ME 611 Modern Product Design Final Project, Fall 2020

Hanna Anderson
School of Electrical Engineering and Computer Science
Oregon State University
Corvallis, Oregon
anderhan@oregonstate.edu

Vinson Guov
School of Electrical Engineering and Computer Science
Oregon State University
Corvallis, Oregon
guovv@oregonstate.edu

Delin Huang
School of Mechanical, Industrial, and Manufacturing Engineering
Oregon State University
Corvallis, Oregon
huandeli@oregonstate.edu

***Abstract*—Many rural and outlying communities lack the transportation methods to transport people and things to and from their location. To address this need, our design goal is to develop amphibious passenger airplane concepts that can achieve and meet the needs of potential customers. To create a viable product concept, we identified potential customer groups - gathering customer requirements and defining related engineering characteristics. From these customer requirements, we generated concept variations related to cabin design, landing gear, and propulsion via brainstorm/mind-mapping and creating a morphological matrix. Plausible full product concept solutions were then created and compared amongst each other using Pugh's Chart analysis and further analysis upon individual performance with a Decision matrix. The end result of the Decision matrix identified a concept variant, titled Hybrid 2, as the overall winning concept. The winning concept is a 20 passenger, mixed economy/business class seating, twin turboprop engine fixed-wing airplane with retractable tricycle landing gear and removable floats for amphibious operation.**

I. Introduction

A common problem faced by many rural and outlying communities today is the transportation of goods, services, and tourism to and from their inhabitance. Often times, these rural and hard to reach communities may not have normal tarmac runways but more commonly dirt, grass and gravel strips, as well as lakes, rivers and oceans. Our design mission is to create and refine concepts that could be sold as an amphibian passenger airplane capable of reaching these rural and outlying communities. In general, the amphibian passenger airplane concept must at least be capable of the following:

- Capable of taking off and landing from runways of dirt, grass, metal mat, gravel, asphalt, and concrete.
- Capable of taking off and landing from fresh and saltwater
- Capable of flight in hot air and icing conditions
- At least 5,000 lb of payload
- At least 500 nautical miles of range
- Visually appealing so it is easily marketable

To target the passenger aircraft market, the amphibian airplane concept must also meet the following criteria:

- At least two flight crew and one cabin crew
- At least 20 passengers with 28-32 inches of seat pitch
- Basic commodities for short range flights

To further ensure that the amphibian passenger airplane concept will later be successful on the market, potential customer groups will be identified. Customer requirements and correlating engineering characteristics related to each customer group will then be extracted, allowing existing market solutions to be benchmarked. From these customer requirements, the scope will then narrow to focus on a select few and related concept solutions will be generated from a variety of creative and rational techniques. Lastly, the generated concept solutions will be evaluated based upon a set of customer and technical criteria and compared against each other. The result of gathering requirements, generating potential concept solutions, and enacting a meticulous selection process will generate amphibious passenger airplane solutions that are ready for the next phase of product development.

The sections to follow will further examine Requirement Gathering (Section II), Concept Generation (Section III), and Concept Selection (Section IV) with respect to the amphibious passenger airplane design mission. Lastly, Section V, Concept Improvement, will analyze ways in which the resulting the final concepts could further be improved.

II. Requirement Gathering

Requirement gathering and market benchmarking are the foundational pillars of the concept development process that are best displayed in a House of Quality matrix (HoQ). The first step in determining specific requirements that the passenger airplane should achieve is to identify customer groups that would actually be interested in using the aircraft. This helps create a more realistic set of requirements to design the aircraft around. Brainstorming as a group, we determined there are five primary customers who would be interested in an amphibious passenger airplane:

A. Economy Class Passengers

Economy class passengers are likely to be focused on getting from location A to location B in the most cost-efficient way possible. Popular destinations include vacation spots, so passengers will have luggage to bring with them for their stay.

B. Business Class Passengers

Business class passengers expect a luxurious travel experience with the expectation of being able to perform basic work while they fly, which requires certain in-flight features to be available.

C. Charter Airlines

Due to the private and for-hire nature of charter airlines, use cases may vary more than a typical passenger airline. Functions may include hauling freight or landing at sub-optimal airstrips or small remote airports.

D. Corporations

Business jets are often used to transport executive employees to certain cities to discuss business with other corporate locations or with other organizations. They are interested in a business-oriented cabin with features that enable them to work while they fly.

E. Shuttle Services

Shuttle services are most likely looking for low ownership cost. This includes low initial airplane price, inexpensive maintenance and refueling, and fast turnaround time.

F. Flight Crews

Flight crews are looking to operate an aircraft that is easy to fly. Flight control automation has been known to reduce errors caused by the fatigue from repetitive tasks [8].

To identify potential customer needs, we researched each customer group and organized the resulting customer needs into an Affinity Diagram (Appendix A, Table VI). From the Affinity Diagram, the importance of each customer need could be extrapolated from the number of occurrences of each need throughout the Affinity Diagram.

