10/28/2019

Team 519: Composite Airframe Life Extension

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Concept Generation

Figure 6: Longitudinal and Transverse directions

Additionally, a weaker core material may be placed between two layers of composite which will have a similar effect, creating a composite of composites. The orientation of the distributed phase can be arranged to provide strength in more than one direction; fibers can be woven into fabrics that provide strength in every direction along a plane; further, the amount of fibers can be varied, and is usually reported as volume fraction. The arrangement of the fibers is generally determined after the fiber material is selected. Lastly, the geometry of the component can be shaped in a way that distributes stress and takes advantage of the composite properties. (Callister, 2014)

Concept generation is an ideation process to open the possibilities for consideration. Concepts were created based on the class of materials to be used for each of the three phases, the orientation of the distributed phase, and the cross-section geometry of the part. Several concept generation techniques were used to facilitate the creation of new and innovative ideas. The methods used were morphological chart, anti-problem, biomimicry, and basic brainstorming. A catalog of 100 ideas can be found in Appendix C.

A total of nine concepts are presented the Concept Generation section: five medium resolution concepts and three high resolution concepts. These concepts are a result of using the various concept generation tools in Appendix C and will be evaluated in more detail in the Concept Selection section. The focus of medium resolution concepts is to determine a single design variable. These concepts tend to offer a significant single advantage, but consequently include several disadvantages. The high resolution concepts are more balanced, generally without significant disadvantages.

Morphological Chart.

The morphological chart focuses on the material selection component, varying the three materials which make up the composite: the distributed material, the matrix material, and the core material. A chart can be created with many different design possibilities that can be mixed and matched together to create hundreds of possibilities, shown in table 4. Following the table, a brief discussion of the merits of each entry in each column relative to the other entries in the column can help narrow down the possible designs to a more manageable number.

Table 4

Morphological Chart

Distributed Phase	Matrix Phase	Core Material
CF low modulus	Thermoplastic polymer	None
CF high modulus	Thermoset polymer	DaVinci Foam
CF Recycled	Metal	Balsa Wood
Aramid Fiber	Ceramic	Polymer
Glass Fiber	Carbon	CF Recycled

Distributed Phase.

Glass fibers are not as light or strong as CF and would probably not give enough increase to be worth extra cost over aluminum. Aramid fibers, of which Kevlar is the most prominent example, are more flexible and should dampen vibration better than carbon (which is why Kevlar is used in body armor) but will result in a larger and heavier part at a comparably high price point. CF is becoming cheaper and more well-known all the time, hence this project. Low modulus CF can offer vastly superior properties to aramid or glass at relatively affordable price point. High modulus could be considered, but if the low modulus can deliver good enough properties, there is no need to overengineer and use more expensive high modulus. NGC probably has access to a large amount of carbon fibers which can be cheaply recycled, making this the cheapest option from their point of view. The recycled material will be substantially weaker than the full-length carbon fibers and may need to be larger or of a different geometry.

The table below includes several grades of carbon fibers available Toray, a leading carbon fiber manufacturer. Exact pricing is not available online, but the low modulus material is significantly cheaper than the high modulus material.

Table 5

Carbon Fiber Grades

	Type	Elastic Modulus (msi)	Tensile Strength (ksi)	Cost
LOW MODULUS	T300	33.4	512	LOW
	T400H	36.3	640	
	T700S	33.4	711	
	T700G	34.8	711	
HIGH MODULUS	M35J	49.8	654	HIGH
	M40J	54.7	640	
	M46J	63.3	609	
	M50J	69	597	
	M55J	78.2	583	
	M60J	85.3	584	

Matrix Phase.

Some of these options can be ruled out easily: the carbon matrix and metal matrix will be far too expensive for this application, even if the team had the budget to afford them. A ceramic matrix would be too brittle for a structural part of an airframe and would be far too heavy. This leaves either a thermoplastic or thermosetting polymer. Most epoxy materials are thermosetting since thermoplastic tends to be more expensive. Thermosetting offers better performance at extreme temperatures, but it is brittle. Thermoplastic behaves more like a traditional ductile metal and may be better for this application but is generally less strong and may or may not be harder to manufacture at a large scale. Thermosetting is easier to manufacture at a small scale since it is liquid at room temperature, which probably makes it the best choice for the team, given the facilities and expertise available. Since the distributed phase is responsible for most of the strength in the composite, a matrix material can be selected based on other parameters, specifically cost. While a stronger, more expensive matrix will offer better performance, if it is not paired up with a comparable improvement in fiber quality, the improvement will not be noticeable.

Core Phase.

Core material is predominantly used in flat laminate panels, not structural components. It should be possible to use the core in the web section, but that will involve additional manufacturing challenges. The additional challenges will probably outweigh any advantages gained, which is why cores are generally not used in structural beams. If a core material was to be used, the best option is likely to be the recycled CF since it will be significantly stronger than any other core material.

Geometry.

The cross section of the beam does not necessarily have to be in the shape of a traditional C-channel. The greater strength of composites opens the possibility for different geometries to be considered. The figure below shows 30 possible cross sections.

