Essentials of Advanced Composite Repair

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Why Repairs Are Necessary on Aircraft
41 foot high tail Vs. 38 foot tall hanger door opening

737-800 is 4 feet taller than older 737-400 model
Boeing C-17 Tail Damage:

The Aircraft

The Work-Stand

Damage
Repairs are necessary in motosports as well
Formula 1 Racing
Rally Car Racing
Motorcycle Racing
Speed-Boat Racing
Tug Racing
Boats, Planes, Trains, etc, etc…Repairs are Required for Many Composite Structures.
Goal of Composite Repair Design

- Rebuild Fiber Load Path Through Structure
- Ideal to Match Original Properties:
  - Strength
  - Stiffness
  - Weight
- Trade-offs:
  - To match strength, repair is stiffer & heavier
  - To match stiffness, repair is weaker & heavier
  - Cannot match all original properties
Common Repair Methods

- Stepped Co-bonded Repairs
  - Wet layup and prepreg materials & processes

- Tapered-Scarf Co-bonded Repairs
  - Wet layup and prepreg materials & processes

- Bolted Doubler Repairs
  - Pre-cured composite doublers
  - Stainless steel or Titanium doublers
Stepped Removal & Repair

- Idea comes from metal lap-joint repair design concepts.
- Each damaged layer is removed in “steps” so as to provide a landing for each replacement layer in the repair.
- Each repair ply then overlaps the corresponding exposed layer in the structure.
Typical Stepped Repair

Loads are distributed through the repair via a lap joint into the underlying layers

The resulting repair sits above the surface
Typical Stepped Repair

Shear stress distribution in a stepped repair
Note peak stress concentrations at edges of each step within the repair
Typical Stepped Removal Process

Plies were removed in steps using a knife to cut through each ply and then scrape off the ply to the correct level.
Stepped Repairs

- **Pros:**
  - Easy to conceptualize & design.
    - (It looks good on paper!)
  - Feasible for flat panel repairs made with discernable materials.
  - Co-bonded layers makes for intimate repair contact at faying surfaces.
  - ???

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Stepped Repairs

**Cons:**

- Requires meticulous machining of each layer in the damaged laminate so as not to damage the underlying plies. (This takes exceptional skill!)
  - Difficult to do on curved surfaces.
  - Damage to underlying layers is common and often overlooked in the industry.
Stepped Repairs

- **Cons:**
  - Requires careful fabrication and placement of repair plies so that they fit into each step w/o gaps or overlaps.
    - Requires precise templates or tracings to ensure repair-PLY fit.
    - Unwanted gaps and overlaps often result in defects in the final repair.
Stepped Repairs

- **Cons:**
  - Takes a trained technician approximately 2 x the time to perform a stepped repair compared to a tapered-scarf repair.
  - Airlines are not likely to do step repairs as a result of the extra labor involved.
Tapered-Scarf Repairs

- A tapered-scarf angle is machined through the composite structure so as to expose each layer along a gently-angled slope.
- Each repair ply then lays over the corresponding exposed layer along the tapered angle.
Typical Repair Approach

First remove damaged material and prepare area for repair

Determine plies/orientations in the original structure & develop repair

Replace plies/orientations to match the original structure
Example of a Tapered-Scarf Removal Process

Practicing a tapered scarf on an Aramid fiber reinforced epoxy sandwich structure
You Can Clearly See the Layers in This Tapered CFRP Sandwich Panel
Typical Tapered-Scarf Repair

Loads are transferred directly through the edges of the repair plies, in plane, on axis, in shear, to the underlying structure.

The resulting repair is flush with the surface.
Typical Tapered-Scarf Repair

Uniform shear stress distribution through a tapered scarf joint
Big Ply Down Scarf Repair

Loads are transferred directly through the big ply laid down first, fully loading this ply in the axis of its orientation prior to transferring load to adjacent plies.

