COMMERCIAL TRANSPORT AIRCRAFT COMPOSITE WING BOX TRADE STUDY

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1 Introduction

Recently composite materials are widely used in the building of transport airplanes. The first significant application of composite materials in commercial transports was an all composite rudder for A300/310 by Airbus in 1983. In 1985, Airbus introduced a composite vertical tail fin in the same airplanes. With the success of A300/310, Airbus introduced a full composite tail structure for A320. The composite weight of A320 is totaled to 15% of structure weight. In the late of 1970, NASA and major airframe companies such as Boeing, Lockheed, MD started the ACEE program. The main goal of this program was to reduce airframe structure weight by using composite materials. With the ACEE program, the empennage of B737 was replaced by composite materials, MD developed a full composite wing for commercial transport, and Lockheed designed new composite vertical tail and aileron for L1011. In the US, the most significant use of composites in commercial transports has been on the B777. Composite structures make up 10 percent of the structure weight of the B777. The empennage, floor beams, flaps and outboard aileron of B777 were developed by composite materials. Composite materials are used for fuselage and wing structures for recently developed commercial transports by Airbus and Boeing. The composite weight percentage of A350 and B787 will be more than 50%. Both airplanes adopted composite materials for wing box and fuselage structures.

2 Trade Study Procedure

In the early stage of airplane development, trade studies on many possible structure concepts are main job for structure engineers. Structure engineer team studies the possibility of adapting the state of art technologies for their new aircraft. New concepts are introduced to the conventional airframe constructions. In the trade study, weight and cost between conventional concept and new technologies are main items. In this view, composite wingbox concepts are estimated for the 90 seats turboprop transport airplane in this work. The wing of 90 seats turboprop transport is designed as an upper wing type. The wing consists of a center wing box, two outer wingbox at the right and left sides, leading edge and trailing edge, inboard and outboard flaps, and ailerons. The wingbox consists of front and rear spars, upper and lower cover panels and ribs. For the first work of this development, 3D digital model of the wing airframe was constructed using CATIA. Then, aerodynamic, inertia and control loads were calculated for the initial sizing using 2D panel methods and point mass models of 3D CATIA model. Based on this 3D CAD model, FE analysis model was constructed. Almost all structures including skin panels, ribs, spars, leading edge, trailing edge and control surfaces were modeled in 2D shell elements by MSC/PATRAN while some skin stringers were modeled in 1D element. Although the material properties are not different along spanwise direction in this FE model, elements were divided to some groups to be used in the HyperSizer program.

The internal loads which were calculated by the FE analysis were used for the detail sizing for each structure components. For this purpose, HyperSizer program was used for structure sizing and concept proofs. This commercial program provides structurally optimized results for the panel and beam components based on the initial FE model

3 Material Selection

With technological improvements in the material properties, or introductions of new airframe fabrication methods, airframe designer should choose major material concepts for the main structural components. For the material selection, selection criteria should be defined first.

Table 1. Material selection criteria

Criteria	Design Consideration
Static Strength	Limit load capability
Stiffness	Deflection requirement
Fatigue	Crack initiation, fracture toughness
Damage Tolerance	Crack growth rate, critical crack length(residual strength)
Impact damage	Bird strike, hail, operation mishap
Crashworthiness	Plasticity, design capability
Weight	Density, minimum gage, design allowable
Corrosion	Galvanic, stress corrosion
Producibility	Commercial Availability, Lead Times, Fabrication Alternatives (welding)
Maintainability	Repair methods availability
Cost	Raw material, fabrication & assembly
TRL	Including past experiences

The selection criteria can be different for each structural component and different areas for each component. For leading edge of wing, impact damage by bird strike is quite more import than other criteria. Weight & cost are the key criteria for material selection for all materials. To proceed material selection, material properties should be defined by number for each criteria. The criteria which cannot be defined by specific number should be described in details for the final selection.

Table 2. Material properties definition

Materials	Yield Strength (ksi)	Young's modulus (10^6 psi)	Density (lb/in^3)	Fracture toughness	Price ($/lbs)
Al 2024	47	10.5	0.101	33.7	2~3
Al 7075	71	10.3	0.101	26.4	2~3
Al-Li 2198	63.2	10.9	0.094	35	5~10
AlMgSc Ko8242	46	10.7	0.096		5~10
CFRP	140	22	0.065	2~5	50~100
GFRP	60	5	0.056	10	15~25

Some criteria such as producibility are not easy to be represented by definite numbers in the early stage. Such criteria can be briefly summarized as some distinctive features such as weldability, creep form capability, or machining/ATL capabilities.

Table 3. Al-Li material characteristic description

Pro	Cons
- Low densities (2.55~2.58) - High elastic modulus - Excellent fatigue and cryogenic strength and toughness properties, - Superior fatigue crack growth resistance	- High price : 5$/lbs - Fast crack growth in compression loading area - Consistent quality is not guaranteed

Brief description of candidate material can be helpful for final decision, as the final call will be done by collaboration between many design functions, even including supply chains, manufacturing and marketing also. With the definition of selection criteria and each properties for every candidate, the final material for each structural components can be determined.