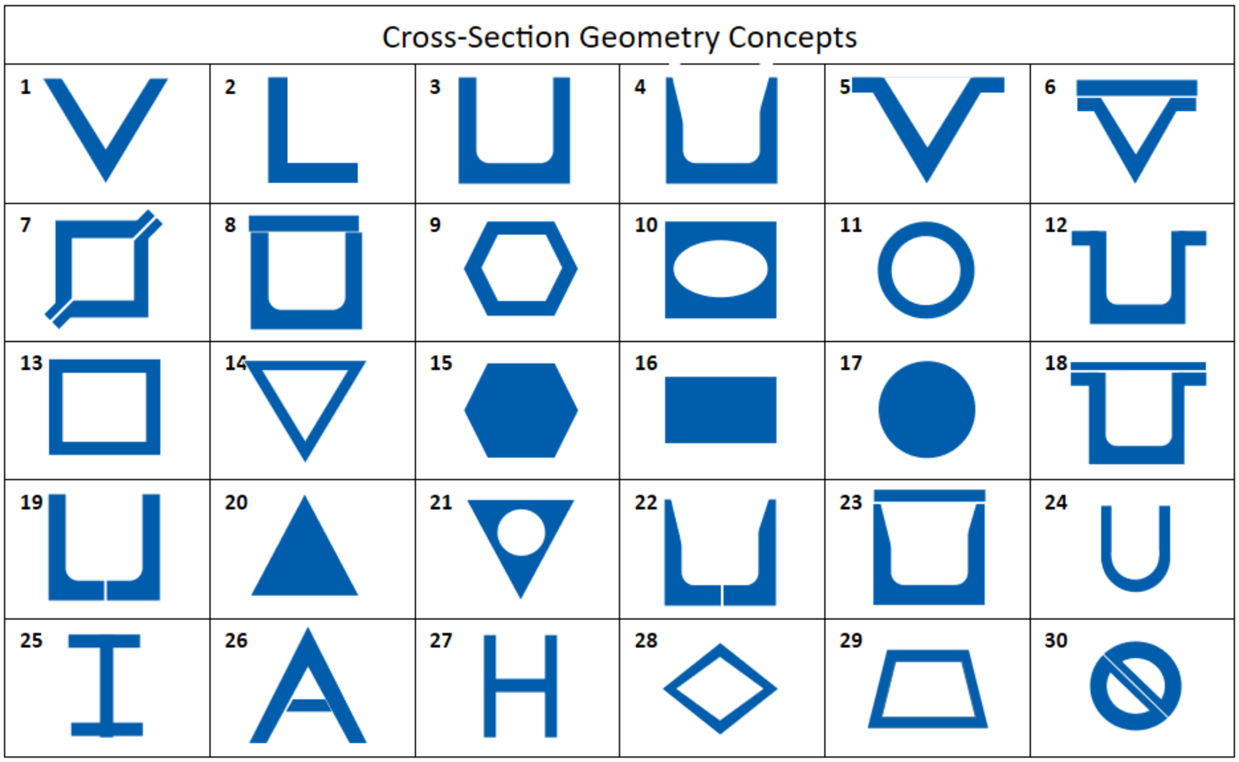

Figure 7: Cross-Section Geometry Concepts

Clearly not all the concepts are equally viable, but the idea of having a two-piece component offers additional functionality to the part (concepts 6, 7, 8, 18, 23). A second piece could be incorporated using the weight saved by the composites to add an additional function to the part. This second piece could be a mounting plate. The plate would not have to be load bearing, it could instead have a slit in it so that other hardware can be attached to the airframe using traditional fastening methods. Depending on the location in the aircraft, the part might need to support computer systems or other equipment; having the option to use traditional bolts to secure these items to the airframe will be an advantage the composite part offers over aluminum.

Since composites are stronger than aluminum, the size of the part may be able to be reduced while providing the same strength. Should the composite prove strong enough, one of the flanges from the C channel could be removed, resulting in an L shape (concept 2). If the composite was not as strong, like in the case of the recycled CF, additional flanges could be added, resulting in an I shape (concept 25).

Medium Resolution Concepts.

Medium resolution concepts are defined in a manner similar to experimental design. Generally, the concepts have a single design parameter which is varied (analogous to the independent variable) and upon which the other design variables depend (analogous to the dependent variables).

Concept 1.

High modulus carbon fiber distributed phase. A composite system using high modulus carbon fiber would add much more stiffness to the airframe than aluminum does. It would be able to withstand even greater loads; however, it is not necessarily needed in this scenario. High modulus carbon fiber would provide more strength than is needed for component. The result would be an overengineered part which would be much stronger and much more expensive than it needed to be.

Concept 2.

A thermoplastic polymer matrix phase could be used in a composite system for the component. Thermoplastic polymers are pliable at high temperatures and can be reshaped easily; they can be recycled or rearranged after the first process of heating and cooling. Thermoplastic polymers are a great matrix phase with high strength and high resistance to shrinkage. They also add ductility to the system, which can be an advantage since the fibers are relatively brittle and the airframe does require a certain degree of ductility. The downside of them would be that it would be difficult to manufacture given need for high temperature. Additionally, many thermoplastics would lose too much strength at the upper operating temperature (85 C).

