Adhesive Bonding Experience at Cirrus Design

Paul Brey
Airframe Engineering

CIRRUS DESIGN CORPORATION

Cirrus Products

SRV

Powerplant	**TCM IO-360ES 200 HP**
Gross Weight	**3000 lbs**
Cruise Speed	**150 KTAS**
Instrumentation	**VFR**

SR20

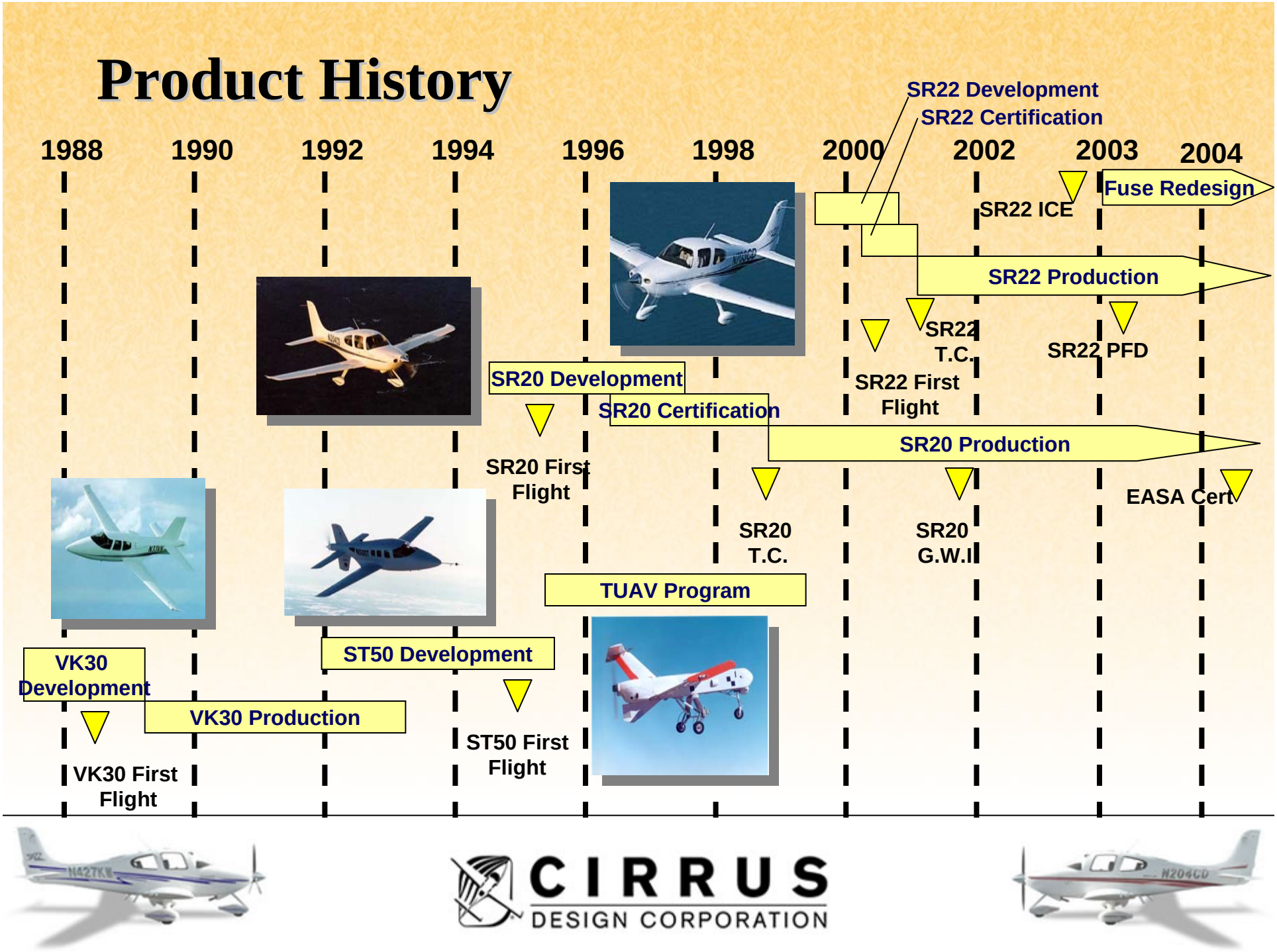
Powerplant	**TCM IO-360ES 200 HP**
Gross Weight	**3000 lbs**
Cruise Speed	**154 KTAS**
Instrumentation	**IFR**

