Concept Selection:

Following concept generation and selecting five medium and three high fidelity designs, we moved forward to further analyze the designs to ultimately select the one best for our application and project. To do this, we performed multiple analysis and comparison tests. First we started by comparing all the engineering requirements of the designs we were moving forward with in a binary pairwise matrix to find how they are weighted against each other. Following that, we compared the engineering requirements in the house of quality to see how their raw scores compared to each other. From the raw scores, we ranked the engineering requirements to understand which requirements are the most critical to the design success. Pugh charts were then used to show which designs provide the best improvement or meet each engineering requirement the best and allowed us to narrow down the designs we moved forward with after concept generation so that we could perform the analytical hierarchy process. After moving through three iterations of Pugh charts and eliminating three out of the six concepts we moved forward with, we performed the AHP to find which design is best suited for this project.

House of Quality:

For house of quality, we started by finding the importance weight factor for each customer requirement. This was done using the Binary Pairwise Matrix below:

Binary Pairwise Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
1. Supports Needed Weight	-	1	1	0	1	0	0	**3**
2. Resists Plastic Deformation	0	-	0	1	0	0	0	**1**
3. Regulates Deflection Under Load	0	1	-	0	0	1	1	**3**
4. Combats All Aerodynamic Loads	1	0	1	-	1	1	1	**5**

5. Controls Airflow	0	1	1	0	-	1	0	**3**
6. Implementation Cost	1	1	0	0	0	-	0	**2**
7. Manufacturability	1	1	0	0	1	1	-	**4**
Total	3	5	3	1	3	4	2	

The binary pairwise comparison in Table 1 above resulted in weight factors of all the customer requirements ranked by importance. The customer requirements that have the greatest weight are ‘Combats All Aerodynamic Loads’, with the overall highest importance with a ranking of 5. Then ‘Manufacturability’ coming in as the second highest importance with a ranking of 4. These weighed the most because the hardtop needs to achieve both factors for Intrepid to be satisfied with our design. The second highest priority importance weight factors were ‘Controls Airflow,’ ‘Regulates Deflection Under Load,’ and ‘Supports Needed Weight.’ These three shared the same importance weight factor and all three are required in order to meet our customers' needs but they play a slightly less pivotal role than ‘Combats All Aerodynamic Loads’ and ‘Manufacturability.’ Controlling airflow, regulating deflection under load, and supporting the needed weight are all necessary functions to create a successful design, but are easier to achieve than airflow control and manufacturability. Therefore, these three are rated lower in the binary pairwise matrix, but still important. The requirements with the lowest importance weight factors are ‘Implementation Cost’ and ‘Resists Plastic Deformation’. Cost is important and if the design returns high improvements in some areas than cost increase can be justified. The hardtop must resist plastic deformation but if it can withstand all the forces and satisfy the previous customer requirements, then it shouldn’t plastically deform. Therefore, other requirements are rated higher than resisting plastic deformation because if they are achieved, they most likely account for deformation resistance as well.

Once the importance weight factors were determined, we constructed the House of Quality table below, translating our customer needs into engineering characteristics:

House of Quality

	Units	lbs.	(in/in) Unitless	inches	lbs	(L/D) Unitless	Dollars ($)
Customer Requirements	**IWF**	Load Bearing Capacity	Strain	Deflection	Hardtop Weight	Lift-to-Drag ratio	Cost
Supports Needed Weight	**3**	9	1	1			
Resists Plastic Deformation	**1**	3	9	1	3		
Regulates Deflection Under Load	**3**	3	1	9	3		
Combats All Aerodynamic Loads	**5**	3				3	
Controls Airflow	**2**					9	
Implementation Cost	**1**						9
Manufacturability	**4**				3		9
Raw Score	202	54	15	31	24	33	45
Relative Weight	-	26.7	7.4	15.4	11.9	16.3	22.3
Rank Order	-	1	6	4	5	3	2

The house of quality table is shown above. In this table, the engineering characteristics can be compared to the customer requirements found from functional decomposition on a 1, 3, 9 scale. A rating of 1 means that the characteristic and the customer requirement have a weak relationship, 3 means they have a medium relationship, and 9 means they have a strong relationship and impact on each other. The ranking was left blank if no relationship existed. The ranking order of each characteristic will help us when eliminating concepts from our medium and high-fidelity concepts and selecting the final design, showing which concepts meet the most requirements or create the best resulting boat performance.

