COMPOSITE MATERIALS AND PROCESSES FOR CIVIL AIRCRAFT STRUCTURES

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Abstract :

The versatile nature of composites attracted the designers to use these materials for several critical aircraft structural applications. As a result, a large number of materials (fibers and resins) are developed for use. Added to this, a large number of fabrication processes are also developed. To realise a cost effective civil aircraft structure, what material and process need to be used is not an easy matter to decide. An attempt is made in this paper to logically select the material and the corresponding fabrication process for various components of an aircraft for civil application.

1. Introduction :

Increasing use of Advanced Composites In Aerospace and other Engineering applications confirms that these materials are performing as expected by the designers. However, for military aircraft applications with mainly the performance as the base for using composite materials, cost is not a major consideration. When it comes to civil aircraft structures, apart from performance, cost also plays a significant role. Cost can be broadly divided into 3 segments.

a) Aircraft initial acquisition cost
b) Aircraft operation cost
c) Aircraft maintenance cost

The overall cost has a strong bearing on the structural material, fabrication process and structural arrangement.

1.1 Aircraft Initial Acquisition Cost :

Airframe cost forms the significant portion in the overall cost of aircraft. Any reduction in the airframe cost, will also reduce the overall acquisition cost of the aircraft. Table : 1 gives some details of relative costs of aluminium airframe and composite air frame. It can be seen from the table –1 that, if properly done, composite airframe costs less than Aluminium air frame.

	Aluminium Construction	Carbon Fiber Epoxy Construction
Total Cost in relative units	100	90
Assembly cost	55	25
Individual part fabrication cost	30	45
Basic material cost	15	20

Table.1 Comparative cost between conventional Aluminium alloy structure and Advanced Composite (Carbon-Epoxy) structure. This data is for a vertical Fin.

The cost reduction is possible provided we have chosen the appropriate technology of fabrication. For cost reduction of the part, large scale co-curing technology needs to be introduced and the number of individual parts should be reduced to bear minimum. This will result in superior structure and also will become less expensive.

1.2 Aircraft operation cost :

One of the main components of operating cost is the cost of fuel consumption. Fuel consumption is having direct bearing on the weight of the aircraft and surface finish. By using composites it is possible to reduce the weight and also improve the surface finish. The co-curing technology not only reduces the cost of airframe but also reduces the weight of the airframe any where between 10 to 20%. Actual % of weight saving depends upon the materials of construction and process adapted to realise the structure.

1.3 Maintenance cost :

Airframe checking and inspection forms a significant portion of the maintenance cost. For the Airframes made out of aluminium alloys, corrosion is the main draw back. The airframe needs to be checked for corrosion attack and also for fatigue cracks. But by using composite materials the corrosion problem is completely avoided and composites are insensitive to fatigue cracks. As a result, the maintenance (inspection) cost can be significantly reduced. Another advantage of using composites is, online structural health monitoring systems can be incorporated or integrated with the airframe while it is being made. This will significantly reduce the maintenance cost.

This will also pave the way to maintenance on demand from the present scheduled maintenance procedures.

2. Processing Techniques :

Manufacturing techniques that are employed to produce airframe parts using advanced composites can be broadly classified into two groups.

a) Techniques that are employed using prepregs and autoclave
b) Liquid Moulding Techniques.

2.1 Prepreg and Autoclave methods :

In this broad class of methods, the basic material is a prepreg. In the prepreg, the reinforcement is pre-impregnated with the required amount of resin and partially cured to what is called as B-Stage and is stored in the cold chest usually at -18 deg.C. Generally these materials require high temperature and pressure for final curing. This is done in an autoclave. Autoclave is a pressure vessel, in which pressure, temperature and vacuum are applied on to the lay-up, which is placed on a mould and vacuum bagged in a programmed manner. In general there are two types of prepregs a) U.D tapes and b) Fabric Prepregs. The design is done using these materials and lay-up is done on a mould and the entire layup is vacuum bagged and cured in an autoclave. The real advantage of this method is that it is a clean process. Since the resin is already in the B-stage it is very easy to handle and there is better control over properties and the weight of the part. Usually toughened resin systems are employed to make prepregs as a result of which it will have better impact resistance. The major limitation of this process is that the prepregs need to be stored in a cold chest at –18 deg.C all the time. They also have a limited out life. Limited out life is a serious limitation of using these materials. The implication of the limited out life is that the layup and curing should be finished within the out life period. Now it is well recognized that, to get best out of composites, co-curing needs to be followed. This out life puts the limitation on the size and complexity of the part.

