#

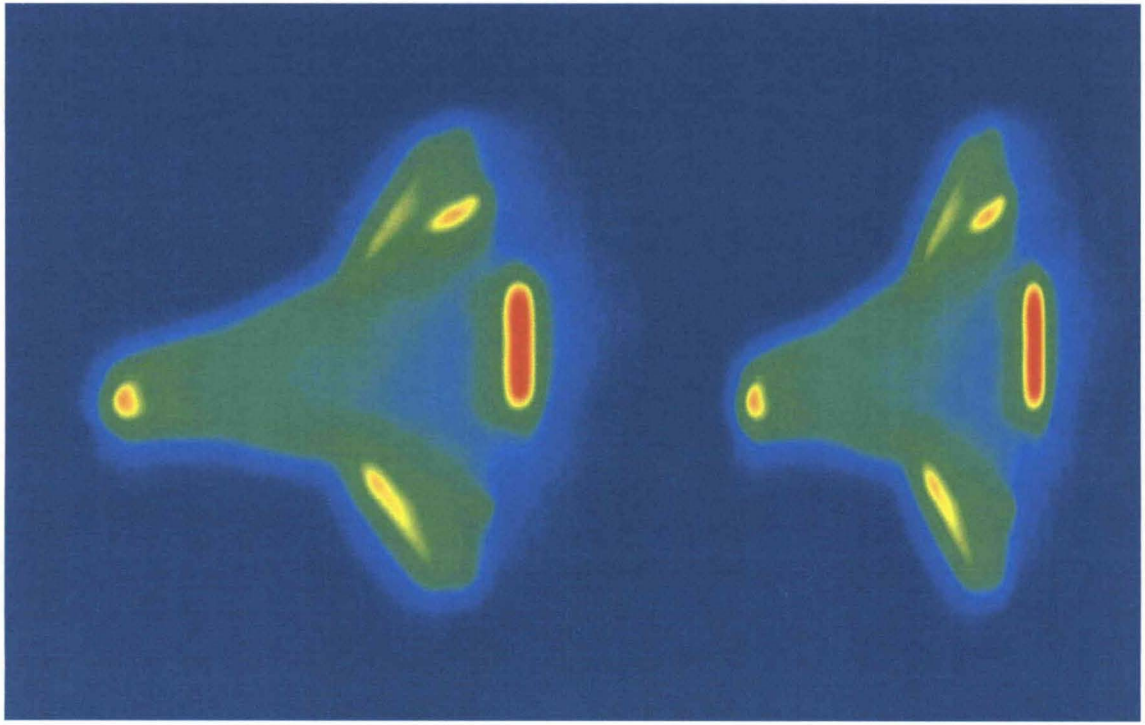
OR

http://www.youtube.com/watch?v=KmOp7Ab3Bds

On-orbit issue

What was the issue?

Who cares if a hunk of ceramic sticks up?



There was extreme interest in not allowing this to happen again…so we used a designed experiment to determine the best way to address it…….

Background For Design of Experiments (DOE)

- DOE is a systematic approach to investigation of a system or process. A series of structured tests are designed in which planned changes are made to the input variables of a process or system. The effects of these changes on a pre-defined output are then assessed.

- DOE is a formal method of maximizing information gained while minimizing resources required.

Background For Design of Experiments (DOE)

DOE can be used to find answers in situations such as:

- What is the main contributing factor to a problem?
- How well does the system/process perform in the presence of noise?
(defined as randomness in response due to uncontrolled variation)
- What is the best configuration of factor values to minimize variation in a response or outcome?

Information extracted from "Design of Experiments in brief", http://www.thequalityportal.com/q_know02.htm

Background For Design of Experiments (DOE)

How to perform it

- Identify the input variables and the response (output) that is to be measured.
- For each input variable, a number of levels are defined that represent the range for which the effect of that variable is desired to be known.
- Produce an experimental plan which tells the experimenter where to set each test parameter for each run of the test.
- Measure the response for each run.
- Look for differences between response (output) readings for different groups of the input changes.
- Attribute the differences to the input variables acting alone (called a single effect) or in combination with another input variable (called an interaction).

Information extracted from "Design of Experiments in brief", http://www.thequalityportal.com/q_know02.htm

Design of Experiments (DOE) Example

Gap Filler Pre Process Change Testing

(These samples were subjected to the ½ lb. pull load which was the spec requirement prior to the process change. The current pull load requirement is 5 lbs.)

- Pre-Process Change Testing
  - Bonded 20 1-ply per P-602 spec
  - Bonded 20 2-ply per P-602 spec
  - Bonded 20 4-ply per P-602 spec
- Results
  - 1 ply failure rate: 12/20 failed = 60%
  - 2 ply failure rate: 9/20 failed = 45%
  - 4 ply failure rate: 2/20 failed = 10%
- This showed us that the increased number of plies appeared to increase bond reliability.