Concept 3.

Aramid fibers with a thermoset polymer is a medium resolution concept because of its reasonable mechanical properties and ability to absorb energy. This characteristic of the aramid fiber would be beneficial in an airframe because it would dampen the vibration produced by the aircraft better than carbon fibers. This composite system is considered a medium resolution because it would probably not offer enough substantial improvements relative to aluminum. Aramid fibers are heavier and weaker than carbon fibers, so the part would be larger and heavier, mitigating the advantages offered by composites. Kevlar is also more expensive than aluminum, given the expense of replacing aluminum, it makes sense to choose the carbon fibers which are superior in every sense except ductility.

Concept 4.

Another possible composite with aramid fibers is to use a thermoplastic polymer matrix. The advantage to this design is it would dampen vibration the most out of any other material combination. It would probably not be extremely expensive, since the higher cost of the matrix could be offset by the lower cost of the fibers. Additionally, the lower strength of the fibers could be somewhat offset by the higher strength of the matrix.

Concept 5.

Given the additional strength offered by composites, the same strength of the two C channel flanges may be able to be achieved with a single flange, resulting in an L shape. This L shaped cross-section could possibly withstand the required loads and also save costs relative to a C channel due to using less materials to get the same results. This shape is possible if used with a strong enough composite system but may not fit the dimensions to fit the section where the C channel is used currently.

Concept 6.

Recycled carbon fiber is much weaker than other options for a distributed phase, but it is significantly cheaper than other materials because it is made from old carbon fiber weaves. Similar to concept 4, the shape of the cross-section can be modified to withstand the load necessary. If the recycled fiber was not strong enough for a traditional C shaped cross section, additional flanges could be added to the beam, resulting in an I shape. The additional material could be enough for the recycled material to provide the required strength.

High Resolution Concepts.

Without a detailed analysis, which will come later, the three designs most likely to succeed are represented here. Note that as of the time of writing, the team still does not know the loads the part will need to withstand, or if there are any specific size requirements for the part. Therefore, there will be not be an FEA included for the high resolution concepts at this time.

This also means that the volume fraction of fibers to matrix cannot be determined at this time, so the high resolution concepts will be limited to selecting the exact materials to be considered.

Concept 7.

The first concept is a low modulus carbon fiber and a thermoset matrix phase with no core and in a C shaped geometry. This would serve as the control design; it is simple with the only substantial change being the change in materials from aluminum to composite. This will be relatively cheap and easy to manufacture and could be integrated very easily into existing airframes.

This composite system would contain a T300 Carbon Fiber distributed phase and an Epon 862 polymer matrix. The T300 Carbon Fiber is used because its elastic modulus and tensile strength are sufficiently higher than that of Al6061. While carbon fibers with higher moduli and tensile strengths exist, T300 offers a significant performance improvement at the lowest price point.

Epon 862 is a very common matrix used in composite manufacturing because of its ease of handling during manufacturing. Epon 862 has a low density that allows for easier hand layup of the composite; being a liquid at room temperature allows Epon 862 to be brushed onto the specimen easily. A higher density matrix would need to be heated constantly, requiring equipment such as a heating table, which would add difficulty and potential create unsafe working conditions during hand layups of the composite.

Concept 8.

The second high resolution concept is to only use pure recycled carbon fiber as the distributed phase. Recycled carbon fiber is much weaker than other options for a distributed phase, but it is significantly cheaper than other materials because it is made from old carbon fiber weaves. As an unaligned and discontinuous fiber, it will be isotropic, which means there is more freedom in design since it resembles traditional aluminum. Like aluminum, it can be machined after manufacture. The recycled carbon fiber can have holes for fasteners and rounds to reduce stress concentrations and various other things that would be expensive to include into anisotropic composites.

Epon 862 would be a suitable matrix for this composite for the same reasons it was the best matrix for the previous concept. It is easy to work with, lightweight, and inexpensive. The low cost of this matrix material complements the low cost of the recycled fibers. Using a single matrix phase material will also simplify the purchasing and manufacturing stages of the project.

Concept 9.

The final concept is a combination of the previous two: A hybrid composite using both T300 fibers and recycled fibers. Again, both options were chosen primarily to save on costs. The orientation of the fibers would depend on the loading of the part, which as of time of writing is not available. Given that the T300 is roughly three times as strong as aluminum, there will probably be room to add some cheaper material and still meet the strength target. This hybrid composite also offers a tailored combination of the T300 Carbon Fiber composite and the fully recycled composite to generate an optimized strength-cost ratio. Utilizing the highest volume fraction of recycled carbon fiber as possible in the structure would be ideal for the purpose of meeting the cost reduction requirement.

The best matrix material to use to minimize costs is, as above, Epon 862. This is the cheapest and easiest material to work with and using the same matrix material will streamline the manufacturing process.