Out of the 100 concepts generated earlier during concept generation, we highlighted three high fidelity concepts and five medium fidelity concepts. We further dwindled the list of concepts down to six concepts to move forward with and further analyze for selection, being:

1. Lightweight Hardtop- less dense fiberglass and resin usage.
2. Aerodynamic Hardtop- aerodynamic enhancements regarding lift-to-drag ratio.
3. Optimal Hardtop- FEA used to minimize material in low stress areas for light weighting.
4. Combination Hardtop- light weight, aerodynamic, and optimal changes implemented.
5. S-2 Glass Hardtop- S-2 glass and resin takes place of current fiberglass and resin.
6. High Lift Wing Hardtop- hardtop modeled as high lift wing.

Pugh Chart 1

		Concepts					
Selection Criteria	Existing Hardtop	1	2	3	4	5	6
Load Bearing Capacity	DATUM	+	-	S	S	-	S
Strain		S	-	+	-	-	-
Deflection		-	+	+	S	+	+
Hardtop Weight		+	+	+	S	S	+
Lift-to-Drag Ratio		S	+	+	+	+	-
Implementation Cost		S	S	S	s	-	-

Manufacturability		S	S	-	-	-	S
Number of +		**2**	**3**	**4**	**1**	**3**	**2**
Number of -		**1**	**2**	**2**	**2**	**4**	**3**

The first iteration of the Pugh Chart is shown above. This Pugh Chart uses the current hardtop as the datum and compares the new concepts with the current hardtop against our selection criteria. From this Pugh Chart we decided to not move forward with concepts 5 and concepts 6 because they had the most negatives. We did, however, decide to use concept 5 as our datum for the next Pugh Chart because it did have several pluses.

Pugh Chart 2

		Concepts			
Selection Criteria	Concept5	1	2	3	4
Load Bearing Capacity	DATUM	+	s	+	+
Strain		+	s	+	s
Deflection		-	s	s	-
Hardtop Weight		+	+	+	S
Lift-to-Drag Ratio		S	+	+	+
Implementation Cost		+	S	S	s
Manufacturability		+	+	s	-
Number of +		**5**	**4**	**4**	**2**
Number of -		**1**	**0**	**0**	**2**

The second iteration of the Pugh Chart shown above uses the fifth concept, using S-2 glass in place of current fiberglass, as the datum and compares the first 4 concepts. From this Pugh Chart we decided that we will move forward in our final Pugh chart with concepts 1,2 and 3. In the following Pugh Chart, we will use concept 4 as the datum. We decided to move forward with the fourth concept as the datum because it had the least number of pluses and the most minuses.

Pugh Chart 3

Selection Criteria	Concept 4	1	2	3
Load Bearing Capacity	DATUM	S	-	s
Strain		s	s	s
Deflection		s	s	s
Hardtop Weight		+	s	+
Lift-to-Drag Ratio		-	+	-
Implementation Cost		+	+	+
Manufacturability		+	+	+
Number of +		**3**	**3**	**3**
Number of -		**1**	**1**	**1**

For this final iteration of the Pugh Chart, we compared our first three designs against the fourth design. From this Pugh Chart we ended up with all three concepts having the same number of pluses and minuses. This will be taken into consideration when we begin our Analytical Hierarchy Process (AHP). All three designs had 3 pluses and one minus when compared with the fourth design datum.