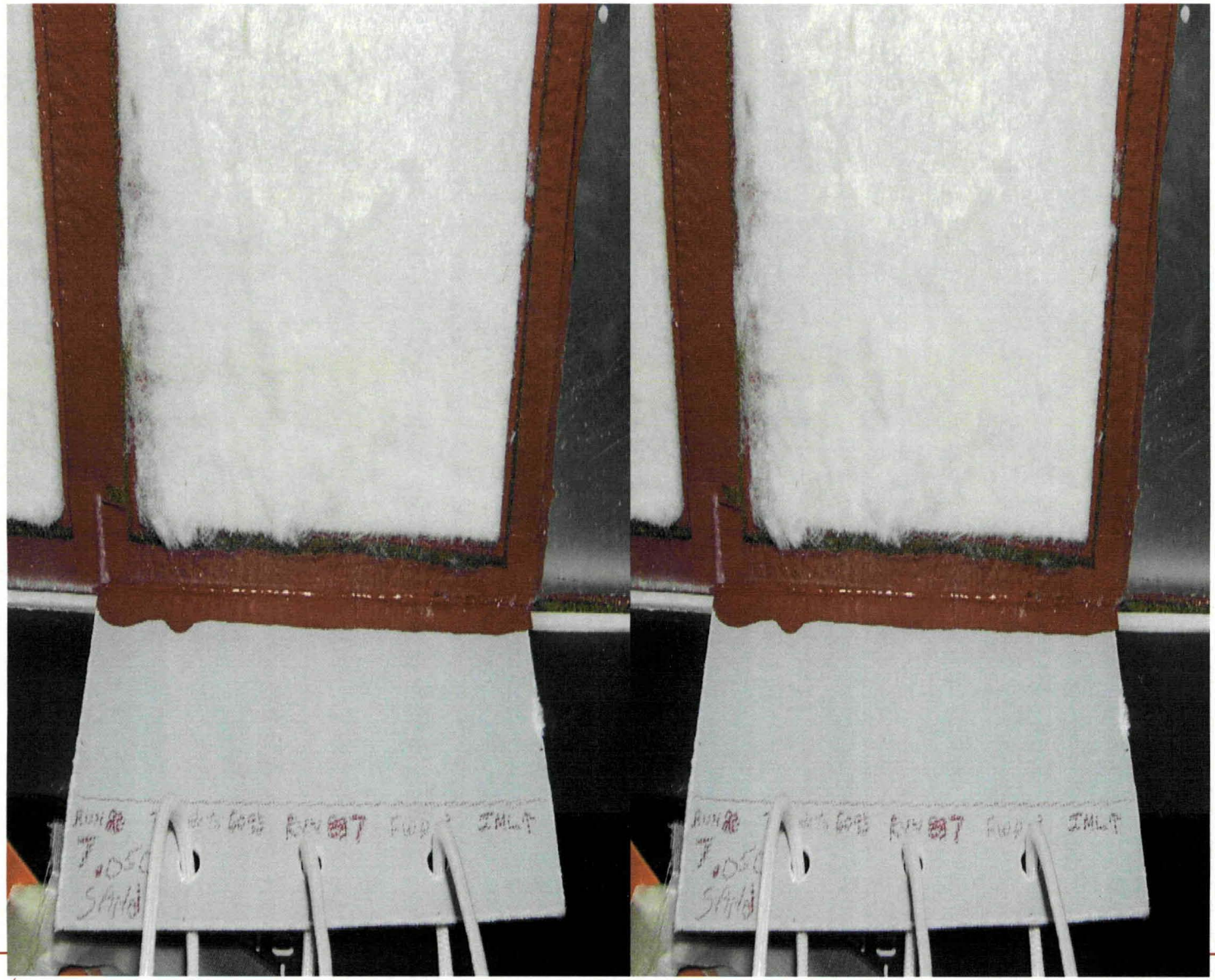
Design of Experiments (DOE) Example

Observations from Pre-test which also may have affected the bondline integrity:

- lack of RTV on filler bar

  - Armalon RTV squeeze out
- poor pressure application
- sidewall bonds
- gap filler protrusion after bond
- non-uniform load during pull test
- partial debonds
- multi-ply gap fillers may not deflect when debonds are present

Sandwich 0.05” Dip



Design of Experiments (DCCE) Example

- This is the kind of thing we all learnec about in engineering school....
- So....the science is well understood
- The methods are well understood
- The selection techniques are well uncerstood

- ……the primary difficulty in performing a set up and test like this is getting management to understand what you're doing; why you're doing it that way; and why it's important to follow the rules.