Table I indicates how popular each of the customer needs is for the customer groups. To narrow our scope for further HoQ development, we reduced our focus down to the customer requirements that were prevalent for two or more customers. This allows us to focus on requirements that are important to the largest amount of people. The provided general requirements along with the additional requirements we generated are used in the HoQ, shown in Table II.

To prepare the customer requirements for being added to the HoQ, each requirement was assigned a weight on a scale of 1-5. The provided general requirements were given the highest weight because they are must-haves for the product whereas the remainder of the requirements were given weights

TABLE I: Prevalence of each Customer Requirement, Based on Affinity Diagram

Customer Requirements	Occurences	Relative Importance
Comfortable Cabin [1]	3	13.04%
Fast Cruising Speed	3	13.04%
WiFi Connectivity [2] [3]	2	8.70%
Restroom	2	8.70%
Disability Access [4]	2	8.70%
Luggage Capacity	2	8.70%
Refreshments [5]	1	4.35%
Quiet Cabin	1	4.35%
Spacious Cabin [1]	1	4.35%
Good Operational Versatility	1	4.35%
Low Cost Ownership [6]	3	13.04%
High Payload Capacity [7]	1	4.35%
Automated Flight Controls [8]	1	4.35%
	23	100.00%
	Total Occurrences	**Total Percentage**

associated with their popularity amongst the five customer groups identified earlier. The "Relative" weight in Table II is the distributed weight of each customer requirement - the weight given to each requirement with respect to the sum of all the requirements weights.

The final item required to complete an HoQ analysis is to benchmark existing products that are already on the market. The purpose of benchmarking is to quantify how well existing products meet the needs of the customer groups we are trying to reach. We selected the following four airplanes as competitor representatives: the Cessna Caravan [21], the Cessna Skycourier [10], the DHC-6 Twin Otter [22], and the Kodiak 100 Series II [23]. These aircraft were selected because they have similar form factors and features our concept should have. Based upon this benchmarking, the customer requirements that remain unaddressed by the competitor products are areas that our product could capitalize on. The full benchmarking analysis with supporting research can be found in Appendix B, Table VIII.

TABLE II: Customer Requirements

Weight (1-5)	Customer Requirement	Relative
5.0	Can take off and land from runways of dirt, grass, metal mat, gravel asphalt, and concrete	8.5
5.0	Can take off and land from fresh and saltwater	8.5
5.0	Can fly in hot air or icing conditions	8.5
5.0	At least 5000 lbs of payload	8.5
5.0	At least 500 nautical miles of range	8.5
3.0	Cabin Restroom	5.1
5.0	Two flight crew and one cabin crew	8.5
5.0	At least 20 passengers with 28-32" of seat pitch	8.5
4.0	Comfortable cabin	6.8
4.0	Fast cruise speed	6.8
3.0	WiFi Connectivity	5.1
3.0	Disability Access	5.1
3.0	Luggage Capacity	5.1
4.0	Low Cost of Ownership	6.8

The next step in gathering requirements is to determine related engineering characteristics that address the customer requirements. This was completed by brainstorming characteristics that would have an effect on the customer requirements. From this brainstorm, we narrowed down the list of possible engineering characteristics to those we thought had a strong correlation with the customer requirements and had some research backing (Table III). The original full list of the brainstormed engineering characteristics can be found in Appendix A, Table VII. Each of the engineering characteristics in Table III was then researched to determine realistic and achievable target values. Based upon the gathered customer requirements, engineering characteristics, target values, and competitor benchmarking, and HoQ chart was created and can be found in Appendix A.

TABLE III: Engineering Requirements and Target Values

	Engineering Requirements	Target Values	Improvement Direction
1	Seat Pitch [9]	30 inches	+
2	Total Engine Power [10]	3000 SHP	+
3	Max Download Speed [11]	10 Mbps	+
4	Water Capacity [12]	20 Gallons	=
5	Seat Width [13]	20 inches	=
6	Overhead bin volume [14] per passenger	3000 in	=
7	Ground Roll [10]	3000 ft	-
8	Total Float Buoyancy [15]	180% of takeoff weight	=
9	Weather Radar Range [16]	80 miles	=
10	Fuel Tank Capacity	450 gallons	+
11	Total 120VAC Passenger-accessible Power [17]	1600 W	=
12	Maximum Reclining Angle (Thigh-body) [18]	135 degrees	=
13	Cabin Altitude (Pressure) [19]	7000 ft	-
14	Relative Humidity [19]	20%	+
15	Percentage of Window Seats [20]	50%	=

G. HoQ Discussion

From the House of Quality, we conclude that "total engine power" has the highest weights among all the engineering requirements. It is weighted heavily among all the engineering requirements (11.9 out of 100) because it has strong relationship with many demanded qualities such as "at least 5000 lbs of payload", "fast cruise speed", and "low cost of ownership". Naturally, greater total power provides more thrust and thus speed. As a result, the airplane can carry more payload or passengers. However, the higher-power engine will be more expensive, so it depends on customers' needs and purpose. The ownership cost of an aircraft greatly depends on the cost of the power plant. For our amphibious airplane, the target total engine power is 3000 shaft horsepower. This was obtained as a minimum value based on competitor airplane research.

