# Staying Ahead Of The Game:
## Keeping a Composite Airplane Fleet Airworthy


Cirrus Design Corporation

Paul Brey

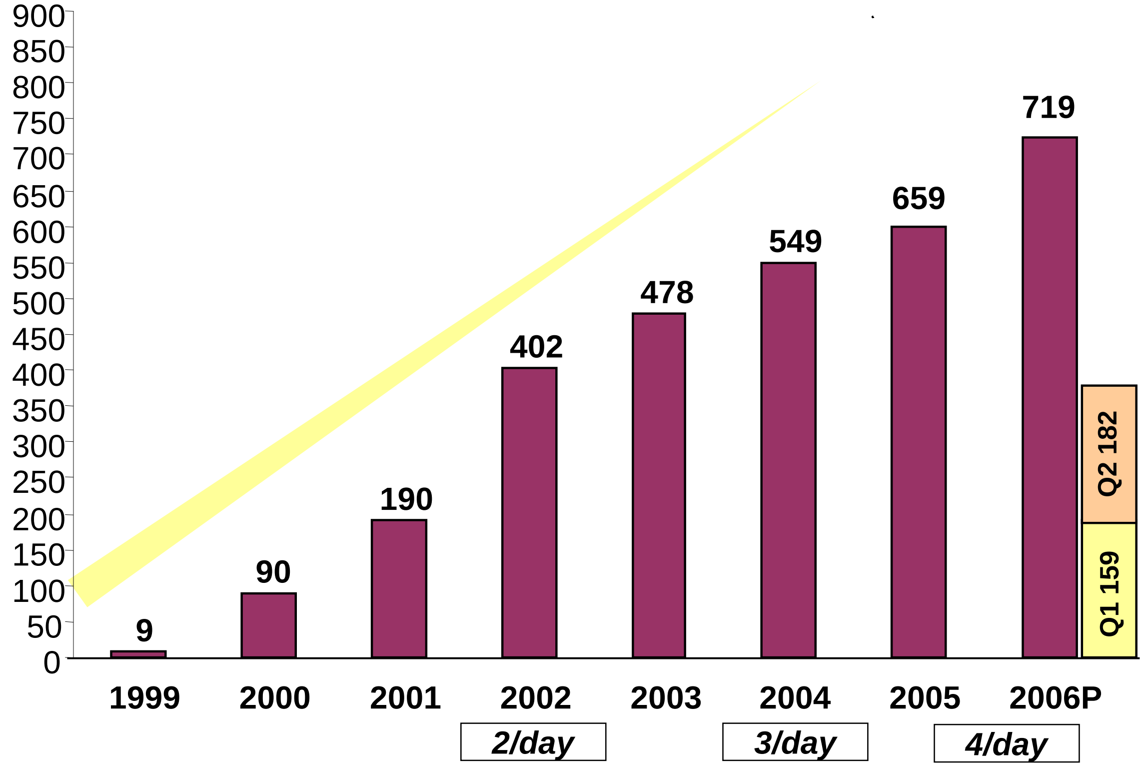
Tim Timmerman

Andy Rokala

# What is a Cirrus airplane?

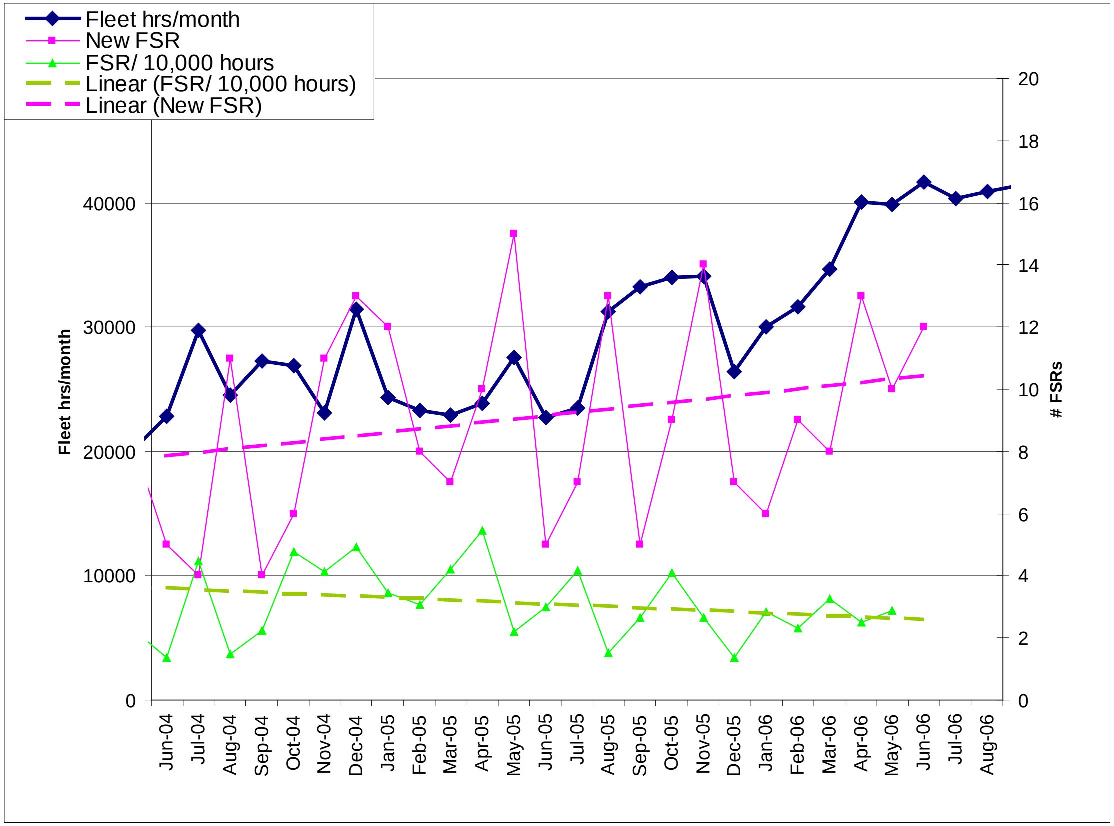
- Certified FAR 23 Normal in 1998
- 4 place single engine, 3000 – 3400 MTOW
- Two models – 200 or 310 horsepower, unpressurized
- S- and E-glass/Epoxy primary structure
- Paste Adhesive bonded primary structure
- Cirrus Aircraft Parachute Recovery System

