Introduction to the

Design and Manufacturing Considerations

Of the Aviator Series Aircraft

By Samuel W. Miller, ScD, PhD, JD

DATED: September 7, 2018

PURPOSE

This document is intended to give the reader an insight into the construction and design criteria that makes the Aviator Series Aircraft competitive and unlike its competitors rapid build from the production standpoint. Information contained herein is proprietary in nature and is not for release without a Non-Compete Non-Disclosure agreement effected between the reader and Aviation Training Partners International Inc.

MATERIAL SCIENCE

Most readers, it is assumed, are familiar with the use of advanced composites used in aircraft manufacturing. How that is done, is of a rather scientific discussion in terms of strength, longevity, and time. To achieve lighter weight, aircraft manufacturers have embraced composites and reduced costs in the manufacturing process to increase the profit margin at the expense of safety.

First of all lets review the types of composite material:

e-glass: cheap not very strong

s-glass: more expensive than e-glass but strong in multiple layers

carbon-fiber: most expensive but very strong and lightweight

The material itself is bound together in layers with a polymer or epoxy resin and is layered in such a way as to give the component its strength in certain directions. This is called a weave, and how that weave is done is critical to the strength, along with what was used to bind the material together. Shaping of those layers is done over another material such as Styrofoam or Divinicell with is foam with glass beads imbedded in the foam. This is called a sandwich construction, and both Cessna and Cirrus make their airplanes with this sandwich construction technique by hand. This is a very time-consuming method and can result in improper binding of the materials between each layer. As such, the negatives are:

- E-Glass cheap but not strong, very time consuming and requires allot of layers to obtain strength, its binder is UV sensitive and breaks down in sunlight
- S-Glass more expensive but stronger than E-Glass, very time consuming and its binder is also UV sensitive breaking down in sunlight
- Carbon Fiber is expensive and very time consuming but its binder takes allot longer to break down,
- Styrofoam Sandwich construction takes up space to create the form and is very sensitive to petroleum products

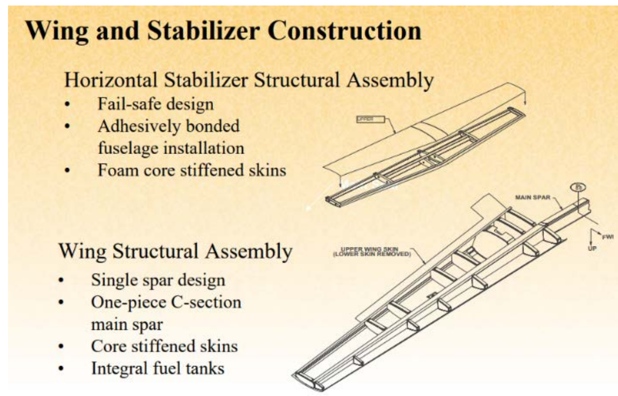
- Divinicell Sandwich construction is not as sensitive to petroleum products and is used to give a part density that it would not normally have but does not effectively add to the material strength of the component.

Please refer to the Cirrus Wing Structure in appendix A which shows how both Cirrus and Cessna manufacture their airplanes by hand. The following photo shows in detail just how they combine to make a Cirrus wing using foam and s-glass.

The fuselage in the Cirrus is made out of foam and E-glass which structurally means that it has a very weak fuselage. They use 2 layers of S-glass over foam with a thin piece of copper for lightening strikes to make the wings. The resulting structure cannot take more than 4 g's without catastrophic failure. This limitation in our opinion is very dangerous as an aircraft at 60 degrees of bank angle can easily exceed this. The FAA in recognition of this limitation has specifically denied Cirrus from performing any spins and rightfully so as the recovery may well rip the wings off or snap the fuselage. Cirrus is not alone here and others who seek to compete in this market duplicate this process.

The main spar in these aircraft are made like the letter C comprised of S-glass along with the ribs. Then bound to the wing halves with an epoxy. The only place where there is carbon fiber is running the length of the spar between the wing half and its contact point with the spar. Having reviewed manufacturing techniques at each of these plants, only Diamond Aircraft is actually using carbon fiber sheets in their wing structure. The photo below comes from Cirrus assembling a wing.