Analytical Hierarchy Process:

Final Rating Matrix			
Selection Criteria	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
L.B.C.	0.1996	0.6008	0.1996
Strain	0.1996	0.6008	0.1996
Deflection	0.1996	0.6008	0.1996
Hardtop Weight	0.1429	0.7143	0.1429
L-D Ratio	0.7143	0.1429	0.1429

Overall Cost	0.0858	0.42929	0.42929
Manufacturability	0.1429	0.1429	0.7143

The table above shows the final rating matrix that the analytical hierarchy process allowed us to create. The complete analytical hierarchy process can be seen in the appendix. For load bearing capacity, strain and deflection, the optimized hardtop and the light weighted hardtop were the top performers for those selection criteria. The optimized and lightweight hardtops also performed best when it came to hardtop weight. This is because the aerodynamic hardtop does not directly address hardtop weight while both the optimized hardtop and lightweight hardtop designs do. However, the aerodynamic hardtop design may greatly increase the lift-to-drag ratio which is a major criterion that Intrepid wants focused on. For overall cost, the lightweight hardtop has the best rating because the other two require significant mold changes and tooling hours. For manufacturability the lightweight hardtop and the aerodynamic hardtop are deemed the most manufacturable because they share the most similarities to the current hardtop model so require less changes to be made.

The rating for each engineering characteristic were considered and through several matrix operations that can be seen in the appendix, alternative values were generated. These alternative values are shown below and played a pivotal role in selecting the design we chose to move forward with:

Concept	Alternative Value
Lightweight Hardtop	0.27235
Aerodynamic Hardtop	0.39712
Optimal Hardtop	0.31943

The alternative values table above shows which design best fits our selection criteria. From this we decided to move forward with a combination of the three because of how close the alternative values all were. While the aerodynamic hardtop has the highest alternative value, it is important to intrepid that we lightweight and optimize the hardtop as well. The most improvement will come from the aerodynamic properties of the hardtop but light weighting the hardtop is paramount to ensuring customer satisfaction. Given these alternative values and the ratings of our high fidelity designs, we have selected a final design.

Final Selection:

We wish to combine all three possible ways of improvement into one ideal design. The final design using the different methods above can be optimized for material minimization using FEA and mathematical methods, can be light weighted through different material usage, and aerodynamically enhanced through geometric or orientation changes. This design that could be crafted combining all designs mentioned in the AHP adequately fulfills both the engineering characteristics and the customer requirements and brings about the new model that will most improve the performance of the 409 Valor. This model will continue to be improved on during the iteration process. While not selected, we may still consider moving forward with the creation of 3 subset models for each individual characteristic of the combined ideal hardtop as well as with the ideal hardtop. We may consider creating full designs for just light weighting from material changes, aerodynamic enhancements from geometrical and orientation changes, and optimization through material minimization, so that there may be a plethora of design options at the end that may range in performance ability and cost.

APPENDIX:

AHP Rating Values

Rating Value	Relative weighting importance	Explanation of weighting

1	A and B have equal importance.	A and B both contribute equally to product success.
3	A is slightly more important than B.	A contributes slightly more to product success than B.
5	A is strongly more important than B.	A contributes strongly more than B to product success.
7	A is thought to be so very much more important than B.	A is very much more important to product success than B.
9	A is clearly demonstrated to be more important than B.	A is demonstrated with evidence to be more detrimental to product success than B.

Table A-2: AHP Rating Explanations

Analytical Hierarchy Process (AHP)

Criteria Comparison Matrix [C]

Criteria Comparison Matrix [C]							
	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost
Load Bearing Capacity	1	1	1	0.33	0.33	1	0.33
Strain	1	1	1	1	0.2	0.2	1
Deflection	1	1	1	1	1	0.33	1
Hardtop Weight	3	1	1	1	0.33	1	0.33
Lift-to-Drag Ratio	3	5	1	3	1	1	1
Implementation Cost	1	5	3	1	1	1	1
Manufacturability	3	1	1	3	1	1	1
Sum	13	15	9	10.33	4.867	5.53	5.67