# A Composite Airplane Fleet




- 2,650 active airplanes in the fleet
- 1.3 million fleet hours

# A Composite Airplane Fleet



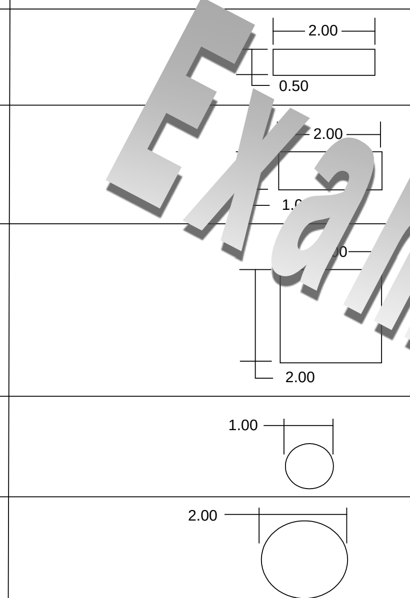

- Growing Fleet = Wider operational variance

  = More repair work

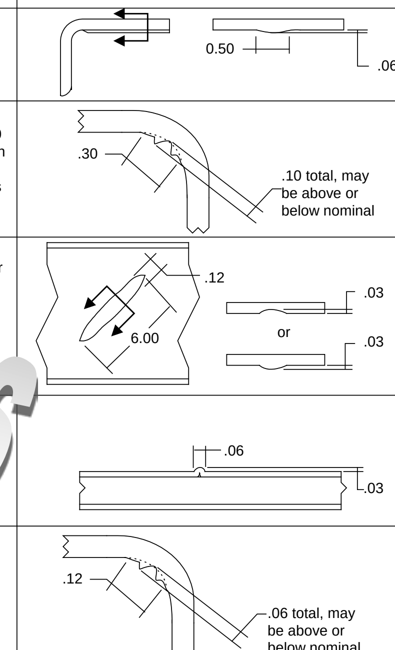
# A Damage Tolerant Design – What Is It?

- Out of the box:
  - Tolerant of the largest defects your design philosophy and QA system allow
  - For the life of the airplane up to ultimate load

| Defect Code | Description |
|---|---|
| DR1 | 2.00 x 0.50 inch General radius and narrow flange areas |
| DR2 | 2.00 x 1.00 inch General defect, including Main Spar radius and other areas |
| DR3 | 2.00 x 2.00 inch Main Spar cap defect, in spanwise or chordwise direction |
| DC1 | 1.00 inch diameter General skin, panel, web, and window post defect (.79 sq inch) |
| DC2 | 2.00 inch diameter General skin, panel, and web defect (3.14 sq inch) |

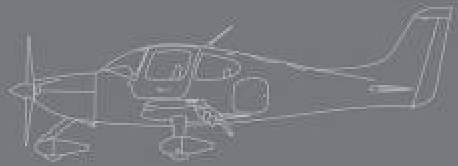



| Defect Code | Description |
|---|---|
| W1 | 4.00 long x .50 wide x .06 high: Wing Spar cap in chordwise diirection |
| W2 | Unlimited length x .30 wide x .10 deep or .10 high: Wing Spar cap in spanwise direction, including inside radius |
| W3 | 4.00 x [illegible]2 wide x .03 dee[illegible].03 high: Spar we[illegible]n any direction |
| W4 | 50[illegible] of co[illegible]oner le[illegible] wrinkle d[illegible]x .06 wide .0[illegible]: san[illegible]ch skins, solid s[illegible] bulkhead web[illegible]ng core ramps |
| W5 | 50% of component length in wrinkle direction x .12 wide x .06 deep or .06 high: rib/bulkhead intergral flange inside radius, skin integral radius |




# A Damage Tolerant Design – What Is It?

- In the field:
  - Tolerant of damage detected  and repaired by defined maintenance
  - For limited amounts of time up to limit load



# A Damage Tolerant Design – What Is It?

During a flight:

- Tolerant of a damage event the pilot is aware of
- For “fly home” loads for the completion of the flight


…or a parachute deployment

# How Do You Design For It?

- A priori knowledge of your manufacturing defects

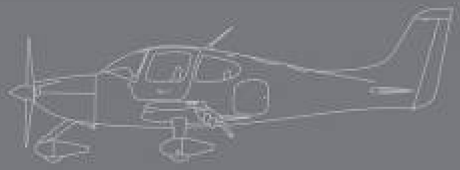
You try – but you will be surprised

- Understanding stress concentrations and your material's response to them

Your design is generic details connected by unique stress concentrations

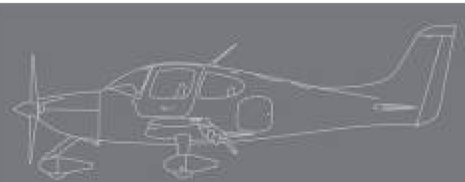
- Choosing the field damage you are willing to deal with ….and having a plan for worse
- Reviewing the success or failure of your predictions periodically, and making adjustments

