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AIRPLANE DESIGN: THE SUPERIORITY OF FSW ALUMINUM-ALLOY PURE MONOCOQUE OVER CFRP "BLACK" CONSTRUCTIONS

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ABSTRACT

CFRP composite structures offer a noteworthy weight lessening over traditional aluminum-alloy semi-monocoque airplanes. This weight lessening enhances the fuel effectiveness of the aerial vehicle by around 20%, which results in a cost sparing in fuel. In this paper introduced a contrasting option to CFRP. Aluminum lithium alloy 2195 with FSW (Friction Stir Welding) is acquainted as a successful option to CFRP structures. The "tough skin" monocoque plan is examined. An old WWII Reggiane 2005 has been upgraded both to CFRP and 2195-FSW. The outcome is a further reduction in weight much more important for different perspectives, as large scale manufacturing cost, reparability and environmental impact. The choice of the Reggiane 2005 is because of the complete knowledge on the original flying machine geometry and burdens. This outcome can be straightforwardly exchanged to larger aerial structures. On a pure mass premise, the advantage of the CFRP Reggiane 2005 is extremely light over the monocoque 2195-FWS. However, the monocoque structure is advantaged in the mounting of accessories. In fact, aluminum alloy structures can be easily machined with extreme precision and modifications can be introduced with extreme flexibility both in the design and the prototyping phase. On the contrary, way CFRP structures are extremely difficult to work and to modify. The though skin and the protected structure approach give approximately the same results. However, the though skin approach has the advantage of easier production technique. On the maintenance and disposal point of view the 2195-FSW structure has larger advantages [1-5].

Keywords: CFRP, aircraft structures, modular construction, FSW, aluminum alloy.

INTRODUCTION

Monocoque, "tough" skin innovation has been broadly examined in the car field and it has been additionally in part tested in Japanese aircrafts of WWII (see Mitsubishi Zero). Low depth ribs are effectively produced in aluminum compound structures as crack stoppers and stiffener. In this paper different CFRP structures are talked about alongside mechanical and manufacturing viewpoints. At that points an answer for assemble a full scale reproduction of Reggiane 2005 is presented. At that point the option in 2195-FSW is examined. An examination between the CFRP and 2195-FSW airplanes finishes the talk. Theoretically, CFRP is the ideal material for the designer: its strength is such as steel and its density is 1/4. Notch sensitivity is extremely low and fatigue life outstanding. However, CFRP performance is extremely dependent from the manufacturing method and damage detection. Whereas metals typically deform upon impact, CFRP internal cracks area are typically undetectable by visual examination. F1 (Formula 1) sport, military and civil craft expertise have found totally different solutions for these issues. However, high amount in term of weight is procured by these "improvements". CFRP machine-controlled production isn't as simple as metal alloys and repair information isn't thus widespread. After life disposal is additionally a tangle. Corrosion, aging and totally different thermal enlargement with metals constant are other difficult new aicraft structures [1], [2], [3].

CFRP "black" aircraft structures

The best carbon fiber composites used on primary class-one structures are fabricated by placing layer upon layer of UD pre-impregnated (prepreg) material to the prescribed ply profile and fiber orientation. Numerical control ATL machines are currently limited in production applications to flat lay-up and significant effort is being directed by machine manufacturers at overcoming these problems associated with laying on the contoured surfaces of the mold. A carbon-epoxy mold is manufactured and accurately polished. The laid-up component with its mold are then enclosed in a flexible bag and closed in an autoclave.

Modern aircrafts, in addition to being complex and costly to manufacture also require frequent workload intensive and expensive maintenance, which is certification and safety critical. For example, some of the required maintenance for commercial airplanes operating under Title 14 Code of CFR (shortly FARs in USA) parts 121 and 135 are the scheduled detailed A, B, C, or D checks. B-checks can be incorporated into successive A-checks. For example, a scheduled comprehensive heavy maintenance visit (HMV) or D-check to be conducted approximately every 5 years or 25,000 flight hours whichever comes first can take up between 35,000 and 40,000 man-hours of work and have aircraft out-of-service for 2 months requiring large and expensive hangar spaces. Practically, the entire aircraft is disassembled and especially checked for corrosion and health of structural elements. The cost of such maintenance can run into several million US$ and must be planned in advance. Typically, a transport category aircraft will undergo 2-3 D-checks before being retired. A D-check will include all items in A and C checks. For example, design service objectives (DSO) for wide-body large transport-category Boeing B777 are 40,000 flight cycles, 60,000 flight hours

