Concept Selection

Once the concepts were generated, the next step was to select the best concept to meet our objective. To do so, the team narrowed down the medium fidelity concepts, based on feasibility and predicted best results, to just two. These were then combined with the three high fidelity concepts to be analyzed and selected as the best concept. The analysis techniques used to select the best concept were a House of Quality, iterations of Pugh charts, and an Analytical Hierarchy Process (AHP) examination. Each of these analysis techniques analyzes how well the concepts meet the project objective. The end goal is to use these techniques to find the concept that best accomplishes the project objective.

Table 7: *House of Quality*

House of Quality		Engineering Characteristics										
Improve Direction												
Units		Kg	Sec	m	m	g	N	n/a	m/s	m	m	deg
Customer Requirements	Importance Weight Factor	Overall Weight	Endurance	Wingspan	Length	Payload Weight	Wing rigidity	Material Durability	Velocity Control	Altitude	Signal Range	Payload Control
UAV constructed of lightweight materials	7	9	7	5	7		7	7	3	3	1	1
UAV implements previously purchased components	3	1				5					1	3
UAV takes off and lands assisted or unassisted	1				3			5	7	1		
The UAV is of the fixed wing style	3	3	9	9	1		9		3	5		3
The UAV has a payload	6	5	5		3	9	1		5	1	1	7
The UAV uses outsourced components	1					9					3	3
The UAV is smaller than double the reference drone	3	7	1	3			1		1		1	
The UAV is category 1	4	7				7			3	9		
Raw Score	905	154	109	71	73	106	85	54	82	79	22	70
Relative Weight %		**17.02**	**12.04**	**7.85**	**8.07**	**11.71**	**9.39**	**5.97**	**9.06**	**8.73**	**2.43**	**7.73**
Rank Order		**1**	**2**	**8**	**7**	**3**	**4**	**10**	**5**	**6**	**11**	**9**

The purpose of the House of Quality is to determine the top engineering characteristic by comparing them to customer requirements. The House of Quality contains 11 engineering characteristics as well as customer requirements. These customer requirements were given importance factors based on the binary pairwise comparison table found in appendix D. The 11 engineering characteristics were individually compared to each customer requirement and given a score depending on how much that customer requirement affects each engineering characteristic. The scoring system has 1 being the lowest score and 9 being the highest possible score for each engineering characteristic. We chose the top five engineering characteristics to move forward with in the concept analysis because they best define the project objective. After each individual score was marked down, the scores for the columns were determined by taking the individual score, multiplying it by the importance factor, and finally summing it all up at the end. From our House of Quality our engineering characteristics were ranked in order of importance as follows: overall weight, endurance, payload weight, wing rigidity, and velocity control.

The Pugh Charts below were used to identify the concepts that would be most beneficial in helping us achieve our goal of light weighting a UAV. Pugh Charts compare multiple concept ideas to a known datum based on criteria in the left most column. The criteria consist of the engineering characteristics that were ranked in the House of Quality. A concept is rated (+) if it would meet a criterion better than the datum could. A (-) if the concept would not do better, and an S if it would produce about the same result. The concept with the worst score is eliminated as a viable idea.

The following Pugh Chart stacks our three high and two best medium fidelity concepts against Styrofoam. Styrofoam was chosen as the datum because that is the material the UAV is currently made of.

Table 8: *Pugh Chart for Iteration One*

Pugh Chart Iteration One	Datum	Concepts				
Selection Criteria	Styrofoam	LW-PLA constructed parts	Lighter Electrical Components	Improve Propeller design	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	S	-	-	+	-
Endurance		+	+	+	+	+
Payload Weight		S	S	-	S	-
Wing Rigidity		+	+	S	S	S
Velocity Control		+	+	+	S	S
# of pluses		3	3	2	2	1
# of minuses		0	1	2	0	2

Most of the concepts in the chart above were able to outscore the datum because they effect different portions of the drone, not just the structure. Styrofoam directly effects the structure and wing design but has a small impact on other aspects of the UAV, like velocity control.