Plan on an on-going Test and Evaluation program



# The Cirrus Design Approach To Damage Tolerance

- BVID:  Design and test for VID to ultimate load for the design life
  - Provides robust structure
  - Tolerant of a wide variety of maintenance and inspections skills
  - Still require repair when it is found
  - Allows Stress Analysts to sleep at night
- No-growth response to VID
- Extensive full scale test of repair concepts

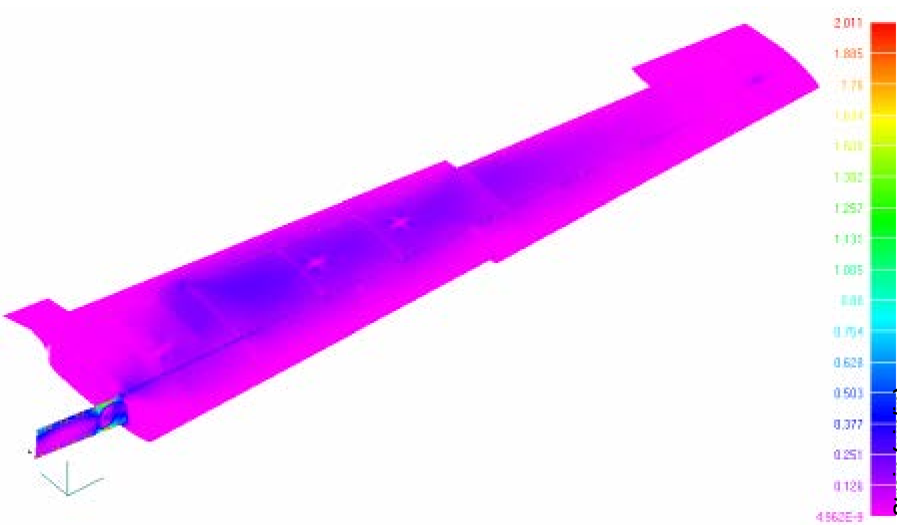


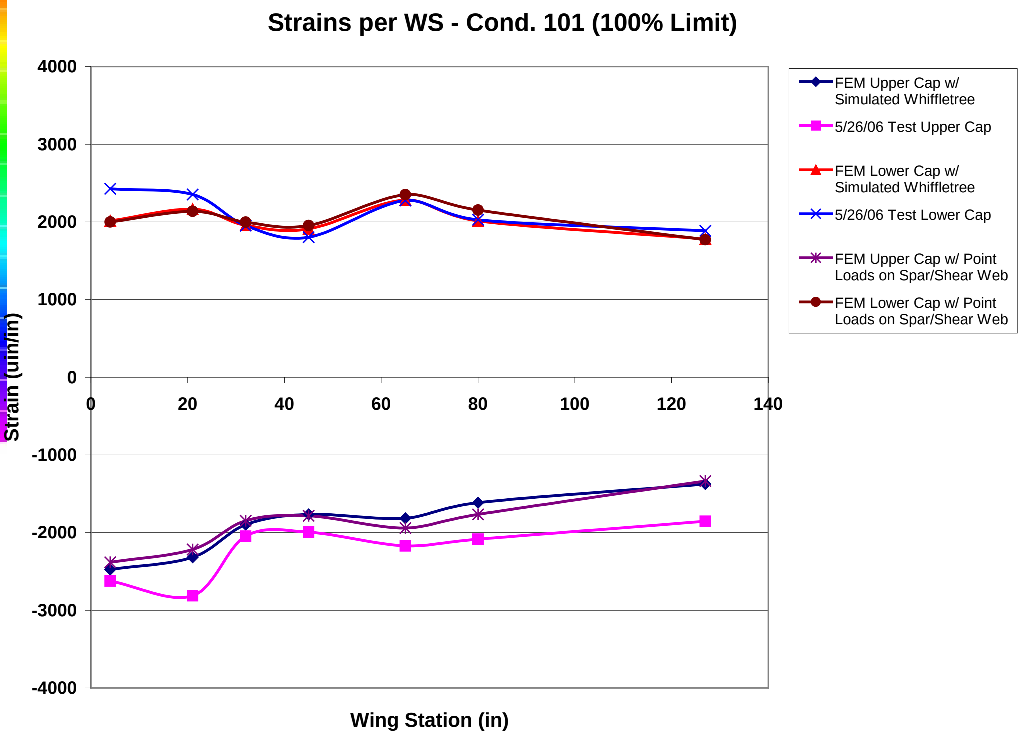
# The Cirrus Design Approach To Damage Tolerance

- Design approach has demonstrated reasonable soundness and conservativeness
  - Maybe too conservative?
- No occurrences of design, material, or process related failures in the primary structure to date!
- As we move to higher performance structures and materials, we will have to carefully evaluate what components of this approach to retain or modify