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or 20 years. DSO's establish design goal by airplane manufacturers which represent expected product life duration before the aircraft is retired. A narrow-body Boeing MD-80 (formerly McDonnell-Douglas) has DSO of 50, 000 flight cycles, 50, 000 flight hours, and 20 years of expected service life. Short- and medium-range commercial airplanes have larger number of takeoffs, landings and pressurization cycles compared to long-range wide-body large aircraft, such as B747/767/777, A330/340/380, which spend most of the flight time in cruise. Operating an aircraft beyond DSO will cause prohibitively costly maintenance and the aerospace technology is advancing so rapidly that after 20 years in service practically any modern commercial aircraft today will become obsolete. Two diverse methodologies are utilized for CFRP, the slim enclosed sandwich (F1) and the tough unprotected skin. The slim, protected skin depends on the idea that the slenderer the better is for composite strength. In this way, when conceivable, the external and the inward skin are covered and cured independently. The adhesion of the external skin to the honeycomb core is given by a glue film with the internal skin is cured specifically. The "FIA homologation" is accomplished by a large portion of the F1 teams utilizing aluminum honeycomb, because of its higher energy absorption. Inserts are standardized and designed to redistribute load. In reinforced joint bolts joints. The bolts are with specialized commercial inserts with reinforcements where the joint configuration is such that peeling stress is present. Pressure up to 10 bar have been utilized for ideal execution. Generally, the first and the last utilize are made with T300 woven fabric to have around 0.1 mm of penance material. Extra layers for lightning security, high temperature protection, inserts might be included. The outcome is a laminate with great surface quality on mold side, and poor geometry and rugosity on the breather fabric side. Void contents are very low and interlaminar shear strength very high. F1 autos have body that is torsionally exceptionally unbending and hence over-dimensioned. Fairings and other external parts protect the body from external impact. Damper and suspension protect the frame from overloads. The second CFRP approach is the "tough skin approach ". In this case the composite is sufficiently thick to endure little effects due to impacts and fatigue during flight. Bolted or riveted joints and repairs are conceivable because of adequate thicknesses. The thick lay-up makes it conceivable to design semi isotropic shells. Extensive amounts of high strength filaments are utilized for impact resistance. Mechanized composite lay-up diminishes producing time. The vehicle parts are fabricated in various destinations to reduce producing costs. The tough skin gives heat insulation and flame protection.

The slim protected (F1) skin makes it conceivable to utilize the best fiber, to have astounding composites because of better manufacturing control. For the "protection" skin, all the most convenient can be utilized. The structure is more complicated and costlier to assemble.

The tough skin methodology is more basic from the assembling perspective. It is more hard to get a decent looking and an all-around finished part. Huge part get together is basic for joint resistance. CNC (Computer Numerical Control) machining might be required. Vast amount of composites are to be utilized for the single part, with the danger of huge scraps.

The weights for the two methodologies are comparable. The CFRP potential can't be completely exploited, since impact resistance and, more critical, manufacturing constrains the material performance [1-5].

The pure monocoque FSW-alluminum alloy approach

The genuine monocoque design depends totally on the quality of the external skin to convey the external loads. The skin must be sufficiently thick with no riveted stiffeners, additional frames and bulkheads. Bolted/riveted joints are mostly substituted by FSW. FSW was the most recent upgrade to the Space Shuttle's External Tank, the single non-reusable largest element of the Space Shuttle. In recent years, NASA developed replacement for aluminum alloy Al 2219 semimonocoque structure used on the original Space Shuttle external tank. The new pure monocoque SLWT (Super Light Weight Tank) was made with Aluminum Lithium Al-Li 2195 bonded with FSW. The new technology reduced the original 30,000 kg mass of the LWT (Light Weight Tank) by 3, 175 kg (about 10%).