Design of Experiments (DOE) Example

Qualification Test of Process Enhancements

– 144 gap fillers distributed as follows

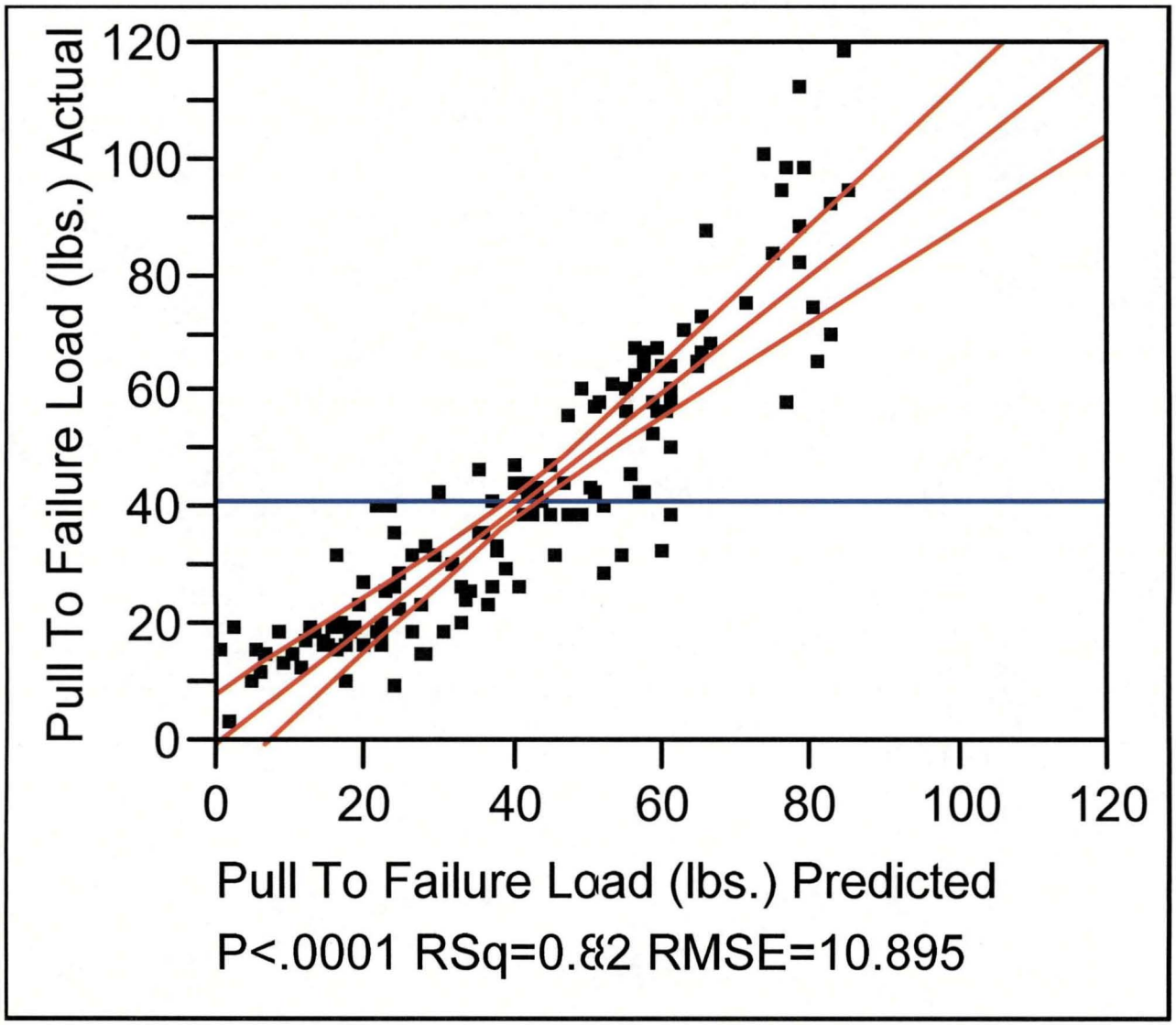
Factors	Levels
Technicians	6 levels - randomly selected from population of technicians with gap filler cert
Inspectors	2 levels- randomly selected from population of TPS quality inspectors
Fill type	2 levels– complete or nominal
Lengths	4 levels – 1.5", 3", 5", and 7"
* Plys/flat panel	3 levels – 1, 3, and 4 ply
* Plys/curved panel	3 levels – 2, 5, and 6 ply

Design of Experiments (DOE) Example

Qualification Test Results

- Ordinary Least Squares Regression was performed on the 142 data points to predict and hypothesize on the effects that the gap filler process improvements may have brought to gap filler bonding at KSC

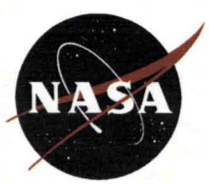
Design of Experiments (DOE) Example



Design of Experiments (DOE) Example

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F	Rank
Technician	**5**	**5**	**1152.939**	**1.9425**	**0.0917**	**3**
QC	**1**	**1**	**107.005**	**0.9014**	**0.3442**	**4**
Length (in.)	**1**	**1**	**54580.025**	**459.7903**	**<.0001**	**1**
Ply	**5**	**4**	**9198.389**	**19.3722**	**<.0001**	**1**
Panel (0 = flat, 1 = curved)	**1**	**0**	**0.000**	**NA**	**NA**	**NA**
Complete or Nominal? (0 = nominal, 1 = complete)	**1**	**1**	**1.983**	**0.0167**	**0.8974**	**5**

The smaller the number the less likely the observed effect occurred by chance.