As you can see in the photo to the left that assembly is very labor intensive, and they also use vacuum bagging to make the skins for each wing half. The ribs in this photo are made out of S-glass, but they have reduced the number of ribs in the G-3 series aircraft depicted below:



The following image is equally disturbing… it is a Cirrus fuselage that shows E-glass with only certain areas having foam for binding between the halves. The two halves are bonded by epoxy at the seems and there are no longerons!

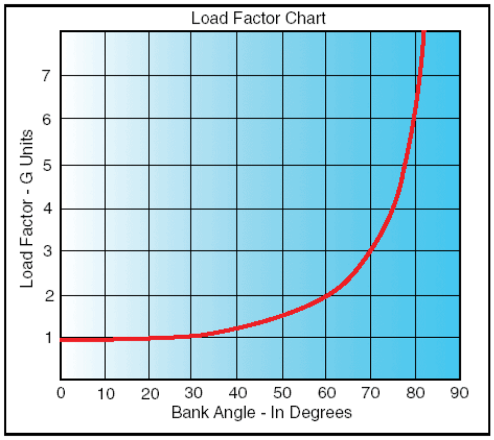
The following photograph is a hand laid aerobatic wing designed to take over 12 g's.

The spar's, ribs and skins are made completely out of carbon fiber. The very question is why then are Cessna and Cirrus making the aircraft with E and S-glass and all we can figure is cost. They actually do not make them they subcontract it out to other companies who have manpower verses more modern manufacturing methods. The costs of retrofitting a plant to make it with modern techniques is simply too expensive.

Table 1. Material Cost relationship and strength

	Carbon Aerospace	Carbon Commercial	Fiberglass	Aluminum 6061 T-6	Steel
Cost $/lb.	$20-$250+	$5-$20	$1.50-$3	$3	$0.30
Strength	90k-200k	50k-90k	20k-35k	35k	60k
Stiffness (psi)	$10x10^6$ -$50x10^6$	$8x10^6$-$10x10^6$	$1x10^6$-$1.5x10^6$	$10x10^6$	$30x10^6$
Density (lb./in^3)	.05	.05	.055	.10	.30
Specific Strength	$1.8x10^6$ – $4x10^6$	$1x10^6$ – $1.8x10^6$	363,640 – 636,360	350,000	200,000
Specific Stiffness	$200x10^6$ – $1,000x10^6$	$160x10^6$ – $200x10^6$	$18x10^6$ – $27x10^6$	$100x10^6$	$100x10^6$
CTF (in/in-F)	$-1x10^{-6}$ – $1x10^{-6}$	$-1x10^{-6}$ – $2x10^{-6}$	$6x10^{-6}$ – $8x10^{-6}$	$13x10^{-6}$	$7x10^{-6}$

A Cirrus aircraft weighing 6,800 lbs. achieving its maximum rating at 3.8 g's needs to have a strength of 25,840 lbs. so based upon the use of fiberglass the aircraft will disintegrate at 5.14 g's. As seen from the chart below a pilot is actually spinning the dice when he achieves more than 78 degrees of bank angle in a fiberglass aircraft. By using the lowest grade commercial carbon would the Aviator +/- 7.35 g's and 13 g's at the same maximum gross weight. Aerospace carbon is used in military and spacecraft but for giggles would give us 13.2 g's to 29.4 g's, but for commercial GA aircraft commercial grade is reasonable.