SR22

Powerplant	**TCM IO-550N 310 HP**
Gross Weight	**3400 lbs**
Cruise Speed	**178 KTAS**
Instrumentation	**IFR**

CIRRUS
DESIGN CORPORATION

Product History



CIRRUS DESIGN CORPORATION

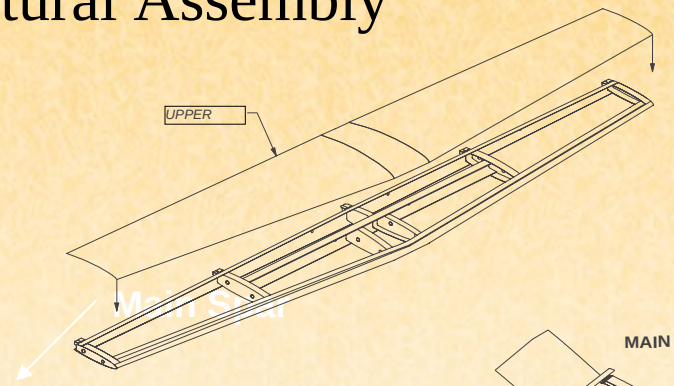
Fuselage Construction

CIRRUS
DESIGN CORPORATION

Wing and Stabilizer Construction

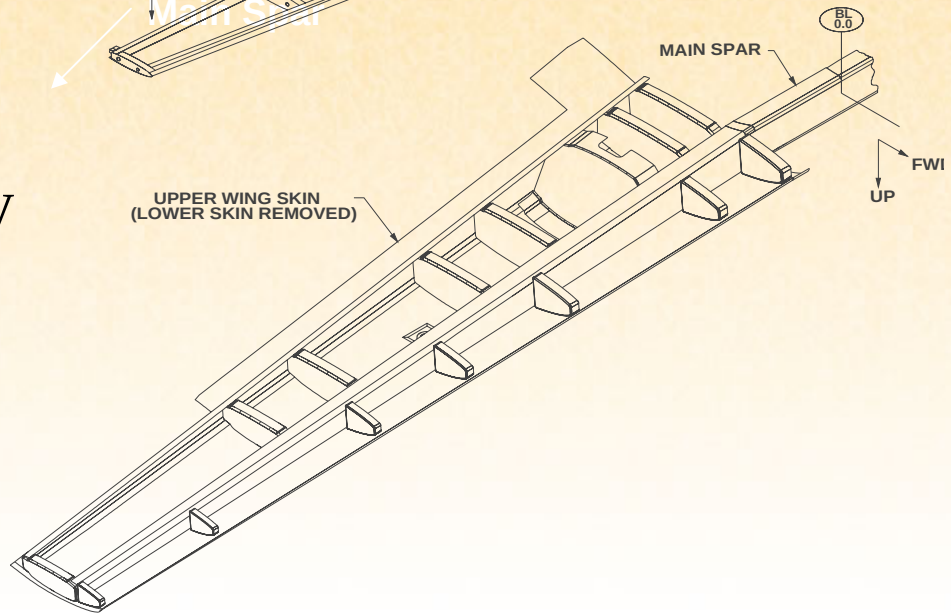
Horizontal Stabilizer Structural Assembly

- Fail-safe design
- Adhesively bonded fuselage installation
- Foam core stiffened skins



Wing Structural Assembly

- Single spar design
- One-piece C-section main spar
- Core stiffened skins
- Integral fuel tanks



CIRRUS
DESIGN CORPORATION

Materials

- E- and S-Glass Prepreg
  - 250F Cure
  - Oven/Vacuum processing
- Divinycell foam core sandwich
  - 3/8” and 1/4”

CIRRUS DESIGN CORPORATION

Materials

- Paste adhesive bonded
  - Low loads
  - Tolerant of laminate and tooling variation
  - Robust with good surface prep
  - Allow up to .080” thick

CIRRUS DESIGN CORPORATION

Adhesive Bonding – What Are The Issues?