# How Do You Validate Your Design/Analysis Scheme?

- A sound, reliable understanding of internal loads



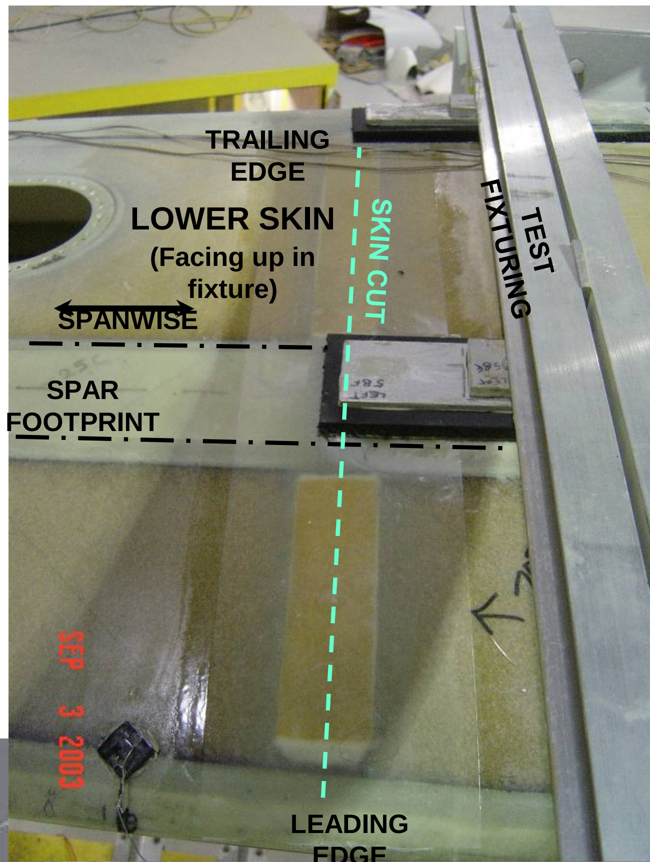


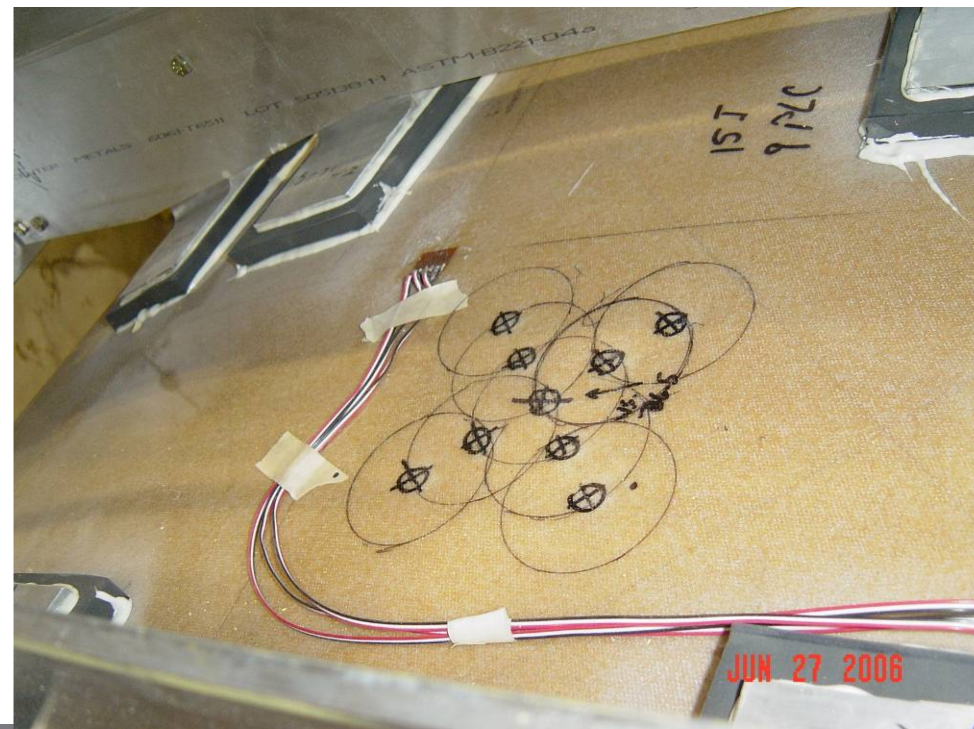

# How Do You Validate Your Design/Analysis Scheme?

- Testing generic details – building block approach
- Testing unique details – point design
  - Static and cyclic, with and without damage
- Understanding scaling sensitivity of defects in your details
- Designing, analyzing, and testing generic repair details
- Element and Full Scale validation of as many details as possible
  - Test to failure provides the most information
- Correlating as many test outcomes as possible to your best analytical approach

# Bridging The Gap – From Tested Design To Real Damage

- Testing repairs that exceed the size and load you anticipate allows interpolation of static, cyclic, and residual strength test results



# Bridging The Gap – From Tested Design To Real Damage

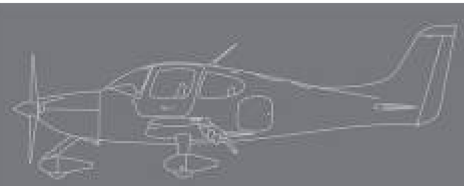
- Repair durability is largely a function of the detail quality of the repair run out
- Design and construct repairs from tested, robust generic transition details
- Cirrus manages the acceptable repair configurations using:
  - AMM for common information, details, and repairs
  - Dedicated repair design for unique situations

# AMM

- Lessons Learned
  - Additional inspection detail to be accomplished after abnormal operations or damage







THE MIND OF AN ENGINEER. THE HEART OF A PILOT.