2.2 Liquid Moulding Techniques :

There are a number of methods under this general head. Many of the techniques are patented processes. They are broadly grouped into two major groups.

a) Resin Transfer Moulding b) Resin Infusion Moulding.

2.2.1 Resin Transfer Moulding :

This is a closed moulding process. Required quantity of dry reinforcement in the correct size, shape and orientation in the form of preform is placed in the specially designed and built closed mould. Then the required quantity of resin is injected into the mould under pressure. Depending on the resin system the parts are cured with or without heat. This is a fast and cost effective method. One can get good surface finish on both sides of the part. The major limitation of this process is fiber loading which is limited to less than 50%. As a result, it is not efficient and not suitable for primary load bearing structures where fiber loading (content) of more than 60% is required.

2.2.2 Resin Infusion Technology :

This is a hybrid technique which is taking advantage of autoclave method and resin transfer moulding. The tooling is similar to autoclave method, except that a flow medium is introduced between caul plate and the layup. Resin is sucked into the flow medium through a specially made resin channel. This resin channel is connected to resin bath. This way of fabricating composite parts is becoming popular for its own merits. In this method of fabrication the fiber loading can be as high as 60% which is very close to prepreg technology. There is no limitation due to out life. This is far more cost effective than the prepreg method. This is particularly suitable for large, co-cured parts. The only limitation about this method is it requires resins of low viscosity which may lead to the composite part being brittle and having poor impact resistance. This can be overcome by proper design.

3. Choice of fabrication method :

3.1 Wing Bottom skin :

It is essential to consider co-curing technology as much as possible. From various considerations like equipping etc., it is not possible to co-cure top skin, bottom skin, spars and ribs together. So it is desirable to co-cure the bottom skin with all the sub-structure in one piece. The top skin with integral stringers can be made separately. This type of fabrication gives most optimum configuration and also can maximize the positive aspects of composites. If the bottom skin has to be made with all the sub-structure together in one shot, the resin infusion is the best choice. The bottom skin, even though subjected to fatigue loading, is not subject to high compressive stresses and for any R ratio less than - 1, the resin properties won't determine the fatigue life. Tensile stresses dominate the fatigue life. Tensile properties are predominantly influenced by fiber properties and the resin properties can be compromised. The most important thing is to co-cure the bottom skin with all the sub-structure which requires a good amount of layup time. For a wing like structure this layup time will be more than the outlife of normal prepregs. Hence, from all these considerations, it is desirable to go for Rein Infusion Method.

3.2 Wing Top Skin :

Usually for transport aircraft wing top skin design is governed by buckling. To improve the buckling strength, the skin is made with integral stiffners called stringers. This also needs to be designed for fatigue loading. In the metal wing, the top skin is not fatigue critical because metals cracks grow only under tensile loads. Where as, in composites, delaminations grow only under compressive loads, hence, it needs to be checked for fatigue life. Delamination growth is largely controlled by the resin properties. Toughened resins are better, to resist the delamination growth. Prepregs uses toughened resin system. So it is desirable to make the top skin with prepregs. Comparatively it takes less time to make the top skin hence the limited out life of prepregs will not be major hurdle to realise the top skin.

3.3 Tail :

The other major part is the tail unit. Tail being the extreme end of the aircraft, it becomes a highly weight critical part. Any change in the weight of the tail adversely affects the overall C.G of the aircraft. It is absolutely essential to choose the material and process, which can give higher allowables and with little variation. Among several fabrication techniques, autoclave fabrication method gives consistent results and prepregs gives better allowables. So it is desirable to make the tail unit using prepregs and autoclave moulding technique.

3.4 Fabrication of Leading edges of Wing, Fin and Horizontal Stabiliser :

The leading edge plays a very important role which initiates the desired flow pattern on the lifting surface. Retaining the shape of the leading edge throughout the life of the structure is very important. It also should resist the impact loads due to insects, hail storms etc. while flying, without suffering major damages. In addition it will be subject to large impact loads due to bird strike. In particular, in the case of bird impact, the structure should be designed such that, it should not resist the entire load and pass the huge reaction to the adjacent structure (front spar). At the same time it should not get damaged in such a way, that the aircraft control becomes a problem. The real requirement is that it should be able to absorb the energy by local damage. All these requirements are efficiently met by Fiber Metal Laminates (FML). FML technology is very close to autoclave technology. The complex shape of leading edges can be efficiently made using autoclave technology. It absorbs energy by delamination, plastic deformation and even fiber breaks. It also provides adequate protection for rain erosion and also provides conductive path for lightening protection. It is possible to design such that the reaction to the main spar is minimum.