On the other hand, "percentage of window seats" has the lowest weights among all the engineering requirements. The only related demanded qualities are "at least 20 passengers with 28-32 inches of seat pitch", "comfortable cabin", and "luggage capacity". Depending on the cabin layout, the percentage of total seats next to a window will vary. It is possible that there are seats between window seats for space efficiency. Seats next to windows definitely provide passengers a more enjoyable experience while they are on-board, so high percentage of window seats means more passengers can benefit. Therefore, we are targeting our amphibious airplane to have at least 50 percent of all seats next to a window.

For the competition benchmarking portion of the HoQ, it is worth mentioning some observations from the ratings we gave each competitor aircraft. Customer requirements, "Restroom" and "WiFi connectivity" were features that were not available on all of our competitor airplanes. However, all the competitor airplanes excelled in customer requirement, "at least 500 nautical miles of range." This indicates the competing amphibian utility airplanes we considered in our HoQ are lacking in passenger amenities but are highly optimized for utility, where range is a factor that greatly influences the versatility of such an aircraft. The poses an opportunity to market our aircraft as more passenger-centric yet still providing the utility benefits from its amphibious nature.

III. Concept Generation

After gathering the customer requirements, the concept development process generates potential solutions that address our customer requirements. To narrow the scope of our development work, our group decided to focus on three higher level design aspects for the amphibious passenger airplane: Cabin design, Landing gear, and the Propulsion system. These three design aspects were chosen based on their importance to the overall design goal, creating an amphibious passenger airplane. The cabin design encapsulates the "passenger airplane" aspect. Passengers will spend a great deal of time inside the cabin of the airplane, making the cabin experience an important design consideration. Landing gear is important for the "amphibious" component. Ultimately this aircraft should be able to land on water or ground, so the landing gear versatility and durability are important. Lastly, the propulsion system is a key component of an airplane that allows it to fly in the air. Without propulsion, we have no airplane.

To generate possible solutions for these design aspects, we utilized a combination of creative and rational concept generation methods:

- Brainstorming / Mind-mapping (*Creative*)
- 6-3-5 Brainwriting / C-sketch (*Creative*)
- Morphological Matrix (*Rational*)

These three methods were selected based upon their quality and quantity of concepts produced. Brainstorming and mind-mapping allow for quick generation creation, while C-sketch gives concepts an actual physical form. Morphological analysis then arranges possible solutions side by side for better evaluation for full product solutions. While TRIZ and Biomimetics are useful for concept generation in general, the types of concepts they generate do not fit the large-scale needs of this design challenge.

The full detailed results of each of the concept generation methods can be found in Appendix B.

A. Mind-mapping

Generating the mind-maps was a collaborative brainstorm effort, referencing prior and recently acquired knowledge related to each of the higher level design aspects. Most ideas were pulled from each group member's previous assignments in combination with new ideas based off of further concept research. A mind-map was created for each of the three design aspects, with themes grouping similar ideas together. The specific lower-level ideas stem off of the broad level theme until each focus area had a plethora of solutions that could be mixed and matched in the upcoming concept selection process. See Appendix B, Figures 8, 9, and 10.

B. C-Sketch

The C-sketch designs were created by utilizing a Google Jamboard, each group member creating an initial two-minute sketch for one of the three high-level design aspects, then adding two-minutes worth of detail to the other two design aspects with the goal of adding more detail in each iteration. The end result was a descriptive sketch for each of the high-level design aspects with collaboration from all group members.

C. Morphological Matrix

The morphological matrix helped us envision specific concept alternatives for each of the high-level design aspects. Many of the elements were referenced from the ideas generated from our brainstormed mind-map. A functional decomposition was performed on the passenger's experience to highlight the key interactions made by a passenger during a flight trip, seen in Appendix B, Figure 14. The design of the interior of a cabin can be quite complex, so it was broken down into several major components: restroom location, # of economy and business class seats, the crew seat location, the door location, and the respective layout's size. This allowed us to create several comparable layouts, found in Appendix B, Figure 16. The cabin layout specifics are highlighted in Appendix B, Table X.

Landing gear is also complex in nature, requiring many interconnected parts in order to achieve its function. We also performed function decomposition on the landing gear to understand what subfunctions are required to land an aircraft, as seen in Appendix B, Figure 15. We discovered from the decomposition that in order to accurately depict a landing gear system, we had to break down the landing gear into smaller subfunctions; steering, surface contact, and braking, where each alternative concept has a solution for each of these subfunctions. The resulting morphological matrix can be found in Appendix B, Table IX.

