10/28/2019

EML4551-2

Team 519: Composite Airframe Life Extension

Cecil E. Evers; Christopher A. Ryan, Gabrielle E. Mohrfeld, Stefan Spiric

2525 Pottsdamer St. Tallahassee, FL. 32310

Concept Selection

The goal of concept selection is to devise a method to analyze the concepts from concept generation and determine which of those concepts best satisfies the design criteria. This is done by comparing the engineering characteristics to determine which are the most important. The design criteria are based on the functions and targets that were determined earlier in the design process. The concepts will be compared against each other and based on the results of this analysis, the final concept will be chosen. The methods that were used to evaluate the best concepts are a house of quality, Pugh charts, and the analytical hierarchy process.

The top three concepts will be selected to build and test. Only testing one design will not provide enough data to make a conclusive recommendation to NGC. The ideal concepts will address the primary customer needs of lowest possible cost and most reliable design, additionally NGC was particularly interested in the use of recycled material.

House of Quality.

The house of quality is a tool that compares the engineering characteristics with the customer requirements to determine which engineering characteristics are the most central to fulfilling the customer needs. For a trivial example, the tensile strength of the part is more important than the color the part is painted. The customer requirements are on the left side and the engineering characteristics run along the top. The customer requirements are weighted to reflect their relative importance in a pairwise comparison contained in appendix D. Unsurprisingly, the most important customer requirement is that the part withstand the same loading as aluminum.

In the middle of the house of quality, there are four possible scores in each cell: a score of 9 indicates that the engineering characteristic is absolutely critical to fulfilling the customer requirement, a score of 3 indicates that the engineering characteristic is directly involved in fulfilling the customer requirement, and a score of 1 indicates that the engineering characteristic is indirectly involved in fulfilling the customer requirement. If there is no relation, the score assigned is 0 and the cell is left empty to improve readability.

		Engineering Characteristics										
Improvement Direction		= ↑	= ↑	↓	↑	↑	↑		↓			
Units		GPa	GPa	GPa	deg C	N/A	N/A	N/A	kg/m^3	sec	$	$
Customer Requirements	Importance Weight Factor	Tensile Strength of Component	Shear Strength of Component	Vibration Frequency/ Intensity	Endure Temperture Extremes	Resist Corrosion	Attaching to Airframe	Access to Material	Density of Component	Takt Time	Cost of Manufacturing	Material Cost
Manufacturing Ability	1							1		3	9	3
Weight	2	1	1	1			1		9			1
Cost	4						3	3	1	3	9	9
Available Material	5	1	1					9				3
Withstand Loading	6	9	9	9	3		1					
Weatherproof	4	3	3		9	9	1					
Long Life Cycle	1			3	3	9	1		9			
Attachment Method	5	1	1	3		1	9					
Raw Score (612)		78	78	74	57	50	70	58	31	15	45	56
Relative Weight %		12.75	12.75	12.09	9.314	8.17	11.44	9.477	5.065	2.451	7.353	9.15
Rank Order		1	1	3	6	7	4	5	10	11	8	7

The bottom row shows the results from the house of quality. The engineering characteristics are rank ordered by their importance to the project. Note that the tensile and shear strength are in terms of specific strength: strength vs density. Every concept is designed to be exactly as strong as aluminum, no more and no less, but this will come at the cost of weight and volume, depending on materials and geometry.

As expected, the most important characteristics, according to the house of quality, are the tensile and shear strength. These impact every customer need. Other noteworthy characteristics are the vibration and temperature resistance.

Pugh Chart.

The series of Pugh charts are in appendix D. They compare the nine medium and high-resolution concepts from the previous section against each other. The purpose of this tool is to select the best concept according to the most important engineering criteria as determined by the house of quality. The concepts from the previous section are called systems 1 through 9 in this section and are shown below.

Systems Key	
Datum:	Aluminum
System 1:	High Modulus CF + Thermoset Polymer + C-Channel
System 2:	High Modulus CF + Thermoplastic Polymer + C-Channel
System 3:	Aramid + Thermoset Polymer + C-Channel
System 4:	Aramid + Thermoplastic Polymer + C-Channel
System 5:	High Modulus CF + Thermoset Polymer + L-Beam
System 6:	Recycled CF + Thermoset Polymer + I-Beam
System 7:	Low Modulus CF + Thermoset Polymer + C-Channel
System 8:	Recycled CF + Thermoset Polymer + C-Channel
System 9:	Hybrid CF and Recycled CF + Thermoset Polymer + C-Channel

The first chart compares all nine concepts against aluminum, and records whether they are better or worse in each category.