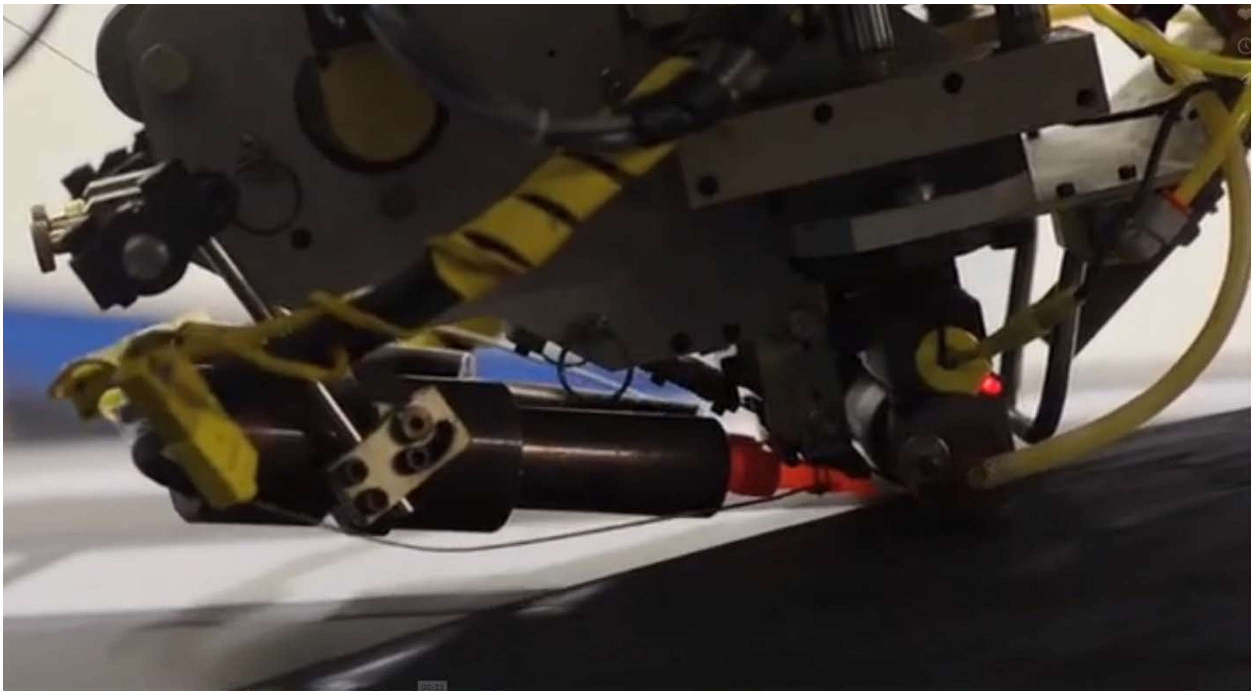


Diamond despite its use of carbon, has a maximum load factor of 2 g's in the DA-20 or 60 degrees of bank angle. What is causing this is that the wings simply cannot be 100% carbon fiber, but instead a composite sandwich and the carbon fiber was used as a stiffener. As such, a Diamond either has a serious design problem for coupling based upon its published specifications under the POH, or they are using low grade fiberglass such as E-glass in the airframe as shown above the numbers tell the truth.

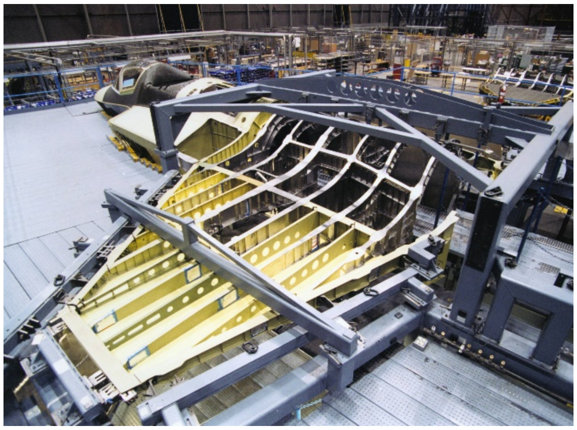
MODERN MANUFACTURING PROCESSES

We no longer have to do hand laid layers and giant autoclaves… cutting days off of each part.

The image below is a prime example of new modern manufacturing processes with carbon fiber. This specific robot lays each layer and bonds instantly each layer by using a laser to activate and cure. The entire aircraft wing or fuselage can be built as one continuous piece precisely the same each and every time with no voids.



To create 10 layers of carbon fiber wing takes only a few hours not days for a GA aircraft, whereas Airbus makes their wings within 1 day because they do autoclave. Plus, they can be made in full length as a single solid component. This is because of the use of new polymers that react to the heat created by the laser and that heat is controlled to within a microsecond. Rib's and spars become more diverse due to this versatility. The images below show just how this versatility is, the left image is the F22 which is assembled and the right image is from a new airliner. Both are 100% carbon fiber with aluminum polymers.



As each section is created it is ready to be moved or integrated into the next piece. If wing longerons are made as in the right image, depth of the robot creates layers in the upper half of the wing and tensioned between the initial layers forming a flexible wing but with high wing loading.

Diamond aircraft still uses the Cirrus style of rib design and is known for wing flapping, whereas with fused longerons any flapping is minimized except under heavy G forces. Of course, Diamond still uses hand laid carbon fiber with vacuum bagging so its production ability is severely limited.