Another Pugh Chart was made using the "Improve Propeller Design" concept as the datum. This datum was chosen because in comparison to Styrofoam, in the chart above, it did not create any noticeable change.

Table 9: *Pugh Chart for Iteration Two*

Pugh Chart Iteration Two	Datum	Concepts			
Selection Criteria	Improve Propeller design	LW-PLA constructed parts	Lighter Electrical Components	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	-	-	+	-
Endurance		+	S	+	+
Payload Weight		S	S	S	-
Wing Rigidity		+	S	S	S
Velocity Control		-	+	S	-
# of pluses		2	1	2	1
# of minuses		2	1	0	3

The results of this Pugh Chart reveal that once again “Regenerative Power Source” will not be the best concept to apply to reach our end goal. It also shows that the “Generative Design” concept will aid our project or, at the very least, it will not hinder it. With the results of this chart, the “Regenerative Power Source” concept can be eliminated as a possible technic for light weighting the UAV.

The last Pugh Chart consists of the remaining concepts, with the “Lighter Electrical Components” concept being used as the datum. By comparing our concepts to each other in this manner, it can be determined which concepts are best to pursue further based on side-by-side comparison.

Table 10: *Pugh Chart for Iteration Three*

Pugh Chart Iteration Three	Datum	Concepts		
Selection Criteria	Lighter Electrical Components	LW-PLA constructed parts	Improve Propeller design	Generative Design
Overall Weight	**Datum**	+	+	+
Endurance		S	S	S
Payload Weight		-	S	S
Wing Rigidity		+	S	S
Velocity Control		+	-	-
# of pluses		3	1	1
# of minuses		1	1	1

The datum chosen this time was harder to overcome in the different categories. The electrical components are such an intricate part of a drone that it influences many other functions. The “LW-PLA Constructed Parts” has consistently scored well in the Pugh Charts, as well as the “Improved Propeller Design”, “Generative Design”, and “Lighter Electrical Components”. These are all concepts that warrant further scrutiny in order to obtain the best results possible. However, as discussed prior, parts designed using generative design can be hard to manufacture as the design technique is more advanced than available manufacturing techniques. As a group, we decided to eliminate that concept for that reason as it also does not significantly differentiate itself from the datums it was compared to.

Looking closer at the Pugh charts, the design concepts that performed the best throughout each iteration were the “LW-PLA Constructed Parts” and “Lighter Electrical Components” concepts. Moving forward in the concept selection process, these are our top two candidates.

AHP

The Analytical Hierarchy Process is performed to select the best concept by performing comparisons between the engineering characteristics and the top concepts. This also checks for bias in the concept selection process. To begin, the top 5 engineering characteristics were put into a matrix where they were compared and given a score based on which characteristic is more important in meeting the project objective. This is seen below in Table 11.

Table 11: *Matrix Criteria*

Matrix [c]					
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control
Overall Weight	**1.000**	1.000	0.333	0.200	0.200
Endurance	1.000	**1.000**	0.333	0.200	0.143
Payload Weight	3.000	3.000	**1.000**	0.333	0.200
Wing Rigidity	5.000	5.000	3.000	**1.000**	1.000
Velocity Control	5.000	7.000	5.000	1.000	**1.000**
Sum	15.000	17.000	9.666	2.733	2.543

Once the matrix was solved above, it was then normalized by dividing the weighted value in each box by the sum of that column. This action was performed to make the data more usable and compute the Criteria Weight of each engineering characteristic. This is seen below in Table 12.

Table 12: *Matrix Criteria Weight*

Normalized Matrix [norm c]						
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control	Criteria Weight {W}
Overall Weight	0.067	0.059	0.034	0.073	0.079	**0.06**
Endurance	0.067	0.059	0.034	0.073	0.056	**0.06**
Payload Weight	0.200	0.176	0.103	0.122	0.079	**0.14**
Wing Rigidity	0.333	0.294	0.310	0.366	0.393	**0.34**
Velocity Control	0.333	0.412	0.517	0.366	0.393	**0.40**
sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	

The following table calculates the Consistency Vector for each engineering characteristic using the Criteria Weight from Table 12. Matrix multiplication between the Criteria Weights and the Criteria Matrix is used to compute the Weighted Sum Vector for each characteristic. That is then used to get the Consistency Vector. These values are noted below in Table 13.