Pugh Chart 1										
Selection Criteria		**Concepts**								
	Aluminum	**System 1**	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**System 7**	**System 8**	**System 9**
Tensile Strength of Component	Datum	+	+	-	-	+	S	+	-	S
Shear Strength of Component		+	+	S	S	+	S	+	-	S
Vibration Frequency/ Intensity		S	S	+	+	S	S	+	+	+
Attaching to Airframe		S	S	S	S	S	+	S	+	+
Access to Materials		-	-	S	S	-	+	-	+	S
Endure Extreme Temperatures		+	-	+	-	+	+	+	+	+
Material Cost		-	-	-	-	S	S	-	+	S
# of Pluses		3	2	2	1	3	3	4	5	3
# of Minuses		2	3	2	3	1	0	2	2	0

In the first Pugh chart, there are three concepts with more negatives than positives: systems 2, 3, 4. These can be eliminated from consideration, since they scored worse than aluminum. System 1 was also eliminated because it has the lowest ratio of positives to negatives. The remining five concepts are then compared in Pugh chart 2. System 7 was selected as the new datum because it was considered the best overall concept. Note that while system 8 has more positives than system 7, system 8 scored worse in the tensile and shear strength, which are the most important criteria. For this reason, system 7 was considered the best concept.

The second Pugh chart compares systems 5, 6, 8, 9 against system 7.

Pugh Chart 2						
Selection Criteria		Concepts				
	System 7	System 5	System 6	System 8	System 9
Tensile Strength of Component	Datum	+	S	-	S
Shear Strength of Component		+	S	-	S
Vibration Frequency/ Intensity		S	+	+	S
Attaching to Airframe		S	+	+	+
Access to Materials		S	+	+	+
Endure Extreme Temperatures		S	S	S	S
Material Cost		-	+	+	+
# of Pluses		2	4	4	3
# of Minuses		1	0	2	0

System 6 scored the highest and will be the datum for the next chart. System 5 scored the lowest and was removed from further consideration. The purpose of the final chart, Pugh chart 3, is to remove a single concept so that only three remain.

Pugh Chart 3				
Selection Criteria		Concepts		
	System 6	System 7	System 8	System 9
Tensile Strength of Component	Datum	+	-	+
Shear Strength of Component		+	-	+
Vibration Frequency/ Intensity		S	+	S
Attaching to Airframe		S	S	S
Access to Materials		S	S	-
Endure Extreme Temperatures		S	S	S
Material Cost		-	S	-
# of Pluses		2	1	2
# of Minuses		1	2	2

Concept 8 is eliminated because it's worse than six, while the other two are either superior or equivalent. These three concepts are the chosen systems. These results make sense because they align closely with the customer needs. System 6 will likely be the cheapest possible design because it uses the cheapest possible fiber and the strongest possible geometry. It may be more difficult to incorporate into the airframe, but that is secondary to strength and price. System 7 represents a good baseline design; it uses reliable materials, but also should be relatively cheap. System 9 aims to be a compromise between the other two systems in terms of strength and cost.

Analytical Hierarchy Process.

The analytical hierarchy process (AHP) is a technique to derive weighted values to use when comparing design characteristics. It is easy for the designer's biases to color their concept selections; the AHP can help identify these discrepancies. The AHP is discussed in Appendix D.

Final Selection.

The top three concepts selected are systems 6,7,9. Three concepts were selected so that the team can make a good recommendation to NGC. There are two primary areas of concern for NGC: reliability and cost. The concepts selected focus on these two primary customer needs.

System 6.

System 6, or concept 6 from page 34, is a composite system made from recycled carbon fiber, thermoset polymer, with a cross-section of an I. This system was selected because it is the best concept to fulfill the customer need of being affordable. Using all recycled fiber and a thermoset resin should make for the cheapest possible material. NGC was also very interested in using recycled carbon fiber because their company probably has a substantial quantity of this material at their advanced composites center in California, left over from the B-2 and B-21 programs. The recycled carbon fiber beam has a cross-section of an I to add extra material at the points of highest internal stress in the beam structure. The I beam design scored higher than the C channel design because the recycled material is weaker than the other fibers, and so more of it will be required, but the lower cost of the recycled fibers should still result in a cheaper product.

System 7.

System 7, or concept 6 from page 35, is a composite system made from low modulus carbon fiber, thermoset polymer, with a cross-section of a C. This system was selected because it is the best concept to fulfil the customer need of being reliable. Part of NGC's motivation for sponsoring this project was the relative lack of industry experience with replacing aluminum airframe structures with composite. From their perspective, it is easier to use the more proven aluminum components rather than design new composite components and go through the time and expense of validating the new material. For this reason, the team selected a concept that will work well as a baseline. Low modulus CF is understood the best out of all of the materials under consideration and will provide excellent strength at a good price point. High modulus CF would probably be stronger than it needed to be and would probably be more expensive than it needed to be, additionally there is a larger supply of low modulus fibers available.

System 9.

The final design selected is a hybrid of the previous two designs and can be found on page 36 as concept 9. While the first two focused on affordability and reliability, respectively, the final design tries to establish a balance between the two by using both low modulus CF for strength at a competitive price and incorporating recycled CF to achieve the same strength and similar reliability at the lowest possible price. The detailed design for this concept can be made from comparing the design characteristics of the previous two designs, since a combination of the two distributed phases using the same matrix material should yield a result that is somewhere in the middle of the two. A graph can be made comparing the modulus of the recycled material and the modulus of the pure material on the y axis and the volume fraction on the x axis. This will allow the team to see the approximate characteristics of any possible volume fraction and make an educated choice when selecting a particular volume fraction for this hybrid concept.