- The design and substantiation process is pretty well understood:
  - Process selection
  - Process development
  - Detail design
  - Structural substantiation

Certification

- Then come the other things:
  - Production scale up issues
  - Product in service issues
  - Process evolution
  - Design evolution

Does the substantiation and cert work support this?

CIRRUS DESIGN CORPORATION

Substantiation Issues

- Bonding Issues for Substantiation
  - Damage tolerance and defects
  - Environment – changes in strength and stiffness
  - Mixed and competing failure modes
  - Overloading and geometric nonlinear effect

CIRRUS DESIGN CORPORATION

Damage Tolerance and Defects

- Can you predict the future?
  - What kind?
  - How many?
  - How close together?
  - How can you describe them and their limitations in an inspection spec?
- The applicant must anticipate and select “acceptable” manufacturing and service defects
- Selection requires a priori knowledge of failure modes, hot spots, and manufacturing limitations
- The real guidance is experience and judgment…

CIRRUS DESIGN CORPORATION

Damage Tolerance and Defects

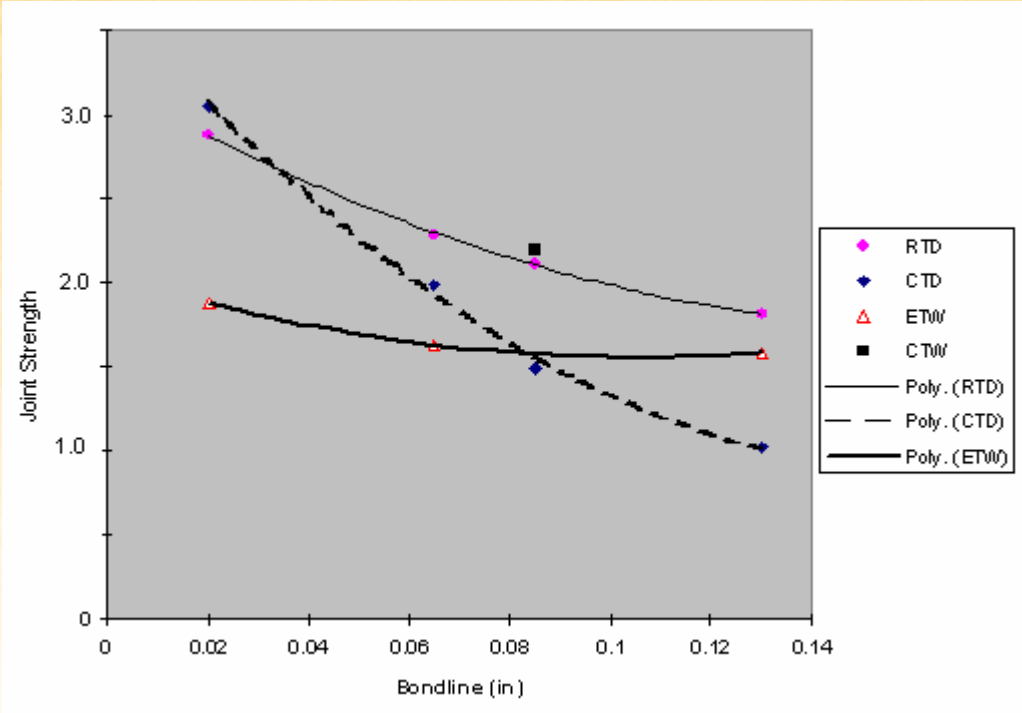
- Considerations
  - Have an NDE plan and understand it's limitations
  - Have a plan to be able both interpolate and extrapolate size and proximity effects
  - Understand that <u>everything</u> is a stress concentration
    - Use the building block approach to understand stress concentration details
    - Consider multiple full scale test articles
    - Accomplish sensitivity evaluation for unique defect and repair schemes