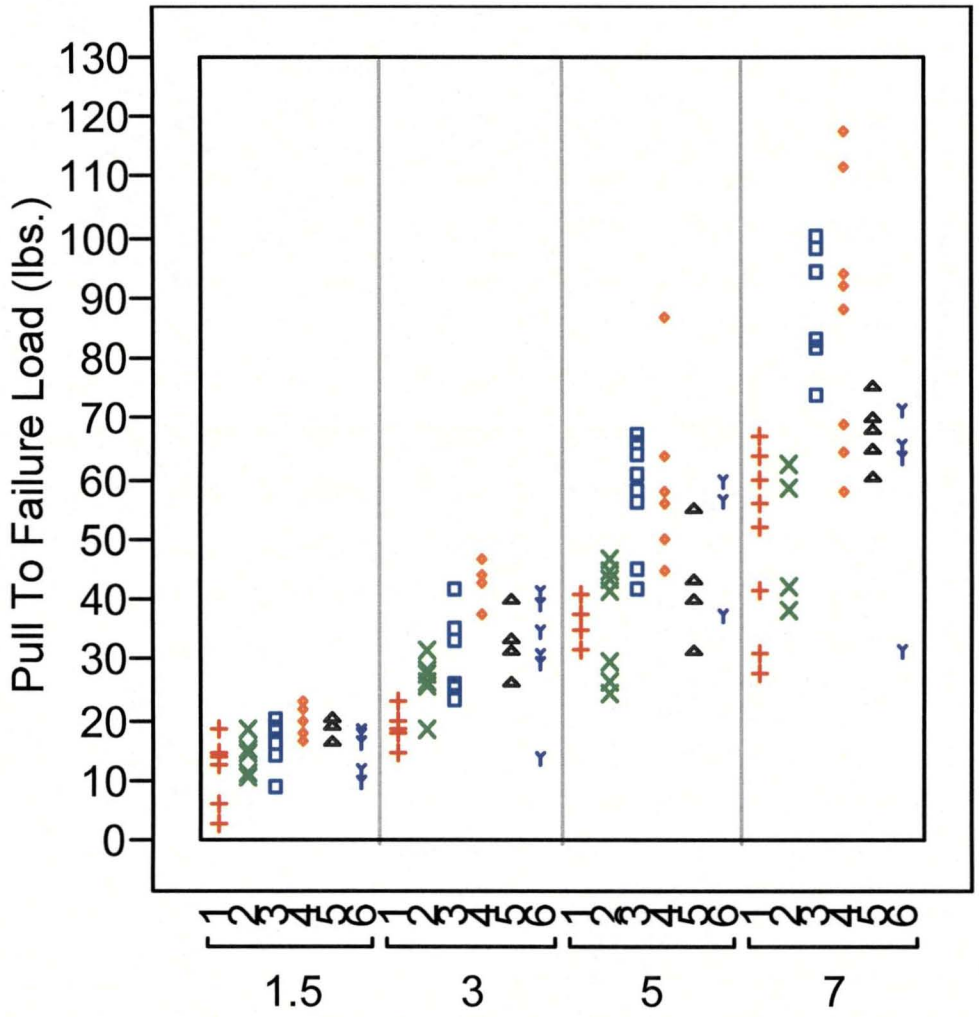
Design of Experiments (DOE) Example

What does this mean?