CIRRUS

# AMM

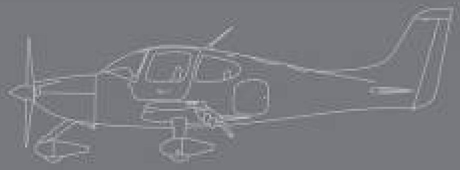
- Damage Assessment and Reporting

- Supports determination of damage severity and whether Engineering support is necessary to design repair

DAMAGE ASSESSMENT AND REPORTING 51-10







# AMM

- No SRM
- Chapter 51 defines basic repair procedures
- Wet lay and pre-cure/paste adhesive repairs
- Includes procedures for surface prep, material mixing and curing





# AMM

- Repair procedures are generic
  - Can be applied within limitations provided in structural chapters
  - Can be called out on dedicated OEM generated repairs

- Contain both step by step instructions along with illustrations

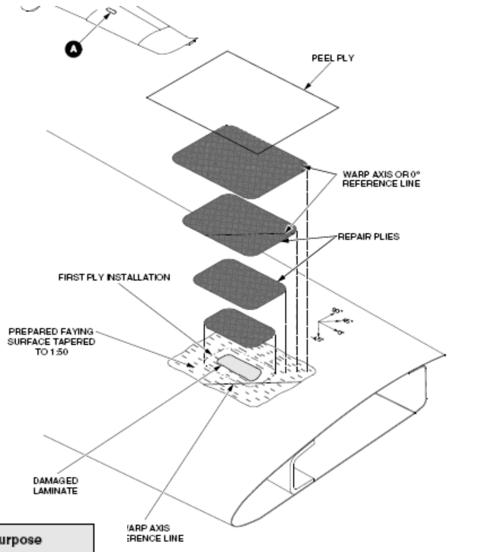



Figure 51-207
Laminating - In Place Method

13773-001
18 Aug 2005

| Description | P/N or Spec. | Supplier | Purpose |
|---|---|---|---|
| Scissors | - | Any Source | Cutting. |
| Paint Brush | - | Any Source | Resin application. |
| Peel Ply | (Refer to 51-30) | (Refer to 51-30) | Repair lay-up. |
| Glass Repair Fabric | (Refer to 51-30) | (Refer to 51-30) | Repair lay-up. |
| Structural Resin Repair System | (Refer to 51-30) | (Refer to 51-30) | Repair lay-up. |

(b) If applicable, prepare backing plate. (Refer to 51-20)
(c) Prepare repair area. (Refer to 51-20)
(d) Prepare repair plies. (Refer to 51-20)
(e) If applicable, prepare EMM surfaces. (Refer to 51-20)
(f) If necessary, mix MGS L418-based filler paste and apply to fill any dents, gouges, or other voids in prepared repair surface. (Refer to 51-20)
(g) Mix structural resin. (Refer to 51-30)
(h) If applicable, remove clecos or sheet metal screws used to temporarily attach backing plate to laminate.
(i) Lay-up glass fabric as follows:
1. Apply thin coat of resin to repair area using a clean brush.
2. Using the template, warp axis and/or 0° reference line, align and center the first, smallest ply over the damaged area.
3. Lightly flatten the ply with the brush. Allow time for resin to wick through the ply from below.
4. "Stipple" the ply with the brush to work air bubbles to the edge of the ply. If necessary, add resin to saturate dry areas. When excess resin has been brought to the surface with the stippling processes and all air bubbles have been removed, coat the ply with a thin layer of resin.

Page 24 51-20

13773-001
18 Aug 2005

# AMM

- Specific repeated repairs are added in Chapters 53, 55 and 57
- Repairs refer back to procedures in Chapter 51 but define specific ply size, orientation and location

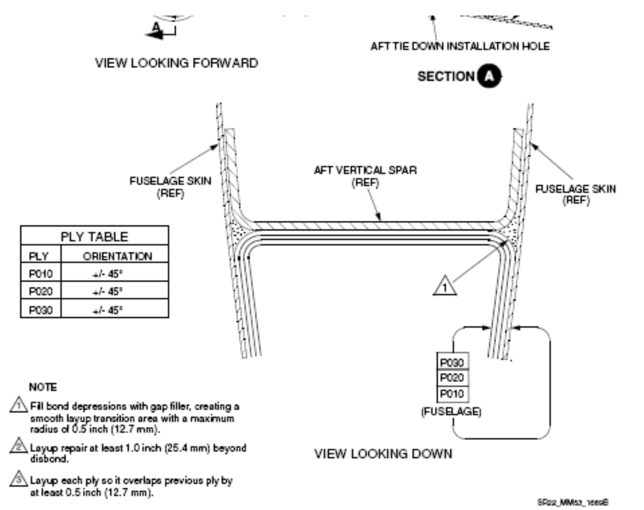



Figure 53-101
Vertical Spar Bond Repair - *Serials 0002 thru 0820* (Sheet 3 of 4)



CHAPTER 53 - FUSELAGE

TABLE OF CONTENTS





**Note:** Ensure plies extend at least 1.0 inch (2.54 cm) beyond disbond.

Ensure each ply overlaps the previous ply by at least 0.5 inch (12.7 mm).