That leave the question materially about lightening strikes to the aircraft. Diamond, Cirrus and Cessna use copper mesh or sheets in the wings but not in the fuselage. This adds to the weight equally in order to create a faraday cage. The use of the new aluminum polymers is part of the mixture and has electrical propensity so no copper sheeting is required. To use these polymers requires a specific heat to activate so unless they redesign their production methods they are not able to reduce their production costs. In our case, lasers make that heat instantly and without varation.

AERODYNAMIC DESIGN

Each of the major manufacturers use a combination complex wing design which requires the use of composites to manufacture. The Aviator series is no different as it also uses compound wing design to improve performance as specific speeds. At slower speeds the wide fuselage is in-material to the drag produced by the aircraft, it is the surface area and induced drag that affect airspeed. Induced drag is created when the airflow over the aircraft is not smooth even well after departing the laminar flow. In some instances, the induced drag is larger than the surface area which is then compensated for by the increase in horsepower (newtons) to overcome this loss. That combination is always a balancing of choices for purpose, and the Aviator is designed to run from 55 knots to 250 knots with minimal drag coefficients.

The Aviator takes this by reducing the surface area and induced drag. What was interesting is that the Aviator's climb is to be expected – more power equals faster climb, but because of its efficiency it has a very fast cruse speed even in lower power engine configurations. This is further discussed in the Engine portion of this white paper.

LANDING GEAR

Diamond, Cirrus and Cessna use steel in their landing gear. Whether fixed or retract, although Cirrus is fixed and to reduce drag use wheel pants. There are limitations galore in both directions when you consider the differences between spring steel and oleo-based landing gear. Spring steel is cheaper but also can fracture and transfers allot of the kinetics into the airframe verses from the airframe through the gear. If you were to go to any flight line, and measure the wingtip to ground on fixed spring steel landing gear they are not equal lengths. As such energy transfer is also unequal.

GA aircraft while tough need to transfer the kinetics to the ground and there is little doubt that trailing link landing gear is the way to go. Large oleo's such as found on the Cessna are expensive and prone to replacement, and spring steel does not always return to its original position. Cheaper oleos exist for trailing link landing gear are for the purpose of delaying the transfer of kinetics but not to bear the totality of the kinetics. Further, carbon fiber tubes are stronger and last longer than steel tubes allowing more flexible design without additional costs as complexity is not any factor.

The Aviator does have retract capability for certain models and the design calls for electric retract with battery backup. Retract Aviators is recommended for aircraft that exceed 200 knots, and conservatively will exceed over 243 knots. This is ***not*** a structural limitation, but instead a matter of practicality due to complexity of aircraft operating at those speeds requires higher performance of the pilot and there is no reason to have induced drag from gear hanging under the aircraft at those speeds.

ENGINES

When we reviewed past experience with engine manufacturers an important criterion had to be met. The option for FADAC, and familiarity for mechanics in case there is a problem would not require special services to keep a plane grounded waiting for parts. When we discussed our flexible needs, Lycoming was right there ready and willing to provide the full range of engine choices, plus their engineering team to ensure that the Aviator will not have problems.

Unlike other aircraft designs, the Aviator is flexible, and changing from one engine to another is very simple as the composite carbon tubes and frames are interchangeable. 160 hp engines give a very moderate docile climb, where 350+ hp gives you serious climb rates and with the aerodynamic efficiency of the aircraft means still very fast cruse at 65% power. This balance is ongoing development with Lycoming and will continue for that level of support for the life of the aircraft.

The Aviators carbon fiber polymer design may well take even higher horsepower turboprop engines although we have not placed this into the appropriate configurations in the wind tunnel. When we do, this may create a 6 – 8 place version under the Aviator series with pressurized cabin. Until that time, Lycoming will be there for everyone to make this a great aircraft series.

CONTROLS

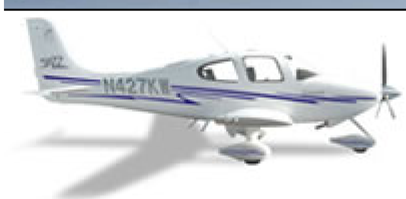
It is a matter of preferences… those trained on stick love stick, those trained on yokes love yokes, and currently the trend is side-stick controls, but simply put, we don’t like them. Pilots generally learn on yoke and there should be no distraction or adaption for the pilot to adjust to. Any plane can have a failure in avionics or engine, and having one hand committed to flying the plane just seems to be a bad idea to us when a yoke or stick allows you to swap hands.