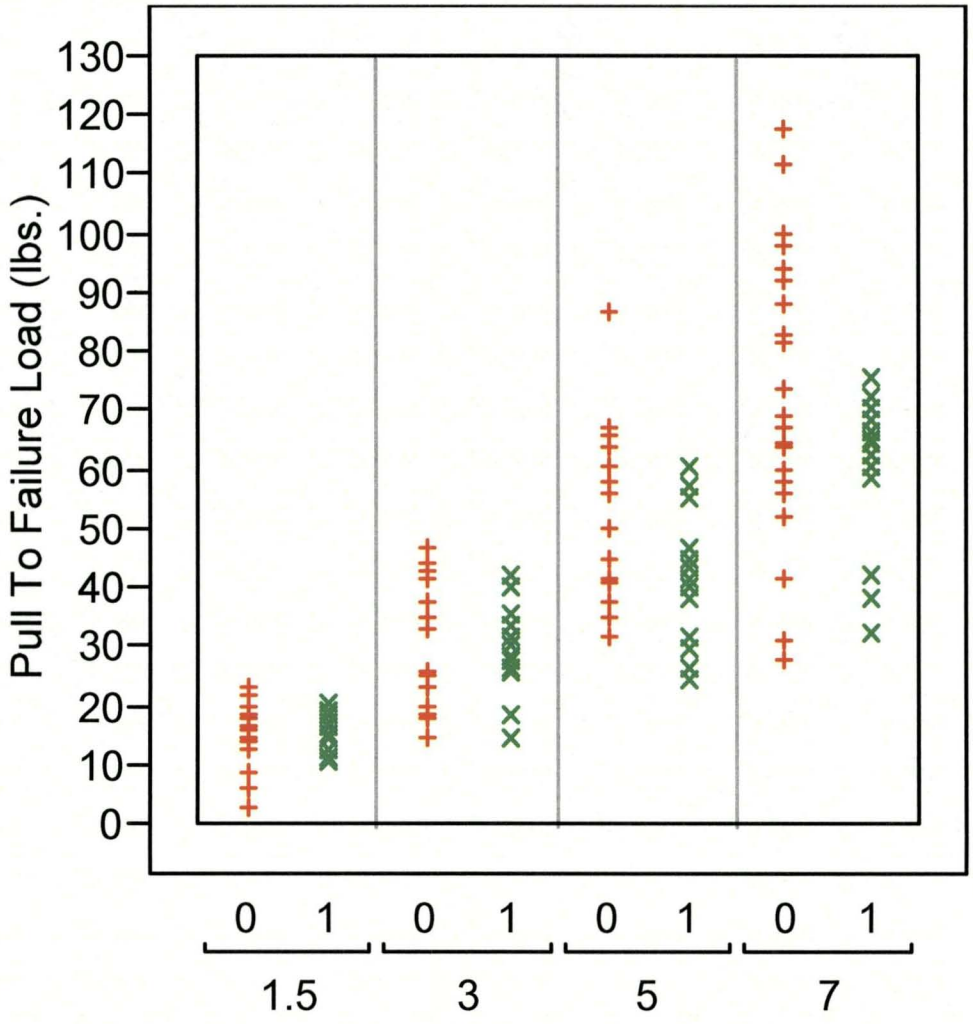
- Ply, and length have the greatest effect on the pull to failure load.
- Fill type (complete or nominal), technician, or QC do not have as great an effect.
- The effect of the panel could not be statistically determined since ply and panel type were not independent. However, examination of the following figures indicates that IML curvature does have an effect on bond strength.
- The following is the overall summary of the 142 data points:

Average Pull Value (lbs.):	**41.09**
Minimum value (lbs.):	**3**
Maximum value (lbs.):	**118**
% Complete Fill:	**35.42%**
% Nominal Fill:	**64.58%**
% Curved:	**43.75%**
%Flat:	**56.25%**
% Failure Rate:	**0.70%**

Design of Experiments (DOE) Example



Design of Experiments (DOE) Example



Design of Experiments (DOE) Example

Major Process Enhancements

- Gap Filler length limited to 1.5 to 7 inches
- Clarified the number of pull loops required for varying lengths
- Moved location of pull loop holes above OML trim line and increase hole diameter
- Added Sandwich method for gap filler installation based on OPF technician recommendations and process testing
- Added description for bonding pressure using tape method on the high gap filler
- Added requirement to sever any sidewall bonds using 0.006 inch thick metal shim
- Increased the pull loads to 5.0 +1.0/-0.0 pounds
- Trim gap filler flush to 0.12 inch recessed after pull test