Table 13: *Criteria Consistency Check*

Criteria Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	{Ws}/{W} Consistency Vector
0.31	0.06	5.24
0.29	0.06	4.86
0.69	0.14	4.95
1.76	0.34	5.18
2.16	0.40	5.40

Using the table above to calculate the Average Consistency, the Consistency Index and the Consistency Ratio could be tabulated in Table 14 below. This shows that our decisions made in the Analytic Hierarchy Process do not show bias toward any engineering characteristics since the Consistency Ratio is less than 0.1. This means that going forward, we can use the data from that chart to help us select a concept without worrying about skewed results.

Table 14: *Criteria Bias Check*

Consistency and Bias Check			
Average Consistency	Consistency Index	Consistency Ratio	Is Comparison Consistent
5.127	0.033	0.029	Yes

The process used to get the results from Table 11 through Table 14 was then repeated for each engineering characteristic and giving weights to the three concepts. These tables and the results can be seen in Appendix D. Using all of those tables, the Final Rating Matrix was able to be computed. This is shown in Table 15 below.

Table 15: *Rating Matrix*

Final Rating Matrix			
	Lighter Electrical Components	LW-PLA constructed parts	Improve Propeller design
Overall Weight	0.20	0.60	0.20
Endurance	0.30	0.61	0.09
Payload Weight	0.11	0.63	0.26
Wing Rigidity	0.20	0.34	0.46
Velocity Control	0.72	0.19	0.08

Performing a matrix multiplication of the transpose of Table 15 and the Criteria Weights from Table 12, the Alternative Weights of the concepts were calculated. These can be seen in Table 16 below.

Table 16: *Alternative Weight of Concepts*

Alternative Weight of Concepts	
Concepts	Alternative
Lighter Electrical components	0.401
LW-PLA Constructed parts	0.352
Improve Propeller design	0.242

The alternative values are determined using the Final Rating Matrix in Table 15 and the Criteria Weights in the second column of Table 13. The alternative values reveal the ranking of the concepts compared to one another. The highest-ranking concept from table 16 is the Lighter Electrical Components concept with a .401 ranking. From our Pugh charts, the top two concepts were consistently LW-PLA constructed parts and Lighter Electrical Components. This conclusion matches the conclusion from the Pugh charts. The top two concepts from the iterations of the Pugh charts were the top two concepts in Table 16. Therefore, the Lighter Electrical Components concept is the best concept to meet the project objective.

Selected Concept

Out of all the concepts generated by Team 518 to best meet our project objective, the best concept is to introduce lighter electrical components to the existing UAV. Figure 2 below shows how this may be done. Introducing a smaller, lighter battery and motor can help reduce the weight of the UAV. Using the tools to select the concepts, this was found to be the best concept to lightweight the UAV, increasing the flight time, and providing surveillance data. However, the light weighting process is very iterative. Changing one piece of the design can allow you to reduce the weight in other areas outside of what you directly improved. When we improve the electrical components of the Believer 1960, reducing the weight, we then will not need to have as strong of a support structure for those parts. That allows for weight to be reduced in the support structure. This kind of process and analysis can be applied to many of the UAV's systems.