(n) Cut three glass-fiber repair plies at ±45°. (Refer to 51-20)
(o) Mix MGS L418-based structural resin. (Refer to 51-30)
(p) Layup glass fabric repair plies. (Refer to 51-20)
(q) Cure repair plies. (Refer to 51-20)
(r) *Serials 0821 & subs:* Install Expanded Metal Mesh (EMM) lightning protection. (Refer to 51-20)
(s) Match drill hinge installation holes covered by glass fabric repair layup.
(t) Match drill aft tie down installation hole covered by glass fabric repair layup.
(u) Using 0.75 inch (19.05 mm) hole saw, cut aft tie down installation hole through skin and centered on BL0.
(v) *Serials 0821 thru 1153:* From aft tangent of tie down installation hole to aft edge of empennage skin, cut a 0.18 inch (4.57 mm) wide slot centered on BL0.
(w) Prepare the surface for primer and paint. (Refer to 51-20)
(x) Paint repair area. (Refer to 51-20)

# Repair Example

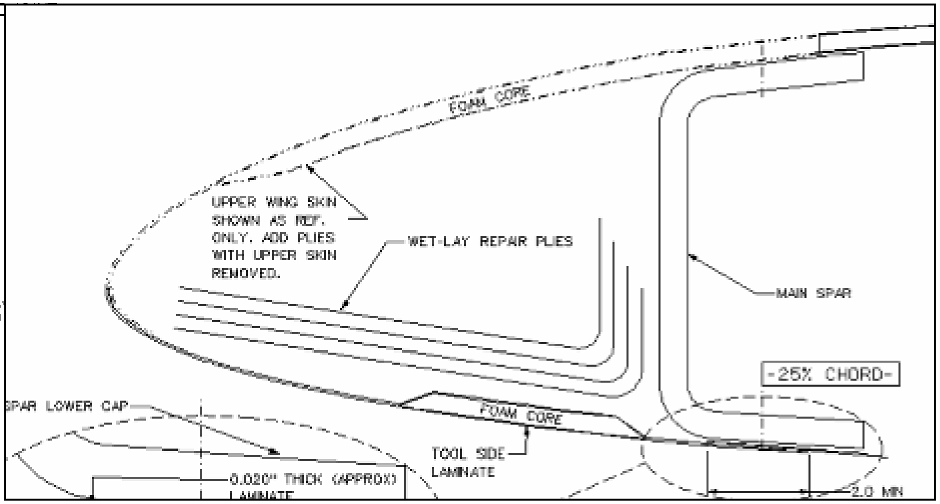
# Off Runway Excursion

# Repair Example

- DER approved repair released
- Repair gives specific dimensions, ply orientation etc
- Step by step along with illustrations as necessary
- Repair refers to AMM Chapter 51

VARY FROM 0.020" THICK (EQUIVALENT TO TWO BAG SIDE PLIES) AT AFT EDGE TO FULL LAMINATE THICKNESS.

5. PREPARE REPAIR AREA AND REPAIR SECTION FAYING SURFACES PER AMM 51-20, "REPAIR SURFACE PREPARATION".
   A. PREPARED SURFACE SHALL BE LARGE ENOUGH TO ENSURE PROPER ADHESION OF WET-LAY PLIES TO BE APPLIED LATER.
6. BOND THE LOWER WING SKIN TO THE EXISTING LOWER WING SKIN LAMINATE AND ADD WET-LAY PLIES TO THE BUTT SPLICE AREAS.
   A. BOND THE AFT EDGE TO THE EXISTING LAMINATE WING SKIN ABOVE THE MAIN SPAR UTILIZING AN OVERLAP
      i. USE STRUCTURAL ADHESIVE PER AMM 51-30, (MGS L418/418)
      ii. MIX ADHESIVE PER AMM 51-30, "STRUCTURAL REPAIR SYSTEMS".
      iii. APPLY ADHESIVE PER 51-20, "REPAIR PROCESSES".
      iv. ACHIEVE BOND THICKNESS OF 0.005" MINIMUM AND 0.060" MAXIMUM.
   B. BUTT SPLICE THE REMAINING EDGE OF THE LOWER WING SKIN REPLACEMENT SECTION.
   C. SEE FIGURES 4 & 5.
7. CURE THE BOND.
   A. CURE PER AMM 51-20, FIGURE 51-2010, USING CURE REQUIREMENTS APPROPRIATE FOR ADHESIVE RESIN S
      (MGS L418/418).



# Repair Example

- Analysis generated to ensure static strength of repair
- Margins are determined based on stress levels that provided acceptable static, repeated load, and residual strength performance
- A comparison is made to a tested repair for damage tolerance assessment
- More testing is accomplished if no suitable similarity can be established

The upper skin has 3 critical areas of repair. The first area that was repaired is tl
the repair. This area was repaired by bond the precure section to the original wir
overlap is sufficient to transfer the ply load from the bagside facesheet to the pre
by a 4 ply wetlay repair [45/-45/45/-45]. As a result of this repair the critical MS

The second area that was repaired is the area that is the overlap joint of the wing
The overlap joint contain a 2.0" overlap. This overlap can carry the shear loads ir
+0.16. The toolside facesheet is repaired with 4 plies at [45/-45/45/-45]. As a re

The third are is the are area where the scarf joint of the wing skin and the precur
2.0". This scarfed area carries the half of the Nxy and Ny loads with an additiona
+0.23. The other half of the load is carried by the 4 wetlay ply repair with a critic

Bonding the WS41 LE rib restores bond strength. The leading edge repair is a s
strength.

**Bond repair to upper skin/main spar: Overlap Joint Cored Section**

From the FEA SR20_wing.MOD, element number 3041 and load case LC 101 (ultimate).