D. Concept Generation Discussion

Most of the additional work required for concept generation emphasizes cabin design and layout. Two of our group members had thoroughly investigated landing systems and propulsion systems in previous assignments, allowing us to spend most of our collective time creating and defining potential cabin layouts. Our decision to focus on the cabin layout is due to the fundamental motivation behind the concept, which is to transport passengers between locations safely and comfortably. In other words, the passenger experience is our priority.

Further defining the cabin layouts into sub-components is important for later concept selection. Many of the customer requirements and evaluation criteria rely on the cabin layout, such as Disability Access, Luggage Capacity, and Restrooms. Creating representative cabin layouts is necessary to understand the underlying dependencies of our cabin subcomponents.

IV. Concept Selection

Having generated concepts for each of the selected high-level focus areas, combinations of the concepts can be brought together to form full product solution variants. The morphological matrix from the concept generation process provided a list of options for each design aspect that we combined to create six airplane concept variants. Below are the concept details for each concept that will be evaluated. Each concept variant is defined by a cabin layout, type of landing gear, and type of propulsion system.

Concept 1
- Cabin layout 1
- Tricycle
- Turbojet

Concept 2
- Cabin layout 1
- Quadricycle
- Turboprop

Concept 3
- Cabin layout 2
- Multi-bogie
- Turbofan

Concept 4
- Cabin layout 4
- Taildragger
- Turboprop

Concept 5
- Cabin layout 3
- Floats
- Rocket engine

Concept 6
- Cabin layout 1
- Multi-bogie
- Turboprop

Concept 6 was chosen as our baseline and Datum for concept selection analysis due to its conventional blend of design. Pugh chart analysis will help identify which concepts are overall better or worse than the chosen baseline. For the evaluation criteria, we chose to use all of the customer requirements from the HoQ with the corresponding weights. Thus, the Pugh chart analysis we perform will reflect how well each concept responds to the customer requirements.

Each concept was then given a - -, -, 0, +, or ++ based upon how better or worse it was compared to the Datum concept. While some of the evaluation criteria was very specific, others were ambiguous and needed further refinement in order to adequately judge each concept. Below is brief explanation of the components that were examined for the ambiguous criterion.

- **Disability Access:** Based on the ease of accessing one's passenger seat, the restroom, and cabin entrance/exit. This depends on distance between restroom and seat, as well as distance from seat to cabin entrance/exit.

- **Luggage Capacity:** Since most of the luggage capacity is available in overhead bins or underneath seating, luggage capacity depends on overall cabin volume which is determined by fuselage cross section area and fuselage length. The longer the fuselage, the wider each overhead bin can be.
- **Comfortable Cabin:** Based on number of restrooms, number of business class seats (the larger of the seat options), and separation of business and economy class seating.
- **Low Cost of Ownership:** Based on the number of business class seats (higher-quality), and type of engine/propulsion system. The number of restrooms also increases the cost.

Two iterations of a Pugh Chart were performed. The first Pugh Chart contains the six concepts described earlier, see Appendix C, Figure 17. From looking at the weighted totals, Concepts 1, 4, and 5 were similar in total value and very close to 0, indicating that these three concepts are very similar to the Datum concept (Concept 6) based upon the evaluation criteria.

To further distinguish results based upon the key features associated with these "winning" concepts, a second Pugh chart was created. The second Pugh chart (Appendix C, Figure 18), highlights the winning concepts (Concepts 1, 4, and 5) from the previous Pugh chart, as well as two hybrids that are based off of the features from the winning concepts. The details of the two hybrid concepts are below:

- **Hybrid 1:** Cabin layout 1, floats, turbojet propulsion
- **Hybrid 2:** Cabin layout 4, floats and tricycle landing gear, turboprop propulsion

After evaluating Concepts 1, 4, 5, Hybrid 1, and 2 against the Datum, Hybrid 1,2 and Concept 5 came out as the front runners for the Pugh Chart analysis.

The next step in the concept selection process is to further examine the individual performance of the top ranking concepts. Hybrids 1 and 2, along with Concept 5 are entered into a Decision matrix. The Decision matrix utilizes the same evaluation criteria and same weights as designated in the Pugh Chart and in the HoQ to maintain evaluation consistency. Each concept is given an individual raw rating based upon how well the concept addresses or fits the evaluation criteria. Based up on the assigned raw scores and the relative weight of each of the criteria, the associated relative scores are summed and a total is calculated for each concept. The completed Decision matrix is located in Appendix C, Figure 19. Table IV highlights the results of the Decision matrix.