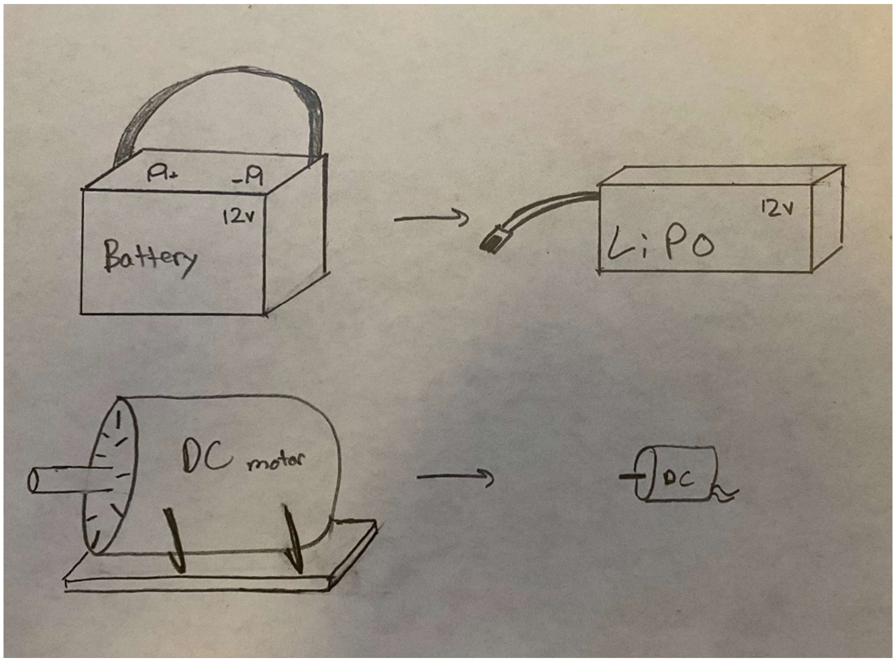

Figure 2: *Lighter Electrical Components*

Appendices

Appendix A: Concept Selection

Table D-1: *House of Quality*

House of Quality		Engineering Characteristics										
Improve Direction												
Units		Kg	Sec	m	m	g	N	n/a	m/s	m	m	deg
Customer Requirements	Importance Weight Factor	Overall Weight	Endurance	Wingspan	Length	Payload Weight	Wing rigidity	Material Durability	Velocity Control	Altitude	Signal Range	Payload Control
UAV constructed of lightweight materials	7	9	7	5	7		7	7	3	3	1	1
UAV implements previously purchased components	3	1				5					1	3
UAV takes off and lands assisted or unassisted	1				3			5	7	1		
The UAV is of the fixed wing style	3	3	9	9	1		9		3	5		3
The UAV has a payload	6	5	5		3	9	1		5	1	1	7
The UAV uses outsourced components	1					9					3	3
The UAV is smaller than double the reference drone	3	7	1	3			1		1		1	
The UAV is category 1	4	7				7			3	9		
Raw Score	905	154	109	71	73	106	85	54	82	79	22	70
Relative Weight %		**17.02**	**12.04**	**7.85**	**8.07**	**11.71**	**9.39**	**5.97**	**9.06**	**8.73**	**2.43**	**7.73**
Rank Order		**1**	**2**	**8**	**7**	**3**	**4**	**10**	**5**	**6**	**11**	**9**

Table D-2: Binary Pairwise Comparison

Binary Pairwise Comparison	1	2	3	4	5	6	7	8	**total**
1. UAV constructed of lightweight materials	**x**	1	1	1	1	1	1	1	**7**
2. UAV implements previously purchased components	0	**x**	1	1	0	1	0	0	**3**
3. UAV takes off and lands assisted or unassisted	0	0	**x**	0	0	0	0	1	**1**
4. The UAV is of the fixed wing style	0	0	1	**x**	0	1	1	0	**3**
5. The UAV has a payload	0	1	1	1	**x**	1	1	1	**6**
6. The UAV uses outsourced components	0	0	1	0	0	**x**	0	0	**1**
7. The UAV is smaller than double the reference drone	0	1	1	0	0	1	**x**	0	**3**
8. The UAV is category 1	0	1	0	1	0	1	1	**x**	**4**

Table D-3: Pugh Chart Iteration One

Pugh Chart Iteration One	Datum	Concepts				
Selection Criteria	Styrofoam	LW-PLA constructed parts	Lighter Electric Components	Improve Propeller design	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	S	-	-	+	-
Endurance		+	+	+	+	+
Payload Weight		S	S	-	S	-
Wing Rigidity		+	+	S	S	S
Velocity Control		+	+	+	S	S
# of pluses		**3**	**3**	**2**	**2**	**1**
# of minuses		**0**	**1**	**2**	**0**	**2**