Table A-3: Comparison Matrix of Engineering Characteristics

Normalized Criteria Comparison Matrix [NormC]								
	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost	Criteria Weights {W}
Load Bearing Capacity								
Strain								
Deflection								
Hardtop Weight								
Lift-to-Drag Ratio								
Implementation Cost								
Manufacturability								
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table A-4: Normalized Comparison Matrix of Engineering Characteristics

Normalized Criteria Comparison Matrix [NormC]								
	LBC	Strain	Deflection	Weight	L-D Ratio	Cost	Mfg. Cost	Criteria Weights {W}
LBC	0.07692308	0.06666667	0.11111111	0.03225806	0.06849315	0.18072289	0.05882353	0.08499978
Strain	0.07692308	0.06666667	0.11111111	0.09677419	0.04109589	0.03614458	0.17647059	0.08645516
Deflection	0.07692308	0.06666667	0.11111111	0.09677419	0.20547945	0.06024096	0.17647059	0.11338086
Hardtop Weight	0.23076923	0.06666667	0.11111111	0.09677419	0.06849315	0.18072289	0.05882353	0.1161944
L-D Ratio	0.23076923	0.33333333	0.11111111	0.29032258	0.20547945	0.18072289	0.17647059	0.2183156
Cost	0.07692308	0.33333333	0.33333333	0.09677419	0.20547945	0.18072289	0.17647059	0.20043384
Manufacturability	0.23076923	0.06666667	0.11111111	0.29032258	0.20547945	0.18072289	0.17647059	0.18022036
Sum:	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
1.048121	0.1056	9.925
2.691252	0.2544	10.579
2.224183	0.2193	10.142
1.520471	0.1137	13.372
1.250903	0.1151	10.868
0.579788	0.0543	10.677
1.706916	0.1671	10.215

Table A-5: Consistency Check Table for Engineering Characteristics

Average Consistency	7.78266
Consistency Index	0.13044
Consistency Ratio (<0.10)	0.09662

Table A-6: Consistency Calculations for Engineering Characteristics

Load Bearing Capacity Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.33	1
Aerodynamic Hardtop	3	1	3
Optimal Hardtop	1	0.33	1
Sum	5	1.66	5

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Load Bearing Capacity Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.2000	0.1988	0.2000	0.1996

Aerodynamic Hardtop	0.6000	0.6024	0.6000	0.6008
Optimal Hardtop	0.2000	0.1988	0.2000	0.1996
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Load Bearing Capacity Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.5975	0.1996	2.9933
1.7984	0.6008	2.9933
0.5975	0.1996	2.9933

Table A-9: Consistency Check Representative for All High Fidelity Designs

Consistency Ratio	<0.10
1- LBC	0
2- Strain	0
3- Deflection	0
4- Hardtop Weight	0
5- L-D Ratio	0
6- Implementation Cost	0
7- Manufacturability	0

Table A-10: Consistency Ratios of All High Fidelity Designs

Hardtop Weight AHP

Hardtop Weight Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.20	1
Aerodynamic Hardtop	5	1	5
Optimal Hardtop	1	0.20	1
Sum	7	1.4	7

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Hardtop Weight Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.1429	0.1429	0.1429	0.1429
Aerodynamic Hardtop	0.7143	0.7143	0.7143	0.7143
Optimal Hardtop	0.1429	0.1429	0.7143	0.1429
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Hardtop Weight Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.42857	0.1429	2,9991
1.7984	0.7143	2.9991
0.5975	0.1429	2.9991

Table A-9: Consistency Check Representative for All High Fidelity Designs

L-D Ratio AHP

L-D Ratio Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	5	5
Aerodynamic Hardtop	0.20	1	1
Optimal Hardtop	0.20	1	1
Sum	1.4	7	7

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized L-D Ratio Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}

Lightweight Hardtop	0.7143	0.7143	0.7143	0.7143
Aerodynamic Hardtop	0.1429	0.1429	0.1429	0.1429
Optimal Hardtop	0.1429	0.1429	0.1429	0.1429
Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

L-D Ratio Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
2.14287	0.7143	2.99996
0.42857	0.1429	2.9991
0.42857	0.1429	2.9991