TABLE IV: 1st Decision Matrix Results

	Alternatives		
	Hybrid 1	Hybrid 2	Concept 5
Total	63.08	68.08	59.17
Relative Rank	2	1	3

Because the totals were similar for each of the concept variants, a second Decision matrix was created but with modifications. In the first Decision matrix, all three of the concepts scored very similar for five of the fourteen evaluation criteria: ability to fly in hot/icy conditions, two flight and one cabin crew member, able to seat at least 20 passengers, WiFi connectivity, and luggage capacity. This is because the concepts are well-defined for the focus areas we chose in the concept generation process, but are not well defined against requirements that are distantly related to the concept focus areas. For the second Decision matrix, we removed these evaluation criteria. As a result, relative weights of the other requirements/criteria increased, creating greater disparity amongst the respective variant totals (see Table V).

TABLE V: 2nd Decision Matrix Results

	Alternatives		
	Hybrid 1	Hybrid 2	Concept 5
Total	57.76	65.66	51.32
Relative Rank	2	1	3

The final winner after completing several passes through Pugh's Chart and Decision matrix was the Hybrid 2 concept, defined by cabin layout 4, retractable float/tricycle landing gear, and a turboprop propulsion system.

A. *Concept Selection Result*

Our final winning concept Hybrid 2 has the following features:

1) Cabin: The cabin layout is depicted in our CAD model, see Figure 5. The cabin consists of a single walkway with seats on both sides, offering a majority of its passengers a window seat. There are a total of 14 economy seats and 6 business seats. In the rear half of the cabin, on one side of the walkway there are two economy seats side-by-side. For our chosen fuselage width, this allows for increased passenger density, lowering the flight cost per passenger. The economy seat pitch is 30 inches and the seat width is 20 inches. This is aligned with the average seat dimensions of major airlines. On the front half of the cabin, we have our business seats. Our business class seat width and pitch also closely match the industry averages for short-haul business class flights, at 40 inches pitch and 20 inches width [9]. Overall the cabin is 57 feet long.

Although the application of our airplane is short-medium haul, we want to provide our passengers with an experience that closely matches the experience provided by longer flights in larger airliners. Our cabin features a restroom in the middle of the cabin that provides a toilet and sink. Many of our competitors do not have an in-flight bathroom due to their short-haul nature but we believe it provides a reassurance to passengers from when they board our airplane to when they step off our airplane. We also focused on the need of having internet access during flight. The world is increasingly dependent on the internet. Many workplaces and schools now store their files in the cloud, which requires internet access to retrieve those files. Without internet, our passengers would not be able to work, study, or play to keep themselves occupied on a long flight.

2) Propulsion: The propulsion system for Hybrid 2 includes twin turboprop engines residing on the wings of the airplane, where the wings are mounted on the top side of the fuselage. The turboprop engines are power-efficient [36] and cost-efficient, giving the Hybrid 2 concept an edge for the "Low Cost of Ownership" criteria. While the fast cruise speed is lower than the other two propulsion types, the turboprop engines assist with Hybrid 2's ability to reach 500 nautical miles. The turboprop engine was also the best choice because it allowed for a smoother ride for the passengers compared to other propulsion systems such as the rocket engine, which would cause uncomfortable acceleration during liftoff.

3) Landing Gear: The landing gear is a retractable tricycle wheel system along with detachable wingtip floats for when amphibious operation is not needed. By using retractable and detachable landing components, the destinations are only limited to your imagination, and your fuel tank.

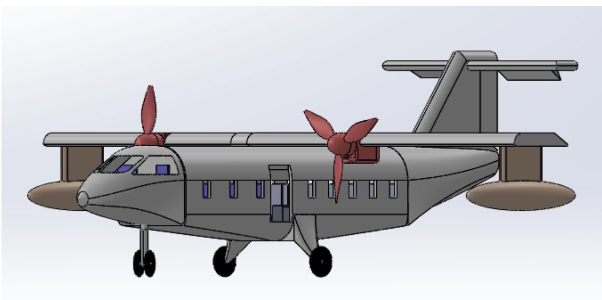


Fig. 1: Hybrid 2 Concept - Front View

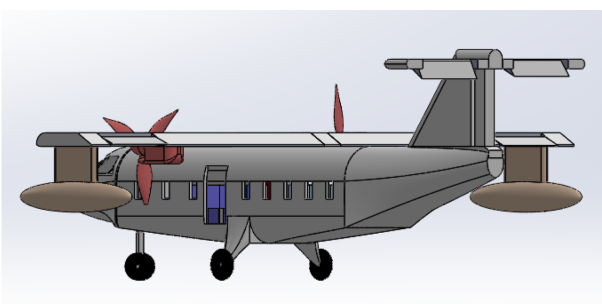


Fig. 2: Hybrid 2 Concept - Back View

V. Concept Improvement

From the concept selection phase, a clear front-runner was established: Hybrid concept 2. Even though this concept has been established as a "good" concept with respect to a baseline variant and based upon individual performance, there is still room for improvement. To further identify possible changes that could enable the front-runner concept to become even better, we utilized TRIZ. Earlier in the development process, we determined that the cabin experience was very important for a passenger-centric airplane. Consequently, the cabin was our primary focus for using TRIZ to identify opportunities for improvements. Normally TRIZ is used during the Concept Generation phase. However, we decided to implement TRIZ after the concept selection process to allow for more fine tuning and optimization of our concept. We wanted to first narrow down to the "best" cabin layout, then see if it could be improved further.The key contradictions and potential solutions we identified can be found in Appendix D, Table XI.