$N_{xy} :=$ [redacted] $\frac{lbf}{in}$

$Q_{allowable} :=$ [redacted] psi

$w := 2.0in$ — width of overlaping area

$Q := \frac{N_{xy}}{w}$ — $Q =$ [redacted] psi

$MS := \frac{Q_{allowable}}{Q} - 1$ — $MS = 0.16$

**Wetlay repair of toolside lower skin/main sp**

**Remark**

Loads were taken form SR20Wing.MOI

**Properties by Lamina**

| ID | Angle | t | |
|---|---|---|---|
| 1 | 45.0° | 0.0100 | 3 |
| 2 | 0.0° | 0.0100 | 3 |
| 3 | 45.0° | 0.0100 | 3 |
| 4 | 90.0° | 0.0100 | 3 |
| 5 | 45.0° | 0.0100 | 3 |

**Allowables by Lamina**

| ID | Material Name |
|---|---|
| 1 | 7781 Wet-lay |
| 2 | 7781 Wet-lay |
| 3 | 7781 Wet-lay |
| 4 | 7781 Wet-lay |
| 5 | 7781 Wet-lay |

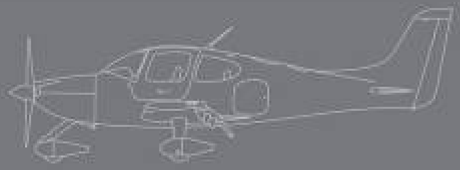
**Load Case**

Nx = 373 force/length
Ny = -6.6 force/length
Nxy = 195.8 force/length
Mx = 0 moment/length
My = 0 moment/length
Mxy = 0 moment/length

**Stresses by Lamina**

Units ...............: force/lengt
Failure Criteria ...: Quadratic S
Remarks .............: L=lower sur

| | Stresses in Fiber Dir | |
|---|---|---|
| No | Sigma1 | Sigma2 |
| 1L | 8963.8 | -1635.8 |
| 1U | 8963.8 | -1635.8 |
| 2L | 9903.8 | -2575.8 |
| 2U | 9903.8 | -2575.8 |
| 3L | 8963.8 | -1635.8 |



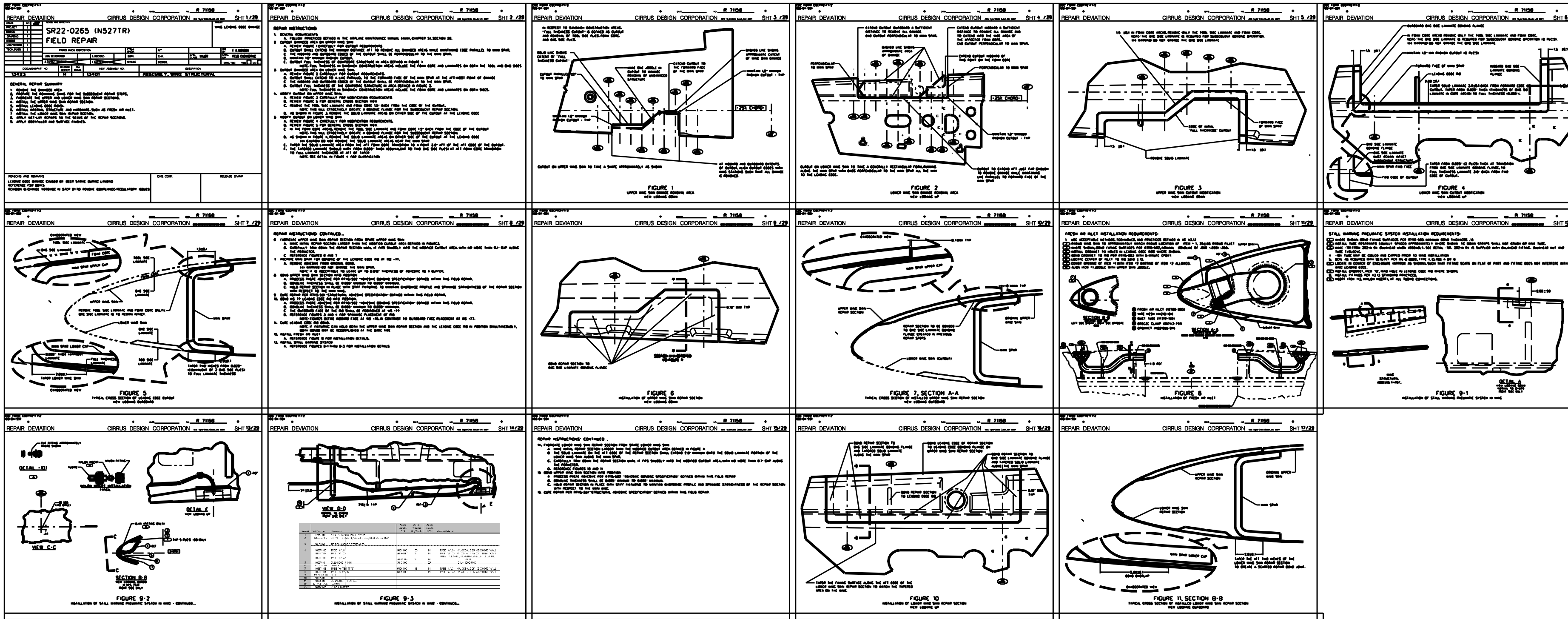
# Another Repair Example

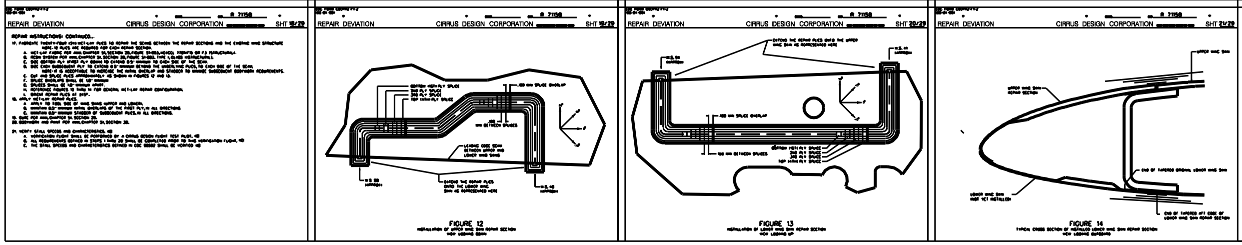
- An Atypically Large LE Repair – Deer Strike