Table D-4: Pugh Chart Iteration Two

Pugh Chart Iteration Two	Datum	Concepts			
Selection Criteria	Improve Propeller design	LW-PLA constructed parts	Lighter Electric Components	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	-	-	+	-
Endurance		+	S	+	+
Payload Weight		S	S	S	-
Wing Rigidity		+	S	S	S
Velocity Control		-	+	S	-
# of pluses		**2**	**1**	**2**	**1**
# of minuses		**2**	**1**	**0**	**3**

Table D-5: Pugh Chart Iteration Three

Pugh Chart Iteration Three	Datum	Concepts		
Selection Criteria	Lighter Electrical Components	LW-PLA constructed parts	Improve Propeller design	Generative Design
Overall Weight	**Datum**	+	+	+
Endurance		S	S	S
Payload Weight		-	S	S
Wing Rigidity		+	S	S
Velocity Control		+	-	-
# of pluses		**3**	**1**	**1**
# of minuses		**1**	**1**	**1**

Table D-6: Matrix Criteria

Matrix [c]					
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control
Overall Weight	**1.000**	1.000	0.333	0.200	0.200
Endurance	1.000	**1.000**	0.333	0.200	0.143
Payload Weight	3.000	3.000	**1.000**	0.333	0.200
Wing Rigidity	5.000	5.000	3.000	**1.000**	1.000
Velocity Control	5.000	7.000	5.000	1.000	**1.000**
Sum	**15.000**	**17.000**	**9.666**	**2.733**	**2.543**

Table D-7: Normalized Matrix Criteria

Normalized Matrix [norm c]						
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control	Criteria Weight {W}
Overall Weight	0.067	0.059	0.034	0.073	0.079	**0.06**
Endurance	0.067	0.059	0.034	0.073	0.056	**0.06**
Payload Weight	0.200	0.176	0.103	0.122	0.079	**0.14**
Wing Rigidity	0.333	0.294	0.310	0.366	0.393	**0.34**
Velocity Control	0.333	0.412	0.517	0.366	0.393	**0.40**
sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	

Table D-8: Criteria Consistency Check

Criteria Consistency Check		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.31	0.06	5.24
0.29	0.06	4.86
0.69	0.14	4.95
1.76	0.34	5.18
2.16	0.40	5.40

Table D-9: Consistency and Bias Check

Consistency and Bias Check			
Average Consistency	Consistency Index	Consistency Ratio	Is Comparison Consistent
5.127	0.033	0.029	Yes

Table D-10: Overall Weight Matrix

Overall Weight			
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design
Lighter Electrical components	**1.00**	0.33	1.00
LW-PLA Constructed parts	3.00	**1.00**	3.00
Improve Propeller design	1.00	0.33	**1.00**
Sum	**5.00**	**1.67**	**5.00**

Table D-11: Normalized Overall Weight Matrix

Normalized Overall Weight				
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design	Design Alternative Priorities{Pi}
Lighter Electrical components	0.20	0.20	0.20	0.20
LW-PLA Constructed parts	0.60	0.60	0.60	0.60
Improve Propeller design	0.20	0.20	0.20	0.20
Sum	1.00	1.00	1.00	

Table D-12: Consistency Check for Overall Weight

Consistency Check for Overall Weight		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.60	0.20	3.00
1.80	0.60	3.00
0.60	0.20	3.00

Table D-13: Endurance Matrix

Endurance			
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design
Lighter Electrical components	1.00	0.33	5.00
LW-PLA Constructed parts	3.00	1.00	5.00
Improve Propeller design	0.20	0.20	1.00
Sum	4.20	1.53	11.00

Table D-14: Normalized Endurance Matrix

Normalized Endurance				
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design	Design Alternative Priorities{Pi}
Lighter Electrical components	0.24	0.22	0.45	0.30
LW-PLA Constructed parts	0.71	0.65	0.45	0.61
Improve Propeller design	0.05	0.13	0.09	0.09
Sum	1.00	1.00	1.00	