- If you don't, every "non-standard" production defect is a crisis

CIRRUS DESIGN CORPORATION

Environment – Changes In Strength and Stiffness

- Is ETW or CTD your real enemy with thick bonds?
- For the 418/L418 paste system Cirrus tested for a particular joint



CIRRUS DESIGN CORPORATION

Environment – Changes In Strength and Stiffness

- ETW Bonds
  - Modulus is reduced
    - Elastic peak stress is reduced…..
  - Plastic strain capability is often improved
  - Failure strength is reduced
  - But, more load redistribution occurs in the structure….
- CTD Bonds
  - Modulus is increased
    - Elastic peak stress is increased….
  - Plastic strain capability is reduced
  - Failure strength is increased
- So, what can you infer from RTD testing?

CIRRUS DESIGN CORPORATION

Competing Failure Modes

- Structural test overloads to account for “worst case” environmental material properties are difficult
  - Do you pick laminate strength, laminate stiffness, adhesive strength, adhesive stiffness, or some other parameter for the overload criteria?
- Test overloads result in unnecessarily high strains
  - Geometric nonlinear effects and secondary loading can cause failure that is not achievable in the operating or ultimate envelope
- Is the answer to accomplish the full-scale test at each environmental condition????

Or

- Do you over-design to pass the worst environmental factor for your selected test condition and pay the weight/cost penalty?

Or

- Can you design a building block program supported by analysis with the necessary confidence in extrapolating analysis to conditions that are difficult to test?