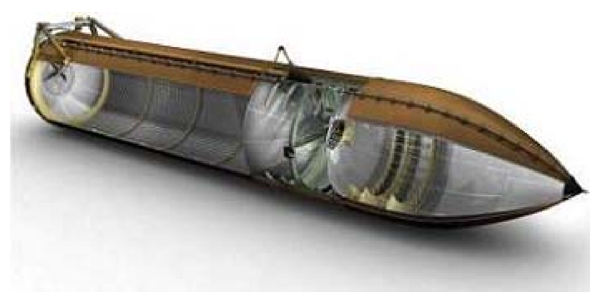

Figure-1. SLWT space shuttle external tank.

The idea is to simplify the Reggiane 2005 fuselage and wing structure into monolithic/monocoque separated parts welded with FSW (Figure-2).

Figure-2. Separated monolithic/monocoque parts of the Reggiane 2005.

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The initial step was to choose the cross section. Considering the type of investigation, shell mesh is more fitting. In fact, the material thickness doesn't pass 1 mm while the entire geometry is in the range of thousand millimeters. The flying machine skin was then taken from the original drawings.

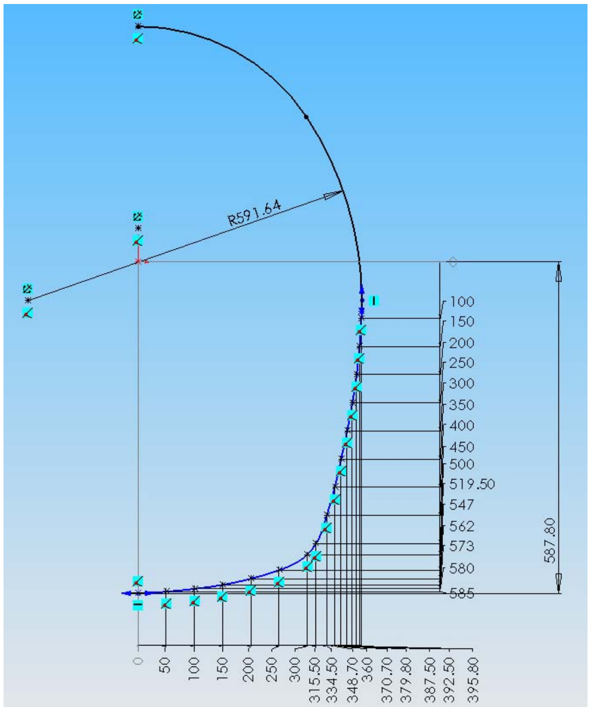

Figure-3. Skin derived from the original drawings of the Reggiane factory.

For CFD coupled to FEA, this skin has been deformed with the most extreme loads Therefore, the wings were bended upwards and the fuselage was deformed by a sudden pull-up at VNE (Velocity Never Exceed) with a tailslide.

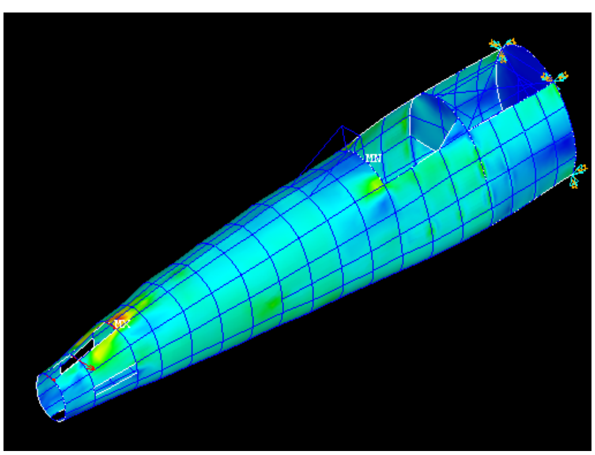

Figure-4. Bis: CAD-CAE skin [1], [3].

For this situation the airframe takes the most extreme vertical and sidelong g-loads (Figure-3, Figure-7 and Table-1). Alternate flight conditions based on FAR23 aerobatic category were utilized as verification. A base thickness of 0.7 mm is necessary. Another extremely basic condition came from be the single leg landing. For this extreme condition a specially shaped structure was inserted inside the fundamental monocoque. In fact, FSW makes it possible to instert "stringers" and strengthening plates inside the basic structure. The same operation is made for the other reinforcement required for air vehicle assembly. In welded aluminum structures it is normal to join parts produced with various manufacturing technologies at it is shown in Figure-5.