BRS

While we cannot fathom a reason why there could be an airframe failure, there can be times when a pilot gets in over his head, engine dies or complete failure of the avionics systems. BRS is there when he is no longer in control of the airplane for any reason.

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

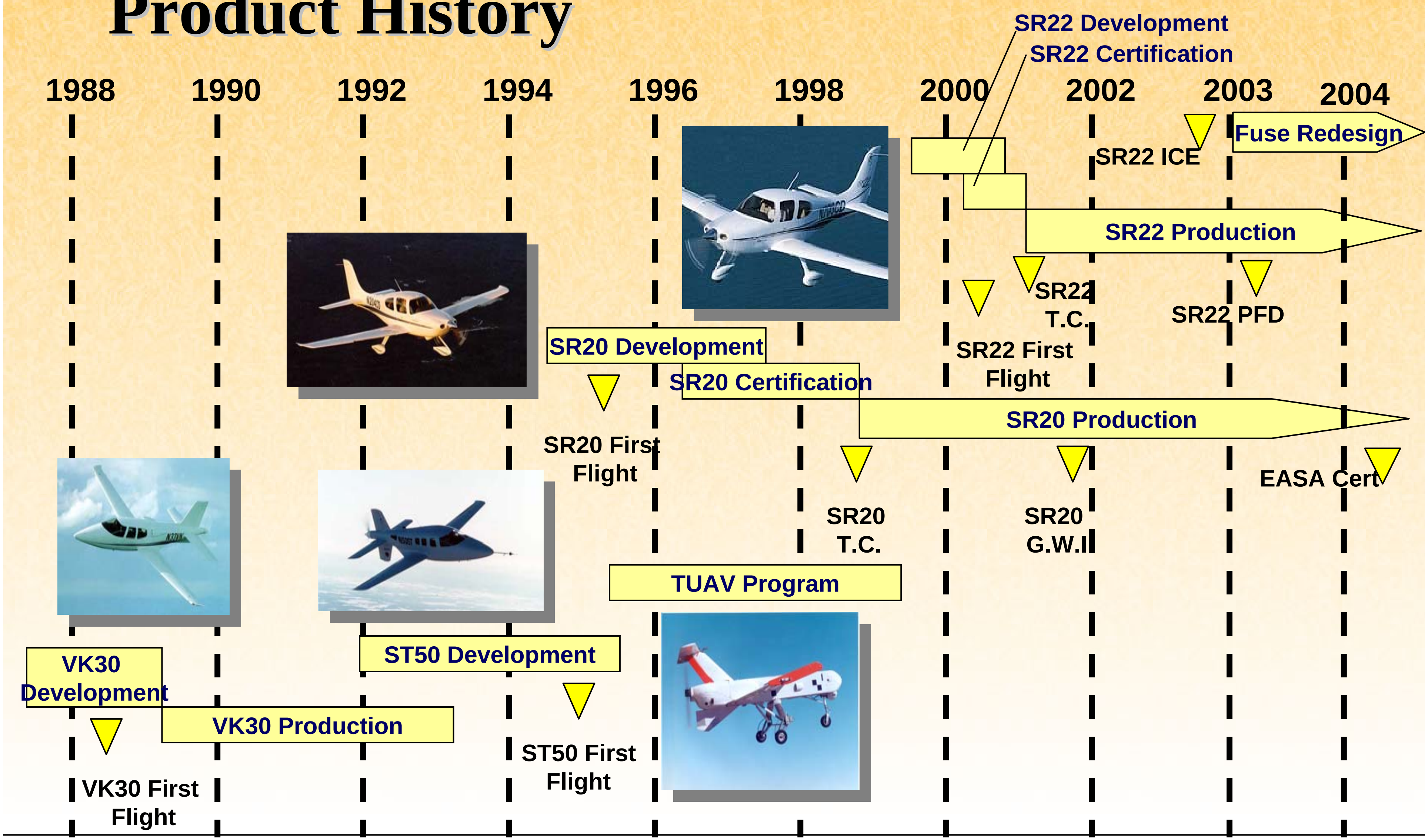
Powerplant	TCM IO-360ES 200 HP
Gross Weight	3000 lbs
Cruise Speed	154 KTAS
Instrumentation	IFR