Table D-15: Consistency Check for Endurance

Consistency Check for Endurance		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.95	0.30	3.15
1.96	0.61	3.23
0.27	0.09	3.03

Table D-16: Payload Weight Matrix

Payload Weight			
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design
Lighter Electrical components	1.00	0.20	0.33
LW-PLA Constructed parts	5.00	1.00	3.00
Improve Propeller design	3.00	0.33	1.00
Sum	9.00	1.53	4.33

Table D-17: Normalized Payload Weight Matrix

Normalized Payload Weight				
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design	Design Alternative Priorities{Pi}
Lighter Electrical components	0.11	0.13	0.08	0.11
LW-PLA Constructed parts	0.56	0.65	0.69	0.63
Improve Propeller design	0.33	0.22	0.23	0.26
Sum	1.00	1.00	1.00	

Table D-18: Consistency Check for Payload Weight

Consistency Check for Payload Weight		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.32	0.11	3.01
1.94	0.63	3.07
0.79	0.26	3.04

Table D-19: Wing Rigidity Matrix

Wing Rigidity			
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design
Lighter Electrical components	1.00	0.14	1.00
LW-PLA Constructed parts	7.00	1.00	0.20
Improve Propeller design	1.00	5.00	1.00
Sum	9.00	6.14	2.20

Table D-20: Normalized Wing Rigidity Matrix

Normalized Wing Rigidity				
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design	Design Alternative Priorities{Pi}
Lighter Electrical components	0.11	0.02	0.45	0.20
LW-PLA Constructed parts	0.78	0.16	0.09	0.34
Improve Propeller design	0.11	0.81	0.45	0.46
Sum	1.00	1.00	1.00	

Table D-21: Consistency Check for Wing Rigidity

Consistency Check for Wing Rigidity		
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.71	0.20	3.59
1.81	0.34	5.26
2.38	0.46	5.17

Table D-22: Velocity Control Matrix

Velocity Control			
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design
Lighter Electrical components	1.00	5.00	7.00
LW-PLA Constructed parts	0.20	1.00	3.00
Improve Propeller design	0.14	0.33	1.00
Sum	1.34	6.33	11.00

Table D-23: Normalized Velocity Control Matrix

Normalized Velocity Control				
	Lighter Electrical components	LW-PLA Constructed parts	Improve Propeller design	Design Alternative Priorities{Pi}
Lighter Electrical components	0.74	0.79	0.64	0.72
LW-PLA Constructed parts	0.15	0.16	0.27	0.19
Improve Propeller design	0.11	0.05	0.09	0.08
Sum	1.00	1.00	1.00	

Table D-24: Consistency Check for Velocity Control

Consistency Check for Velocity Control		
Weighted Sum Vector	Criteria Weights	Consistency Vector
2.27	0.72	3.13
0.59	0.19	3.05
0.25	0.08	3.02

Table D-25: Consistency and Bias Check for All Individual Criteria

Consistency and Bias Check for All Individual Criteria				
	Average Consistency	Consistency Index	Consistency Ratio	Is Comparison Consistent
Overall Weight	3.000	0.000	0.000	yes
Endurance	3.138	0.069	0.133	no
Payload Weight	3.039	0.020	0.038	yes
Wing Rigidity	4.674	0.837	1.610	no
Velocity Control	3.066	0.033	0.063	yes

Table D-26: Final Rating Matrix

Final Rating Matrix			
	Lighter Electrical Components	LW-PLA constructed parts	Improve Propeller design
Overall Weight	0.20	0.60	0.20
Endurance	0.30	0.61	0.09
Payload Weight	0.11	0.63	0.26
Wing Rigidity	0.20	0.34	0.46
Velocity Control	0.72	0.19	0.08

Table D-27: Alternative Weight of Concepts

Alternative Weight of Concepts

Concepts	Alternative
Lighter Electrical components	**0.401**
LW-PLA Constructed parts	0.352
Improve Propeller design	0.242