CIRRUS DESIGN CORPORATION

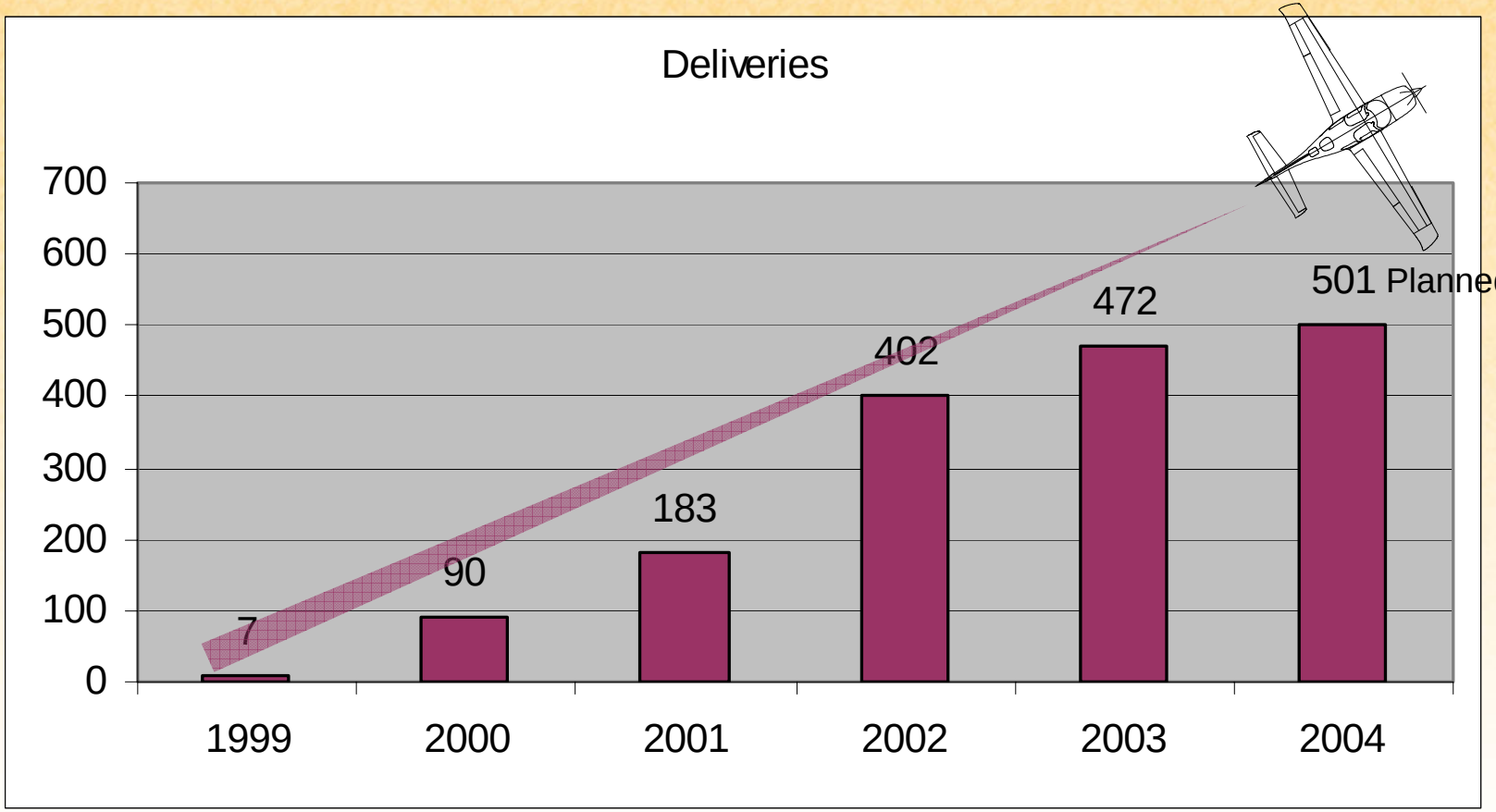
The Things After Initial Certification

- Production scale up issues
- Product in service issues
- Process evolution
- Design evolution

- These issues challenge the substantiation basis of the product every day
- Remember…..they are all positive in terms of customer value and profitability!

CIRRUS DESIGN CORPORATION

Production Scale Up



CIRRUS DESIGN CORPORATION

Production Scale Up

- Facility controls and changes
  - Growth requires facility changes and operational realignments
  - How does your test data and analysis methods support changes in
    - Particulates and ventilation?
    - Contaminants?
    - Temperature and humidity?
    - Part staging?
    - Batching and delays?
  - Can you tell when these factors might be affected?
- Personnel issues
  - How sensitive is your process to training and operator skill?
  - Adequate and continuous training and monitoring is crucial

CIRRUS DESIGN CORPORATION

Production Scale Up

- Scaling up purchasing
  - Can you supplier provide the material quantities you need for your business plan?
  - Are your materials single source?
    - How will you deal with second source or alternate material qualification?
    - Will it push you back into full scale test?
    - This should play a significant role in material selection
- Scaling up Supplier Quality Assurance
  - Moving to large quantities requires effective supplier SPC
  - Balancing JIT inventory and rate production requires an understanding of "go/no-go" decisions on materials that may be non-conforming but still acceptable
    - This can and should be addressed at the substantiation level

CIRRUS DESIGN CORPORATION

Product In Service Issues

- The is little general experience at the small field FBO level with bonded structures for service damage assessment
- Damage assessment and repair must be included in the substantiation plan

Product In Service Issues

- Here is one approach to having confidence in ferry flights…

Fractured compression skin bond

Process Evolution

- Every intended manufacturing process changes
- Continuous Improvement means:
  - Manufacturing will never remain at steady state
  - Cycle time reduction efforts will inevitably try chip away at perceived process “margins”
  - This concept is successful in all other industries….
- If your company is well run, you will be challenged to reduce direct material, labor, and overhead costs on a regular basis
- Management changes
  - Significant leadership changes in a company can actually wipe out an existing culture and replace it
  - The substantiation approach needs to be flexible so that changes can be assimilated without requiring extensive new test programs