Design of Experiments (DOE) Example

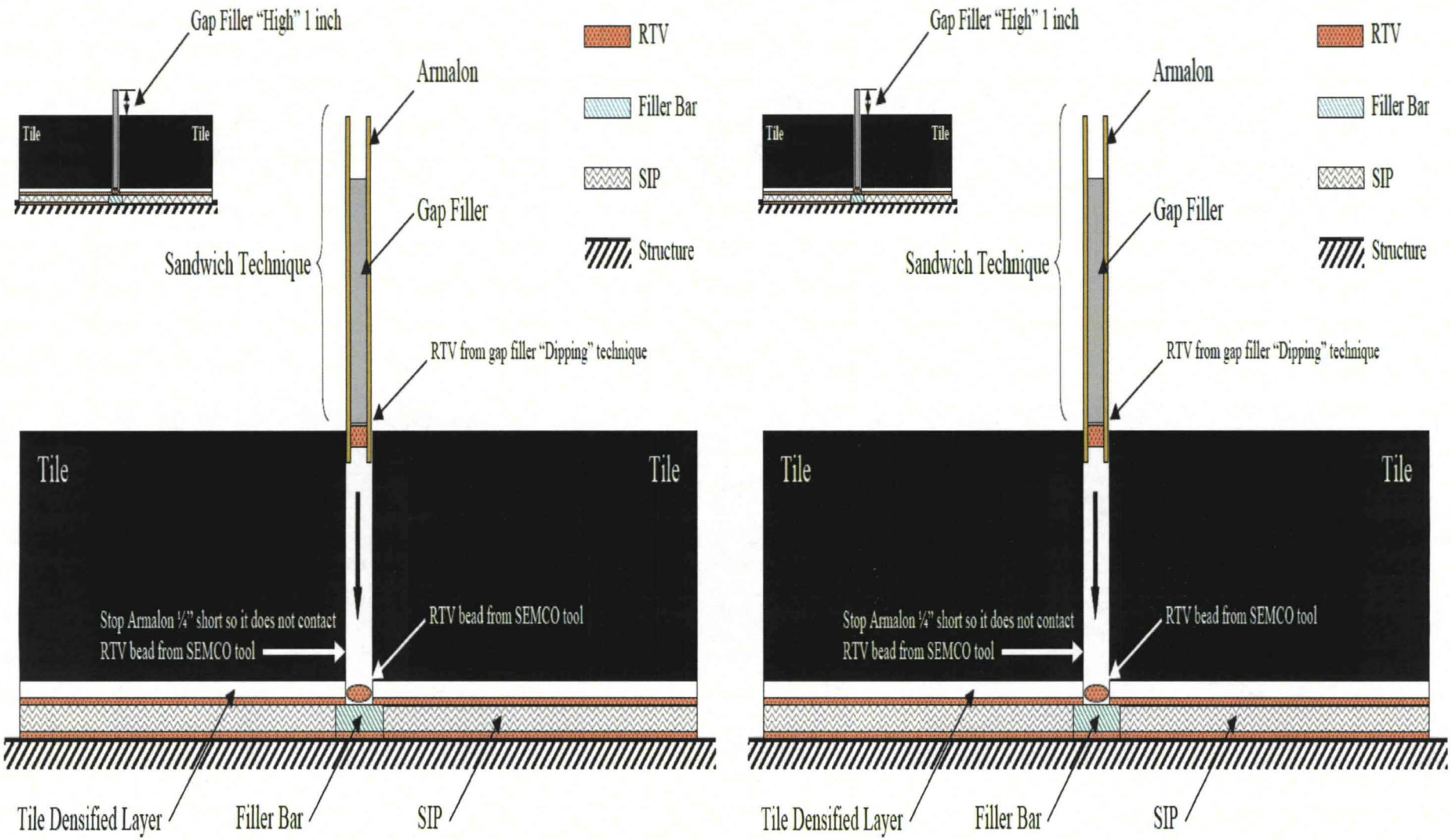
Conclusion of gap filler experiment

- New process allows for an average gap filler pull to failure value of 41 lbs.
  - Range of pull to failure values range from 3 lbs. To 118 lbs.
- Length and to a lesser degree, ply, have the greatest effect on the pull to failure load
  - Curved or flat panel effect cannot be determined statistically but from observation of trend on previous charts, IML curvature does seem to have an effect on bond strength.

Conclusion

- So…..what did we get out of all of this?
  - Proven enhancements to the process
  - Better understanding of the installation process……
  - AND ---
  - Not a single gap filler issue during remaining missions for Space Shuttle
  - AND
  - Better management support for use of advanced statistical methods in the operational environment.