3.5 Control Surfaces of Wing :

These are also highly weight sensitive parts. In order to maintain the C.G of wing in the desired location (forward of 25 % chord), the rear portion of wing weight need to be controlled. Any increase in the weight will adversely affect the C.G of the wing. The process and material are selected in such a way that, with minimum thickness, it should resist the loads and also should have good impact resistance. To meet all these requirements, prepregs (Carbon – epoxy) and autoclave moulding technique is the preferred route.

4. Conclusion :

The increased use of composites in airframes acknowledges the satisfactory performance of composites. To reduce the cost of aircraft acquisition, operation and maintenance proper application of appropriate fabrication technique is very essential. The author in this paper has provided some explanation for choosing the appropriate fabrication technique. The proposed materials and fabrication techniques are summarized in Fig. 1 and Table – 2.

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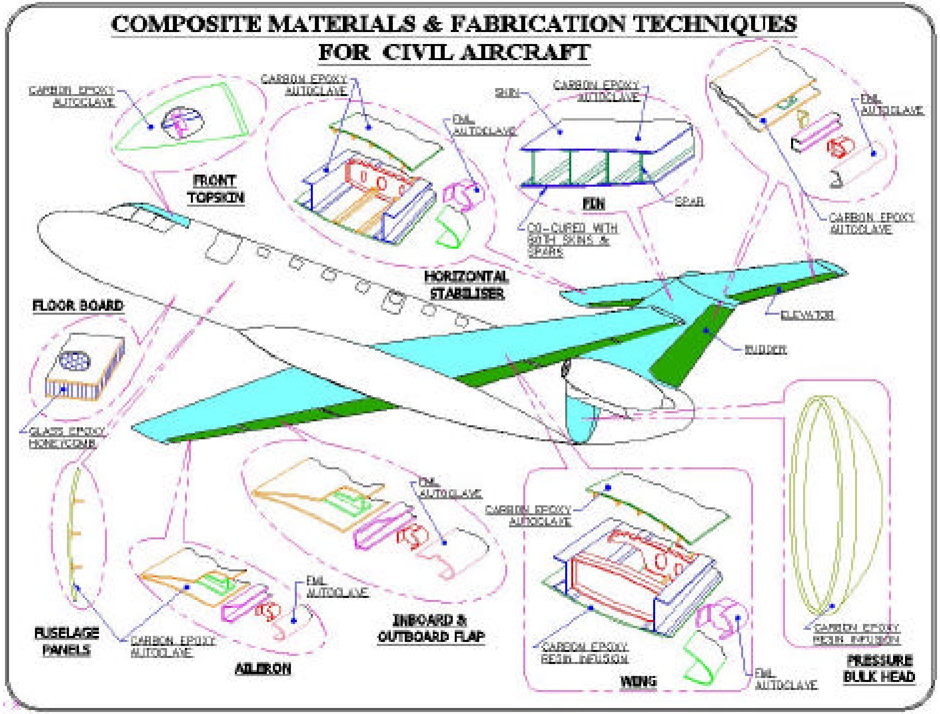

Fig. 1 – Proposed materials and fabrication techniques

Prepregs (Carbon-Epoxy)	**Dry fibers & resin**	**Fiber – metal – laminates Carbon – glass – aluminium**	**Pultruded sections**
Carbon proxy	(Carbon Fibers-Epoxy Resins)		
<u>Autoclave Processing</u>	<u>Resin Infusion</u>	Autoclave Moulding	a. Floor Beams (Carbon – Epoxy)
a) All control surfaces	Bottom skin with Integral ribs and spars of the wing	All leading edges (wing, fin, horizontal stabilizer)	
b) Empennage	Radome (Glass or Kevlar fibers with low loss polyester resin)		**<u>Floors</u>** Honey comb panels (Glass + Nomex core) Engineers to our requirements
c) Wing Top Skin d) Front Fuselage	Wing tip Horizontal stabilizer tip	Glass fiber Epoxy (for Wing tip, Horizontal stabilizer tip, Fin tip)	**<u>RTM</u>** Window frames (carbon – Epoxy)
e) Machined bulk-heads of fuselage f) Doors g) Fuselage skin panels with integral stiffners	Fin tip		Wing – fuselage fairing Fin fuselage fairing } Glass Epoxy

Table : 2 Composite Materials for Civil Transport Aircraft

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