CIRRUS DESIGN CORPORATION

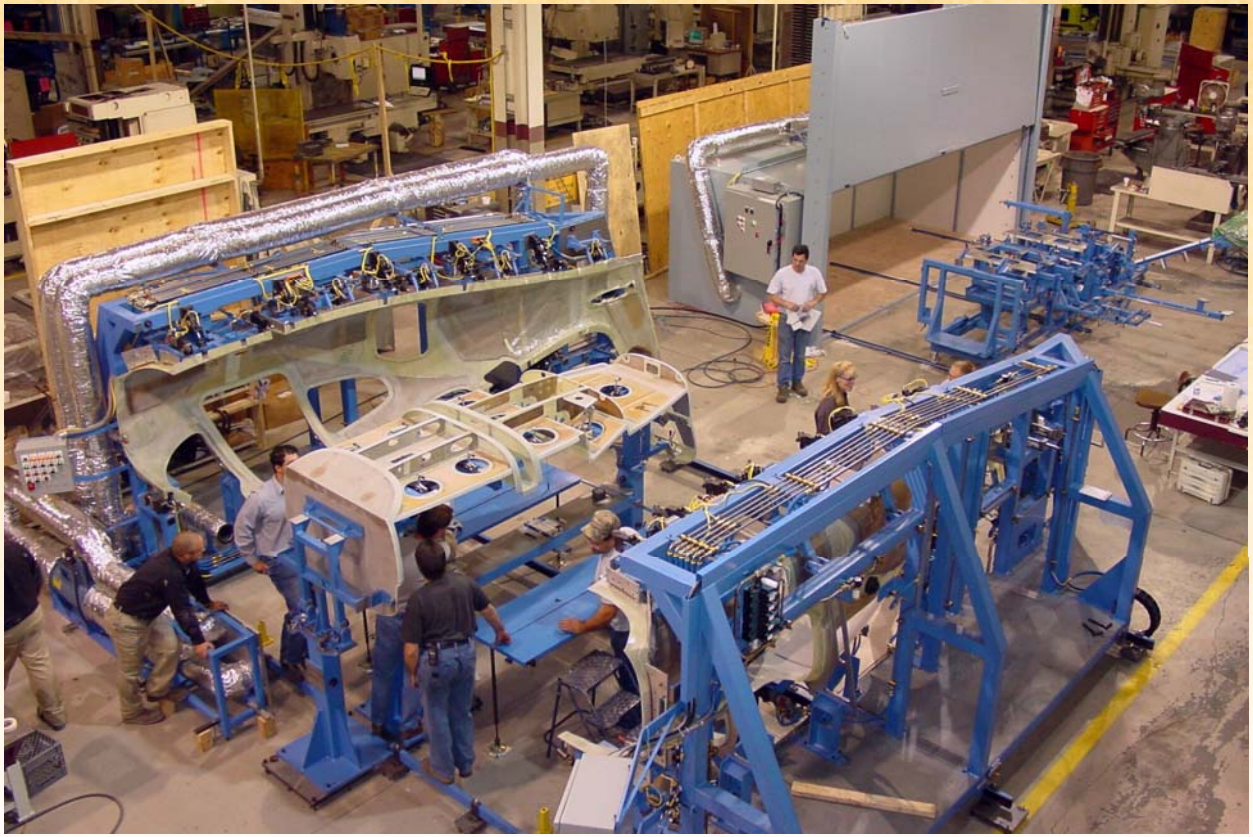
Process and Design Evolution

- As an example, our fuselage bonding process went from this….
  - 5 subassy stages
  - 2 complete tool sets
  - 5 initial cure oven runs per unit
  - 24 technicians on 3 shifts to produce 10 units per week

CIRRUS DESIGN CORPORATION

Process and Design Evolution

- To this….
  - 2 subassy stages
  - One tool set
  - Initial cure in tooling
  - 6 technicians on one shift to produce 10 units per week



CIRRUS DESIGN CORPORATION

Thank You!

CIRRUS
DESIGN CORPORATION