Figure-5. CNC and laminated parts welded together in a racing motorbike frame.

Further improvements can be made by utilizing low aspect ratio stringers/ribs coined or CNC machined in the skin of the monocoque structure. A case of this auxiliary reinforcement can be found in the cast aluminium alloy castings on the intake manifold of an automotive Engine (Figure-6).

Figure-6. Ribbed intake manifold casting.

This arrangement gives vital changes in fatigue strength and stiffness. These ribs can be simulated in FEA (Finite Element Analysis) 3D simulation by varying material properties (Figure-7).

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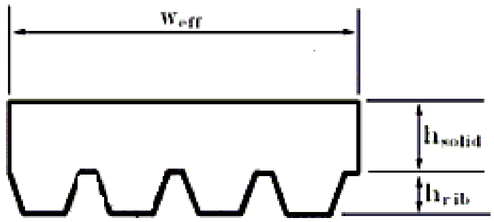

Figure-7. Rib simulation for mass optimization.

Equations (1) and (2) are used to calculate the equivalent stiffness.

$$x_G = \frac{W_{eff}\, h_{solid} \frac{h_{rib}}{2} + \sum_{i=1}^{Nribs} h_{solid}\, h_{rib} \left(h_{solid} + h_{rib} + \frac{h_{rib}}{2} \right)}{W_{eff}\, h_{rib} + \sum_{i=1}^{Nribs} h_{solid}\, h_{rib}} \quad (1)$$

$$J = \frac{W_{eff} h_{solid}^3}{12} + W_{eff} h_{solid} \left(x_G - \frac{h_{solid}}{2} \right)^2 + \frac{W_{eff} h_{rib}^3}{12} + W_{eff} h_{rib} \left(x_G - \frac{3h_{rib} + 2h_{solid}}{2} \right)^2 \quad (2)$$

For the optimization it is assume reasonable values for the total sheet thickness (h_{solid}+h_{rib}). The condition of equal weight between the solid H0 and the ribbed skin is given by equation (3).

$$W_{eff}\, h_{solid} + \sum_{i=1}^{Nribs} h_{rib}^2 = W_{eff}\, H_0 \quad (3)$$

Therefore, number of ribs can is optimized to maximize the shell-stiffness to weight ratio. The best solution is a reinforced skin of 1 mm with 1000 of ribs/meter. The ribs are 0.5 wide and 0.5 mm high. This optimal reinforced skin has a stiffness improvement of 76% when compared with the original 0.7 thick skin with the same weight.

Figure-8. Rendering of the "though skin" Re 2005.

CONCLUSIONS

On a pure mass premise, the advantage of the CFRP Reggiane 2005 is extremely light over the monocoque 2195-FWS. However, the monocoque structure is advantaged in the mounting of accessories. In fact, aluminum alloy structures can be easily machined with extreme precision and modifications can be introduced with extreme flexibility both in the design and the prototyping phase. On the contrary, way CFRP structures are extremely difficult to work and to modify. The though skin and the protected structure approach give approximately the same results. However, the though skin approach has the advantage of easier production technique. On the maintenance and disposal point of view the 2195-FSW structure has larger advantages.

Table-1. Performances of Re 2005 "tough skin".

Length	**8.73 m**
Wingspan	11 m
Height	3.15 m
Wing area	20.4 m^2
Empty weight	700 kg
Loaded weight	1,000 kg
Powerplant	AUDI V12 TDI
Never exceed speed	650 km/h
Maximum speed	628 km/h at 6,950 m
Cruise speed	515 km/h
Stall speed	65 km/h
Service ceiling	11,500 m (37,700 ft) ()
Rate of climb	6,000 m in 6.5 min

Symbols

Symbol	Description	Unit
W_{eff}	Reference width of sheet	m
h_{rib}	Height and width of rib	m
h_{solid}	Thickness of sheet	m
N_{ribs}	Number of ribs per Weff	-
x_G	Mass centre coordinate	m
J	Flexural inertia moment	m^4
H_0	Thickness of unribbed sheet	m
n	Load factor	g

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