Table 5. Final material selection result

Component	Material	Comments
Fuselage	Conventional Aluminum	Welding for lower panel
Wing	CFRP	Metal rib
Empennage	CFRP	Thermoplastic
Removables	CFRP	GFRP for impact critical area

4 Full Composite Wing of the Commercial Transport Aircraft

Various concepts were considered and validated for the wing box design in the preliminary design phase. For the skin panel and stringer structure, several different stringer concepts for the skin panel were considered such as T-shaped, C-shaped and blade type stringers. The optimal stringer spacing was another design variable to be optimized by the HyperSizer program. In the skin panel design, stringer run-out is quite important. In our design, we chose three piece wingbox. In this concept, outer and center wing box joint design is one of the key issues in the early wingbox configuration set-up. Wing bending moment is the design loads for upper and lower wing skin panels.

In addition, two different composite spars were considered; one is the one piece spar with cocured/cobonded stiffeners and the other is the three pieces spar with mechanically fastened stiffeners. Many point loads, such as engine inertia load, wing-fuselage mating loads, are introduced in the winbox through the spars. Concentrated loads in composite structure come to a catastrophic failure in overall structure. Several loads distributing design concepts are introduced and evaluated.

For the rib structure, which support compression loads between upper and lower skin panels, full composite and metal were constructed and compared in the cost and weight. In the composite rib design, optimal rib spacing is quite important for overall weight and cost optimization. Ribs are usually attached skin panel and spar via metal clip with mechanical fasteners. Different rib-panel and spar fastening concepts are evaluated.

Through this work, the overall weight and manufacturing cost were estimated for each concepts and the optimal structure concept was suggested for the overall wing airframe construction.

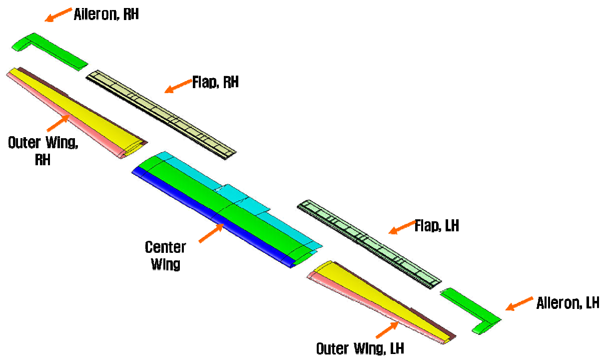


Fig.1.Regional Turboprop Wing Configuration.

Table 6. Various skin panel stringer concepts

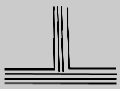
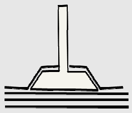
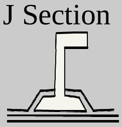
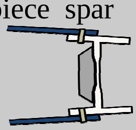
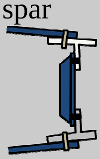
Concept	Design suitability	Structural efficiency
I blade 	Buckling of flat plate with a free edge Better for lower stringers	Symmetric, Buckling of flat plate with a free edge
T blade 	Better for lower stringers	Symmetric, Buckling of flat plate with a free edge
J Section 	Better for metallic	Asymmetric, Complex compression flexural torsion modes

Table 7. Two different spar concepts

Concept	Design suitability	Structural efficiency
Single piece spar 	May require fasteners to reinforce bonds at highly loaded areas	Carries material in lower loaded regions
3 piece spar 	Pre-cured stiffener is co-bonded to spar web spar web & spar cab is mechanically joined	No advantage of composite material by mechanical fastening

5 Weight Estimation

The final structural concept should be approved by weight & cost comparison to conventional metallic wing concept. Each component of full composite wing is sized to the design ultimate loads. Design ultimate loads are applied to FEM model of full composite wing. Internal loads for each component are calculated by FEM analysis. Detail sizing is carried for structural elements for metal & composite wing. By using 3D cad program, the initial weights for each element are estimated. To verify the weight potential of composite wing, HyperSizer is used for weight estimation of upper and lower skin panels. Uniaxial stiffened panel family with T-shaped stringer is selected for optimization process. T-shaped stringers are bonded to skins as defined previous chapter. Panel height, flange width, spacing are optimized main variables. Final panel weight for metal and composite wing is calculated for upper and lower panels.

6 Conclusion

The result in table 8 shows that composite upper skin panel has 24% weight reduction potential to metal wing concepts. The lower wing has 13% weight reduction potential also. These final weight estimation can be used for fabrication cost for all wing structures. With the weight & cost estimation for metal and composite wing, the final material for wing and each wing component can be decided.

Table 8. Weight estimation for metal/composite wing

Sample Part	Metal	Composite	Composite weight potential
Upper skin	29.92	22.63	24%
Lower skin	24.11	20.91	13%

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