BACK UP


Gap Filler "High" 1 inch
Armalon
Gap Filler
Sandwich Technique
RTV from gap filler "Dipping" technique
RTV
Filler Bar
SIP
Structure
Tile
Tile
Stop Armalon ¼" short so it does not contact RTV bead from SEMCO tool
RTV bead from SEMCO tool
Tile Densified Layer
Filler Bar
SIP
Gap Filler "High" 1 inch
Armalon
Gap Filler
Sandwich Technique
RTV from gap filler "Dipping" technique
RTV
Filler Bar
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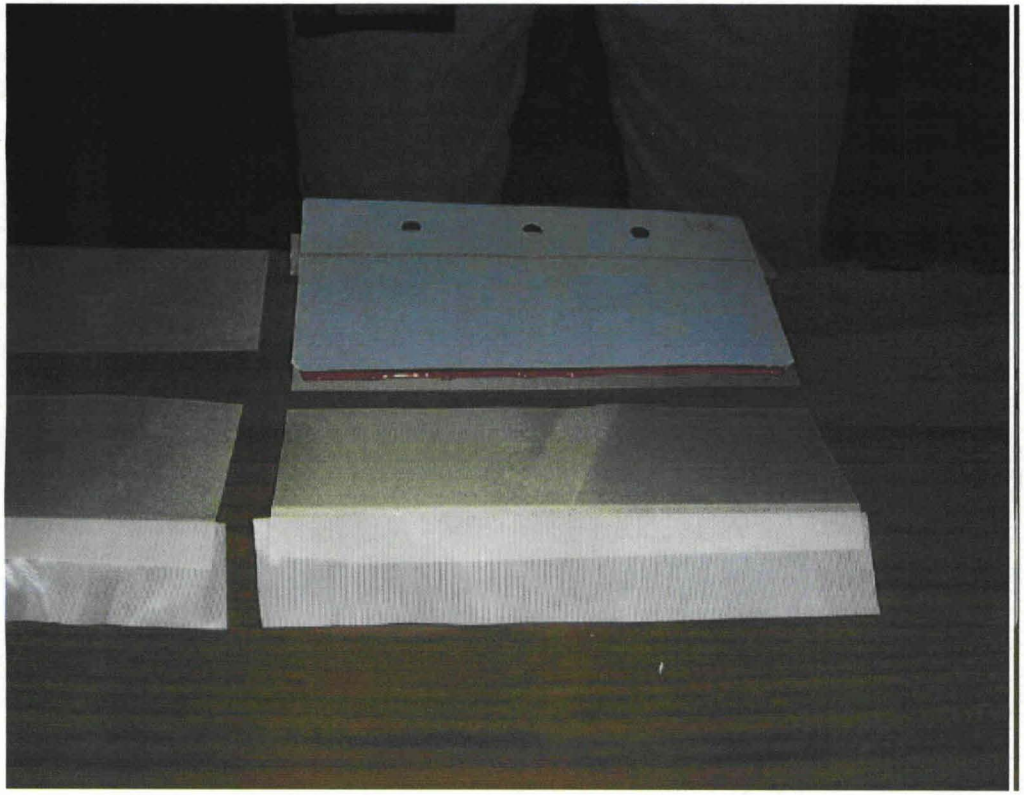
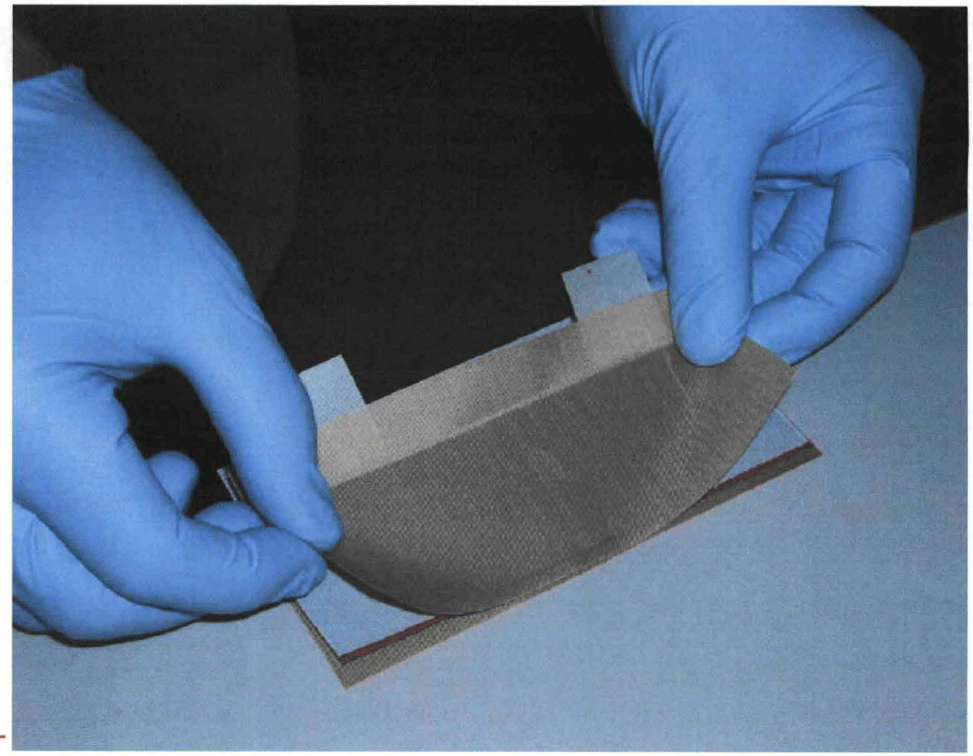
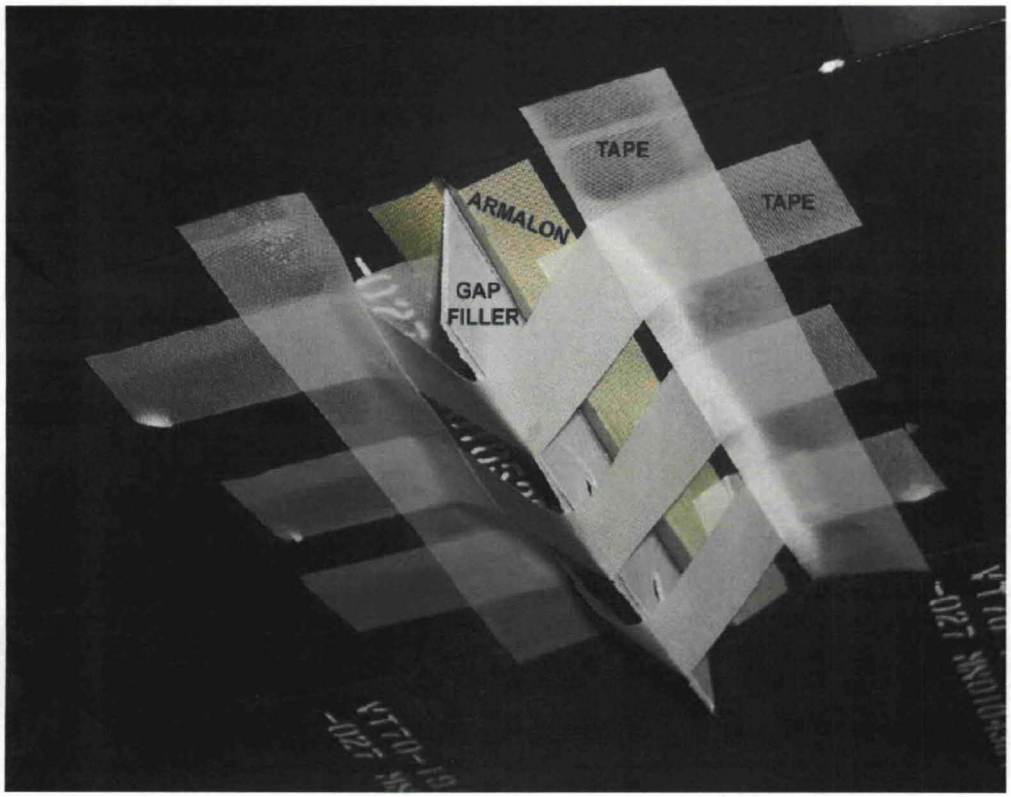
Stop Armalon ¼" short so it does not contact RTV bead from SEMCO tool
RTV bead from SEMCO tool
Tile Densified Layer
Filler Bar
SIP