One of the more realizable solutions that came from this analysis was the use of standing seats for each of the passengers within the cabin via the "Parameter Changes" solution.

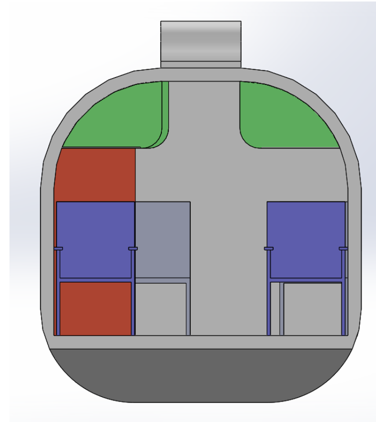


Fig. 3: Hybrid 2 Concept - Fuselage Cross Section

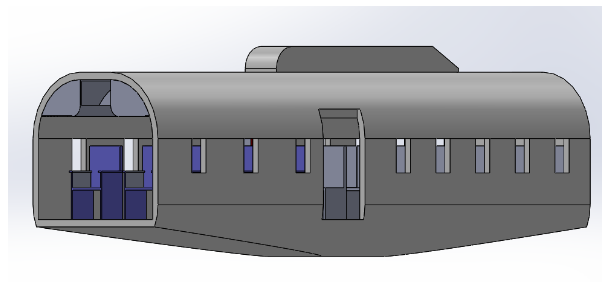


Fig. 4: Hybrid 2 Concept - Fuselage

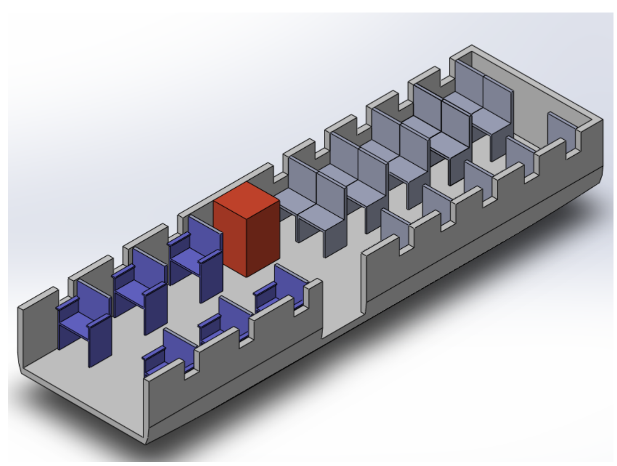


Fig. 5: Hybrid 2 Concept - Top View

This solution was proposed by trying to improve the weight of a stationary object (reduce the material of the cabin) while preserving the volume of stationary (maintaining the same cabin size). Another realizable solution for this contradiction is the use of removable seats. When the airplane is not at full-capacity for a flight, the unoccupied seats could be removed.

When looking to reduce the cabin weight (weight of stationary) and maintaining cabin integrity (preserving strength), TRIZ suggests using Cheap Short-lived Objects. In application for the cabin this could take the form of using disposable seat covers. Disposable seat covers have the benefit of protecting the original seat upholstery from wear and damage. This allows us to design a seat that is more optimized for comfort, but lacks durability features that its cushioning abilities. The durability is instead offered by the seat cover which is a consumable item that can be replaced if worn out.

Adding these fine details to the front-runner concept (Hybrid 2) creates a concept that is ready for the next stage in the concept development process, where the design meets reality.

Fig. 6: Concept Improvement - Standing Seats [30]

Fig. 7: Concept Improvement - Seat Cover [32]

VI. Conclusion

The goal of designing an amphibious passenger airplane started by using the methods we learned in this course to generate a concept that is based on competing interests and available technologies. The application of Quality Functional Deployment yielded a better understanding of our customer's needs. The House of Quality along with functional decomposition helped us determine the relationships between customer demands and engineering specifications. With the discovery that a few key components of our aircraft design largely influence our ability to meet those demands, we generated concepts using both irrational and rational methods as a team with those components as focus areas. Then we scored each generated concept variant with the application of Pugh's matrix and decision matrix with weighted objectives to determine the best concept that will meet our customer needs the best. For further detailing of our concept, TRIZ was used not in the concept generation phase, but after the concept selection phase to further optimize our winning concept before it is embodied in the next stage of product design. The concept development process (requirement gathering, concept generation, and concept selection) proved to be a robust means of delivering a concept.