Table A-9: Consistency Check Representative for All High Fidelity Designs

Implementation Cost AHP

Implementation Cost Comparison			
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop
Lightweight Hardtop	1	0.20	0.20
Aerodynamic Hardtop	5	1	1
Optimal Hardtop	5	1	1
Sum	11	2.4	2.4

Table A-7: Comparison Matrix Representative of All High Fidelity Designs

Normalized Implementation Cost Comparison				
	Lightweight Hardtop	Aerodynamic Hardtop	Optimal Hardtop	Design Alternative Priorities {Pi}
Lightweight Hardtop	0.0909	0.0833	0.0833	0.08585
Aerodynamic Hardtop	0.4545	0.4167	0.4167	0.42929
Optimal Hardtop	0.4545	0.4167	0.4167	0.42929

Sum	1.000	1.000	1.000	1.000

Table A-8: Normalized Comparison Matrix Representative for All High Fidelity Designs

Implementation Consistency Check		
Weighted Sum Vector	Criteria Weights {W}	Consistency Vector
0.257575	0.08585	3.000
1.287878	0.42929	3.000
1.287878	0.42929	3.000

Table A-9: Consistency Check Representative for All High Fidelity Designs

Criteria Comparison Matrix [C]

	Column	Column	Column	Column	Column	Column	Column
	1	1	1	0.333333	0.333333	1	0.333333
	1	1	1	1	0.2	0.2	1
	1	1	1	1	1	0.333333	1
	3	1	1	1	0.333333	1	0.333333
	3	5	1	3	1	1	1
	1	5	3	1	1	1	1
	3	1	1	3	1	1	1
Sum	**13**	**15**	**9**	**10.333**	**4.8667**	**5.5333**	**5.6667**

Consitency Check

WSM	{W}	Cons Vec
WSM	{W}	Cons V
0.656846	0.085	7.727625
0.665	0.086455	7.691854
0.866377	0.113381	7.641302
0.904309	0.116194	7.782724
1.748209	0.218316	8.007715
1.572582	0.200434	7.845893
1.402388	0.18022	7.78152

Consistency Calculations

Column	Column
Avg. Cons	7.782662

Column	Column
Cons Index	0.130444

Normalized Comparison Matrix [NormC]

Column	Column	Column	Column	Column	Column	Column	{W}
0.076923	0.066667	0.111111	0.032258	0.068493	0.180723	0.058824	0.085
0.076923	0.066667	0.111111	0.096774	0.041096	0.036145	0.176471	0.086455
0.076923	0.066667	0.111111	0.096774	0.205479	0.060241	0.176471	0.113381
0.230769	0.066667	0.111111	0.096774	0.068493	0.180723	0.058824	0.116194
0.230769	0.333333	0.111111	0.290323	0.205479	0.180723	0.176471	0.218316
0.076923	0.333333	0.333333	0.096774	0.205479	0.180723	0.176471	0.200434
0.230769	0.066667	0.111111	0.290323	0.205479	0.180723	0.176471	0.18022
1	1	1	1	1	1	1	1

Calculations

Column
7.782662

Column
0.130444

Column	Column
# elements	7

Column	Column
AHP for # e	1.35

Column	Column
Cons Ratio	0.096625

PART 2

Final Rating Matrix

Column	Column	Column
0.1996	0.6008	0.1996
0.1996	0.6008	0.1996
0.1996	0.6008	0.1996
0.1429	0.7143	0.1429
0.7143	0.1429	0.1429
0.0858	0.42929	0.42929
0.1429	0.1429	0.7143

Transpose Final Rating Matrix

0.1996	0.1996	0.1996	0.1429	0.7143	0.0858	0.1429
0.6008	0.6008	0.6008	0.7143	0.1429	0.42929	0.1429
0.1996	0.1996	0.1996	0.1429	0.1429	0.42929	0.7143

Alternative Value

Column	Column
Lightweigh	0.272351
Aero	0.397122
Optimal	0.31943

Table A-10: Excel Sheet Used for AHP Calculations of Engineering Requirements Against Designs