# Another Repair Example

- Remove damage
- Inspect for other damage/disbonds
- Prepare for repair installation

# Another Repair Example



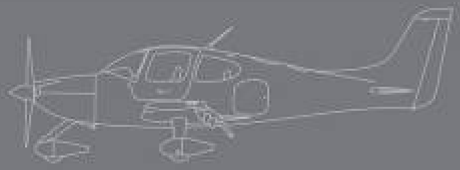

21 pages of repair details

Design & Analysis Time

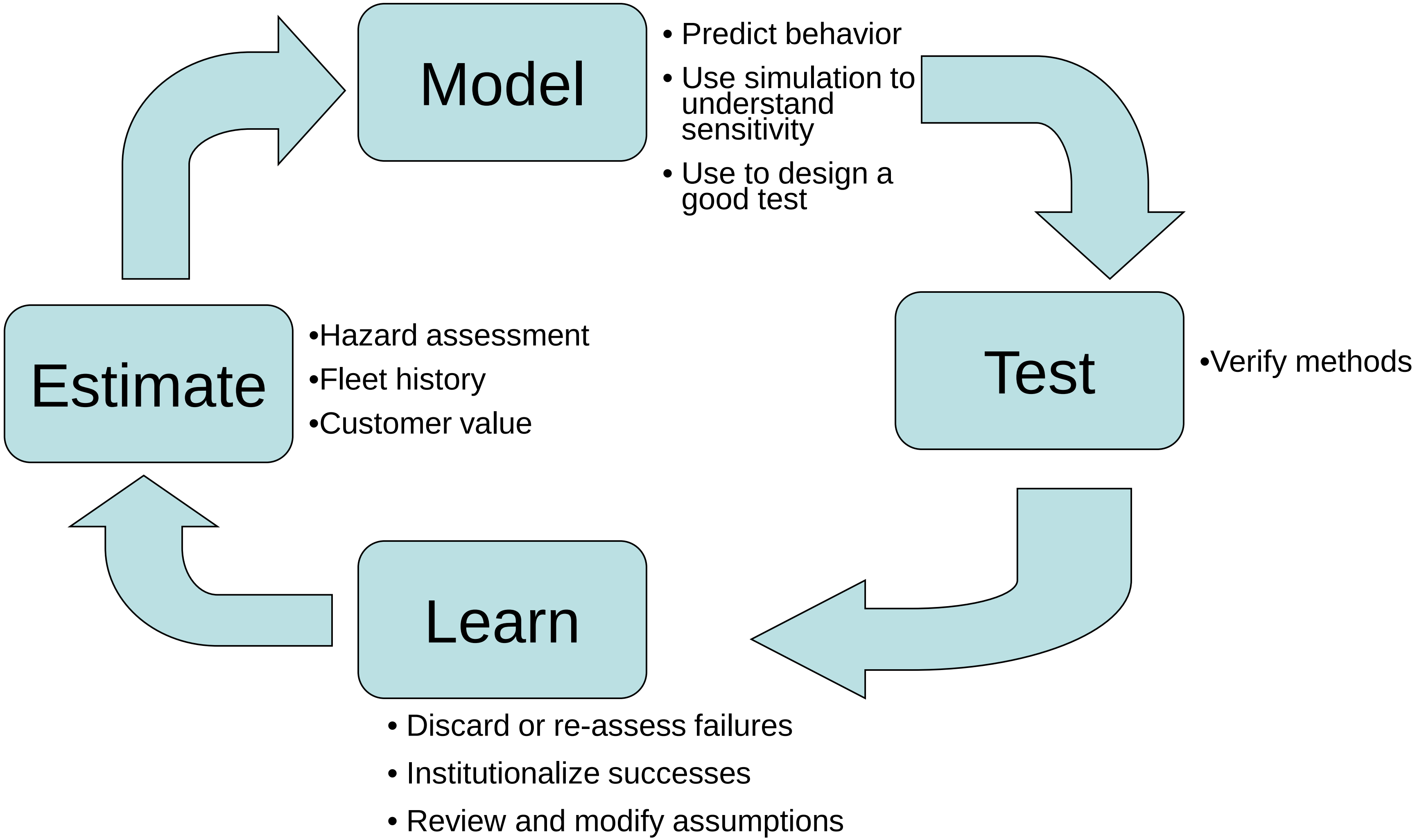
~ 48 hours

# Learning From The Past And Present

- Keeping ahead of your initial assumptions and your customers is an iterative process
- A damage tolerant design lends itself perfectly to providing safe and cost effective designs
- Value derived from
  - Preventing design related structural safety issues
  - Minimizing structural warranty cost
  - Not disappointing customers
  - Keeping repair cost to a minimum
  - Keeping hull insurance cost as low as possible
  - Reducing risk of repair failures



# Learning From The Past and Present



# Thank You!


CIRRUS
DESIGN