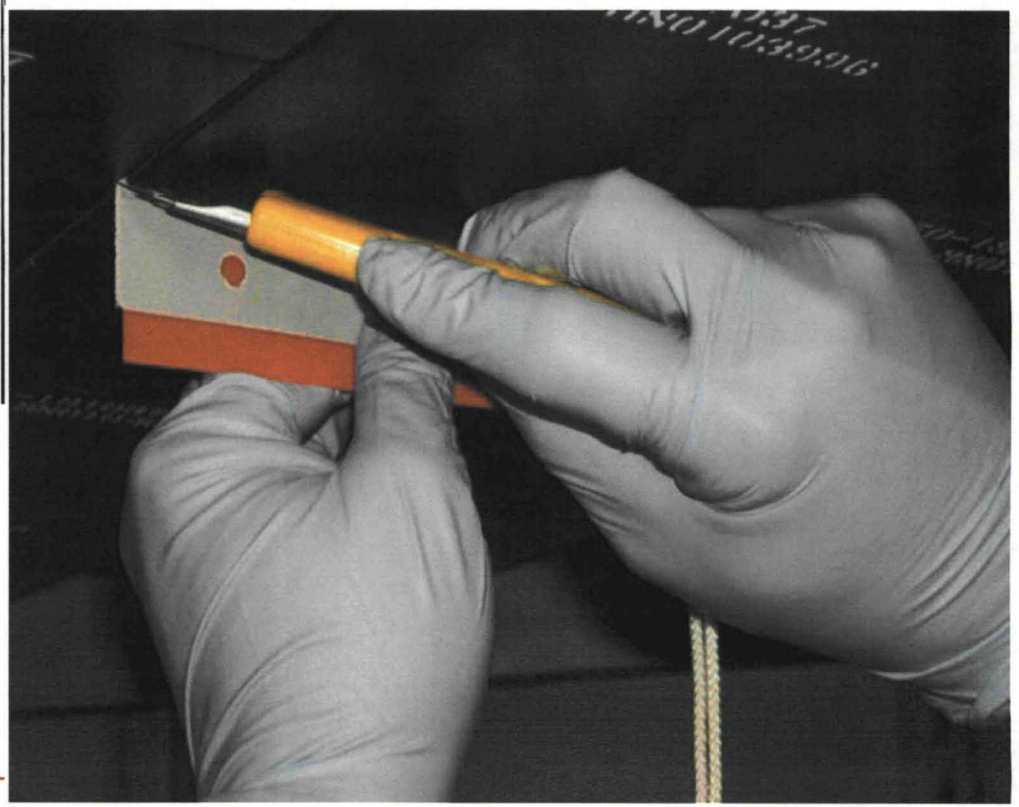
Sandwich & G/F High





G/F Bonded High and Trimming





Armalon Placement & Semco