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

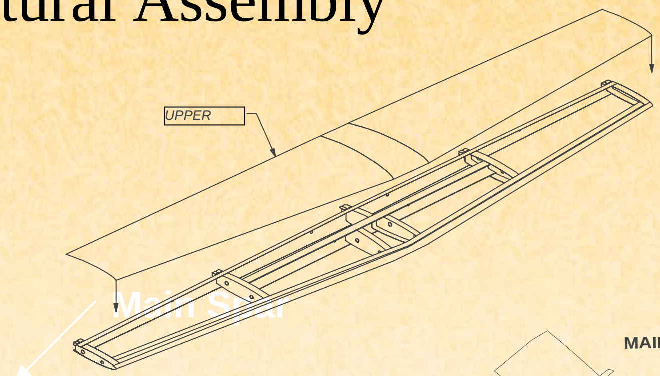
Fuselage Construction

CIRRUS
DESIGN CORPORATION

Wing and Stabilizer Construction

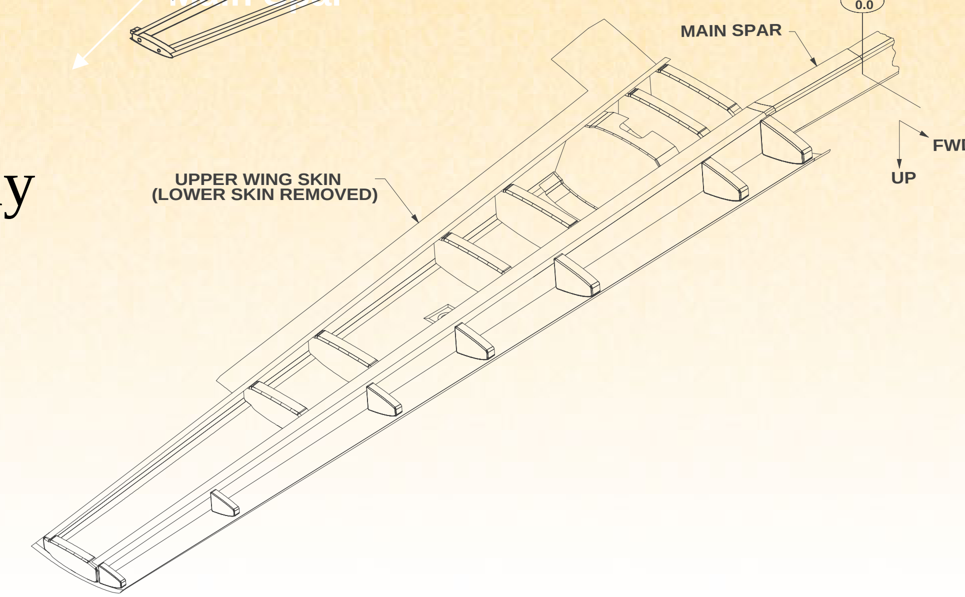
Horizontal Stabilizer Structural Assembly