Appendix A
Requirement Generation

TABLE VI: Affinity Diagram to Identify Customer Requirements

	Customers					
	Economy Class	**Business Class**	**Charter Airlines**	**Corporations**	**Shuttle Service**	**Flight Crew**
Customer Needs	Comfortable Cabin [1]	Comfortable Cabin [1]	Good Operational Versatility	Comfortable Cabin [1]	Low Cost of Ownership [6]	Automated Flight Controls
	Fast Cruising Speed	Fast Cruising Speed	Low Cost of Ownership [6]	Fast Cruising Speed		
	WiFi Connectivity [2] [3]	WiFi Connectivity [2] [3]	High Payload Capacity [7]	Low Cost of Ownership [6]		
	Restroom	Restroom				
	Disability Access [4]	Refreshments [5]				
	Luggage Capacity	Quiet Cabin				
		Spacious Cabin				
		Disability Access [4]				
		Luggage Capacity				

TABLE VII: Brainstormed Engineering Requirements with associated Customer Requirements

Customer Requirement	Engineering Requirement	Direction of Improvement
Comfortable Cabin	Recline Angle (body-thigh)	=
	Cabin Altitude	-
	Temperature	=
	Noise	-
	Humidity	+
	Seat Width	+
	Seat Pitch	+
	Total Passenger AC Power	-
Fast Cruising Speed	Total Engine Power	+
	Cruising Speed	+
WiFi Connectivity	Max Download Speed	+
	# of devices allowed on network	+
Restroom	Restroom size	+
	Water capacity	+
Disability Access	Width of doors/walkways	+
	Seat Width	+
Luggage Capacity	Carry-on Luggage Volume per Passenger	=
	Size of Underseat Area	+
Can take off and land from runways of dirt, grass, metal mat, gravel, asphalt, and concrete	Ground Roll	-
Can take off and land from fresh and saltwater	Total Float Buoyancy	=
Can fly in hot air or icing conditions	Weather Radar Range	=
At least 5000 lbs of payload	Power	+
At least 500 nautical miles of range	Fuel Tank Capacity	+

TABLE VIII: Benchmarking Competitor Products for HoQ

Customer Requirements	Cessna Caravan [21]		Cessna Skycourier [10]		DHC-6 Twin Otter [22]		Kodiak 100 Series II [23]	
	Researched Info	**Score (1-5)**	**Researched Info**	**Score (1-5)**	**Researched Info**	**Score (1-5)**	**Researched Info**	**Score (1-5)**
Can take off and land from runways of dirt, grass, metal mat, gravel asphalt, and concrete	Rough-field tires (handles grass, graven and rudimentary runways) Landing Ground Roll: 715 ft Takeoff Ground Roll: 1,160 ft	4	"rugged landing gear for use on unimproved airstrips" Runway Length: 3,300 ft	2	Takeoff Distance: 1,200 ft Landing Distance: 1,050 ft	3	Takeoff Ground Roll: 934 ft Landing Ground Roll: 765 ft	4
Can take off and land from fresh and saltwater	Water Takeoff: 2,341ft	3	N/A	2	Floats/Skis	3	Floats/Skis	3
Can fly in hot air or icing conditions	Garmin GSR-56 satellite data link, weather services	3	Optional Weather Radar	3	WX Weather Radar System	3	WX Weather Radar System	3
At least 5000 lbs of payload	3,305 lbs	2	5,000 lbs (passenger variant) 6,000 lbs (freight variant)	3	3,031 lbs	2	3,500 lbs	2
At least 500 nautical miles of range	1,070 nm max	5	900 nm max	5	763 nm max	4	1005 nm max	5
Restroom	N/A	1	N/A	1	N/A	1	N/A	1
Two flight crew and one cabin crew	Two flight crew, no cabin crew	2	Two flight crew, no cabin crew	2	Two flight crew, no cabin crew	2	Two flight crew, no cabin crew	2
At least 20 passengers with 28-32 inches of seat pitch	10-14 passengers	2	19 passengers	3	19 passengers	3	8 passengers	1
Comfortable cabin	Cabin Height: 4 ft 6 in Cabin Width: 5 ft 4 in	3	Economy seating	3	Cabin Height: 4 ft 11 in Cabin Width: 5 ft 9 in	4	Multiple Premium Interior Configurations	4
Fast cruise speed	186 ktas	4	200 ktas	5	182 ktas	4	183 ktas	4
WiFi Connectivity	N/A	1	N/A	1	N/A	1	N/A	1
Disability Access	Wide loading doors	3	87" x 69" cargo door	4	Left Cabin Door Width: 4 ft 8 in Left Cabin Door Height: 4 ft 2 in	3	Cargo Door Width: 4 ft 1 in Cargo Door Height: 4 ft 1 in	2
Luggage Capacity	Land: 325 lbs, 31.5 cubic feet Water: 925 lbs	3	overhead and under seat storage	4	With passengers: 785 lbs Front and back storage	4	With 8 passenger and full fuel: 3,300 lbs	3
Low Cost of Ownership	$1.6 million [24]	5	$5.5 million [25]	3	$6.5 million [26]	2	$2.36 million [27]	5