Abaris Training does not recommend this repair technique for highly loaded or optimized composite structures!
Tapered-Scarf Repairs

- **Pros:**
  - Fast & easy to machine taper-angle and to fabricate repair plies.
  - Perfect size and fit of repair plies is less important to performance.
  - Flush surface is attainable.
  - Important for critical aerodynamic surfaces & L.O. structures
Tapered-Scarf Repairs

**Pros:**

- Can machine a taper with a die grinder or “jitter-bug” sander.
  - No special tools or devices necessary.
- Less risk of damaging underlying layers in tapered area.
- Co-bonded layers makes for intimate repair contact at faying surfaces.
Tapered-Scarf Repairs

- **Cons:**
  - Not applicable to repairs of thick structures as one might do more damage to the original structure attaining the correct scarf angle ratio.
  - Minor risk of damaging “good” structure within and outside the scarf area.
  - ???
Typical Wet Layup Repair Process

Remove damaged skin & core then taper-scarfed skin

Repair/fill core cavity as required & machine flush
Typical Wet Layup Repair Process

Apply wet resin to dry fabric, cover with plastic, and squeegee the resin throughout the layer as needed.
Typical Wet Layup Repair Process

Wet-out the surface with an interface coat of resin and layup each repair ply to match the orientation of corresponding plies in structure.
Apply peel ply, bleeder, & breather materials and vacuum bag for cure
Typical Wet Layup Repair Process

After curing, remove breather, bleeder, & peel ply and inspect the repair
Prepreg Repairs Follow a Similar Process and Typically Require an Elevated Temperature Cure Using Portable Hot-Bond equipment
Bolted Doubler Repairs

- Historically the norm for metal structural repairs
  - Also bonded metal doublers for thin skin metal structural repairs
- Normally reserved for thicker, solid composite laminate structures where a scarf or step repair would not be feasible.
Typical Doubler Section

Seal all around the patch

Fasten as prescribed

Outside Doubler

Laminate

Plug

Structure

Inside Doubler
Bolted Doubler Repairs

- Determining when to use a doubler can be tricky.
- If the laminate is less than 1/8 inch thick: tapered-scarf repair
- If the laminate is greater than 1/2 inch thick: doubler repair
- In between: do a repair design analysis
Bolted Doubler on CFRBMI Panel
Tapered Scarf Repair on Similar CFRBMI Panel
Pros:

- Can be faster and easier to accomplish compared to taper-scarfed or stepped co-bonded repairs.
- Requires less removal of original structure (compared to step or tapered-scarf repairs) to accommodate the repair.
- Most mechanics are already trained in drilling & fastener installation procedures.
Bolted Doubler Repairs

- **Cons:**
  - Doublers must be made to closely match surface contour.
    - Can be problematic in compound areas
  - Additional tooling may be required to facilitate fabrication of repair patch.
  - Autoclave cure of composite patch may be required to achieve properties.
Bolted Doubler Repairs

**Cons:**

- Risks associated with drilling into underlying structure for fasteners.
- Expensive Ti fasteners required in carbon reinforced structures.
- Sealing of the repair questionable and not often durable.
The goal is to replace the structure to serviceable strength and stiffness.

It takes special training and practice to do top quality composite repairs.

One approach does not fit all types of damage.

Repair technicians have to know their materials and processes in order to accomplish good quality repairs.
Next Event Reminder!

Please plan to attend the next SME Tech-Group Webinair event on Tuesday, June 12th, 2007 at 1:00-2:00 pm EDT!

Rich Emrich from Integran Technologies will be presenting a novel and innovative new tooling concept involving the use of Nanovar® surface technology designed to improve the durability of advanced composite molds and fixtures used in manufacturing. This event promises to be a real learning experience!

Contact Victoria Townsend at vtownsend@sme.org for more information about this exiting event!
Thank You For Attending!

Feel free to contact me directly if you have additional questions after this session.

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