- 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

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

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…

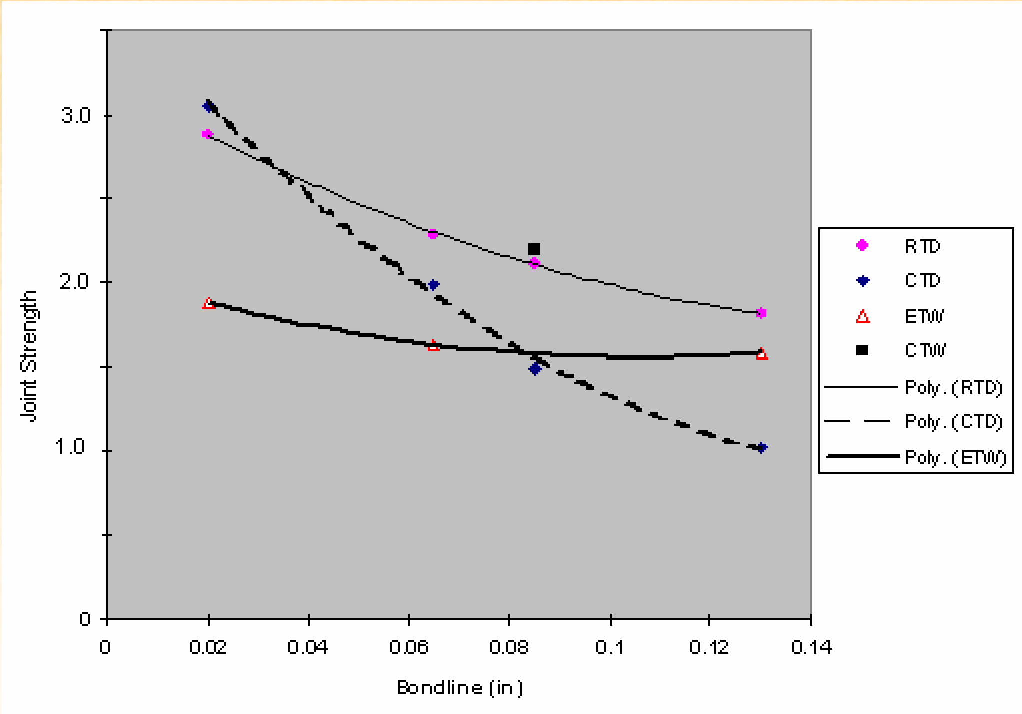
Damage Tolerance and Defects

- 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

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?

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????

<u>Or</u>

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

<u>Or</u>

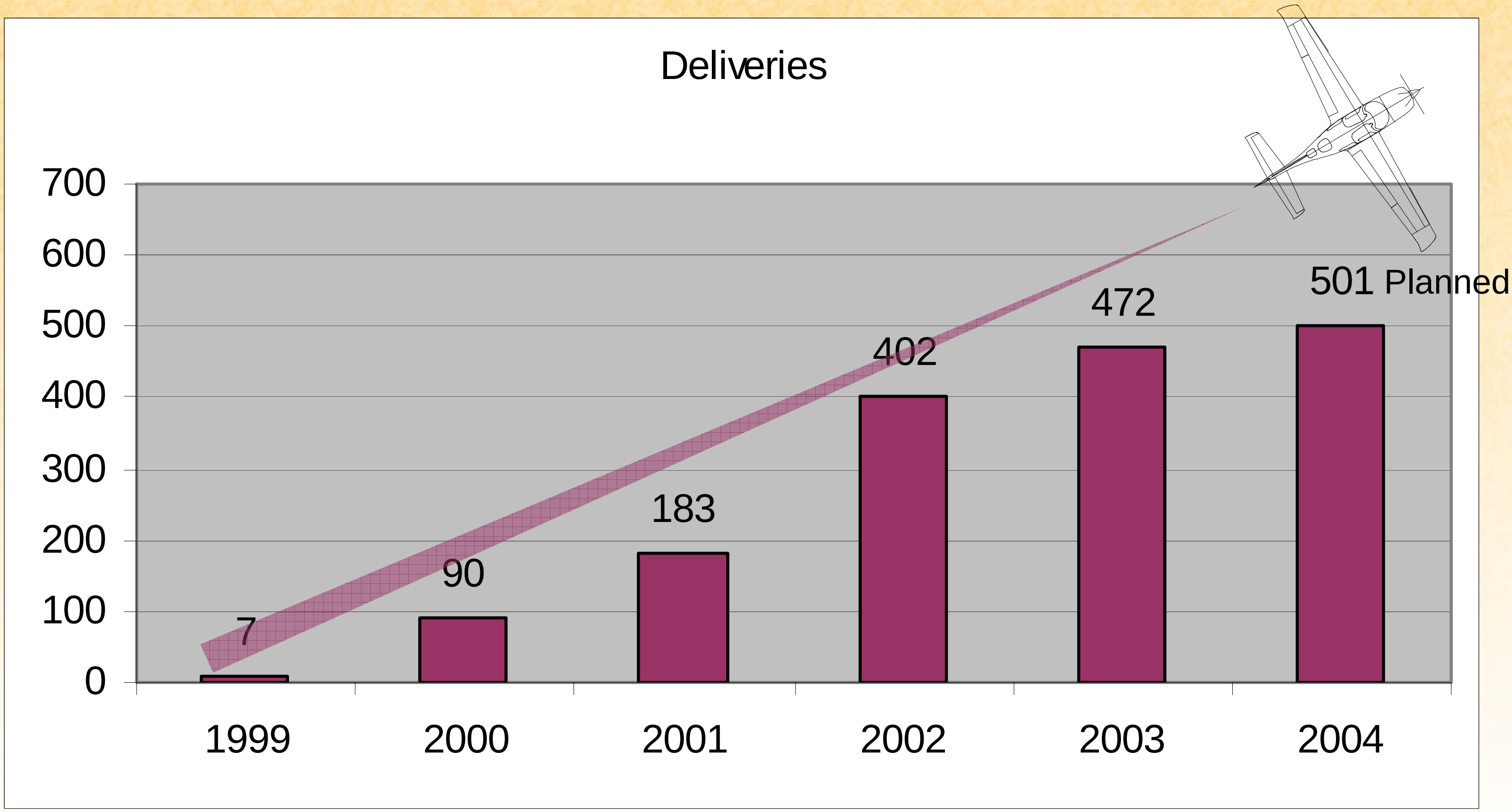
- Can you design a building block program supported by analysis with the necessary confidence in extrapolating analysis to conditions that are difficult to test?

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 <u>every</u> <u>day</u>
- Remember…..they are all positive in terms of customer value and profitability!

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

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

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

CIRRUS DESIGN CORPORATION

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

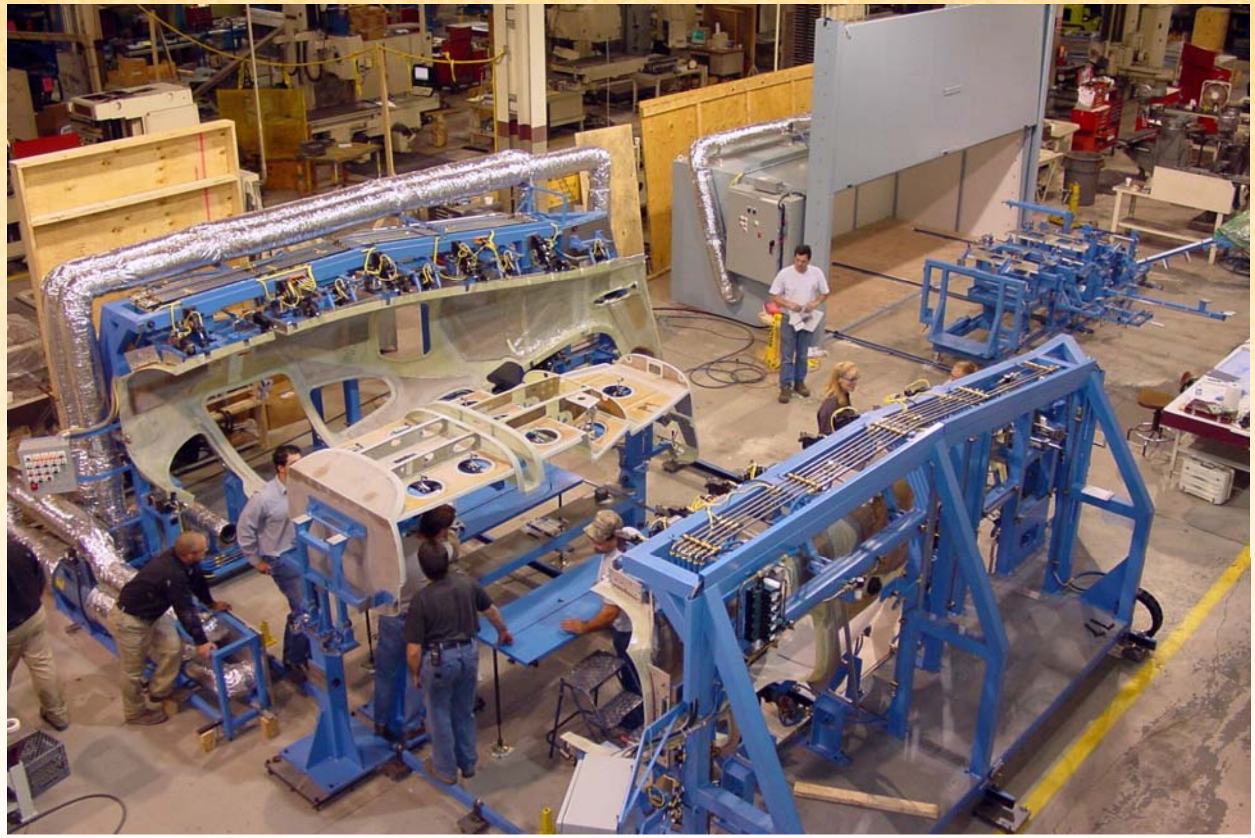
Process and Design Evolution

- 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

CIRRUS
DESIGN CORPORATION