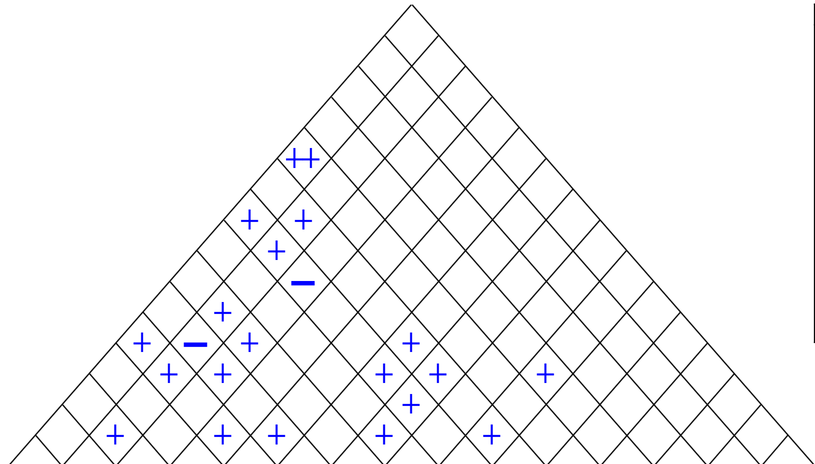
Title: Passenger Aircraft

Author: Delin Huang, Hanna Anderson, Vinson Guov

Date:

Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	x	x	x	▼	x	x	▲	x	x	▼	▲	x	▲	**Competitive Analysis** (0=Worst, 5=Best)			
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	**Quality Characteristics** (a.k.a. "Hows") / **Demanded Quality** (a.k.a. "Whats")	Seat Pitch	Total Engine power	Water Capacity	Seat Width	Carry-on Luggage Volume per Passenger	Ground Roll	Total Float Buoyancy	Weather Radar Range	Fuel Tank Capacity	Total Passenger AC Power	Min. Seat Recline Angle (Thigh-Body)	Cabin Altitude (Pressure)	Cabin Relative Humidity	Percentage of Window Seats	Max. Download Speed	Cessna Caravan	Cessna Skycourier	DHC-6 Twin Otter	Kodiak 100 Series II
1	9	8.5	5.0	Can take off and land from runways of dirt, grass, metal mat, gravel asphalt, and concrete		O	▲		▲	Θ			O							4	2	3	4
2	9	8.5	5.0	Can take off and land from fresh and saltwater		O	▲		▲	Θ	Θ		O							3	2	3	3
3	9	8.5	5.0	Can fly in hot air or icing conditions		O				O		Θ	O				O			3	3	3	3
4	9	8.5	5.0	At least 5000 lbs of payload		Θ	O	▲	O	Θ	Θ		Θ	▲						3	3	2	2
5	9	8.5	5.0	At least 500 nautical miles of range		▲	▲		O				Θ	▲		Θ				5	5	4	5
6	9	5.1	3.0	Restroom	▲		Θ			O	O									1	1	1	1
7	3	8.5	5.0	Two flight crew and one cabin crew	O			O												2	2	2	2
8	9	8.5	5.0	At least 20 passengers with 28-32 inches of seat pitch	Θ	O	Θ	O		O	Θ		O	Θ	O			▲		2	3	3	1
9	9	6.8	4.0	Comfortable cabin	Θ	O	O	Θ	Θ	▲			▲	O	Θ	Θ	Θ	Θ	O	3	3	4	4
10	9	6.8	4.0	Fast cruise speed		Θ	O		▲		▲	O	O							4	5	4	4
11	9	5.1	3.0	WiFi Connectivity															Θ	1	1	1	1
12	9	5.1	3.0	Disability Access	Θ			Θ	O					▲	▲	▲	▲			3	4	3	2
13	9	5.1	3.0	Luggage Capacity	O	O	▲	O	Θ	O	O		O					▲		3	4	4	3
14	9	6.8	4.0	Low Cost of Ownership		Θ	O			▲	O	O	O	O		O	O		O	5	3	2	5
15																							

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value	30 inches	3000 SHP	20 gallons	20 inches	3000 cubic inches	3,000 feet	180% Takeoff Weight	80 miles	450 gallons	1600 Watts	120 degrees	7,000 feet	20%	50%	10 Mbps
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	8	6	7	7	9	6	7	7	6	5	8	9	6	4
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Weight / Importance	228.8	344.1	239.0	181.4	196.6	323.7	286.4	116.9	316.9	139.0	91.5	162.7	111.9	74.6	86.4
Relative Weight	7.9	11.9	8.2	6.3	6.8	11.2	9.9	4.0	10.9	4.8	3.2	5.6	3.9	2.6	3.0

Appendix B
Concept Generation

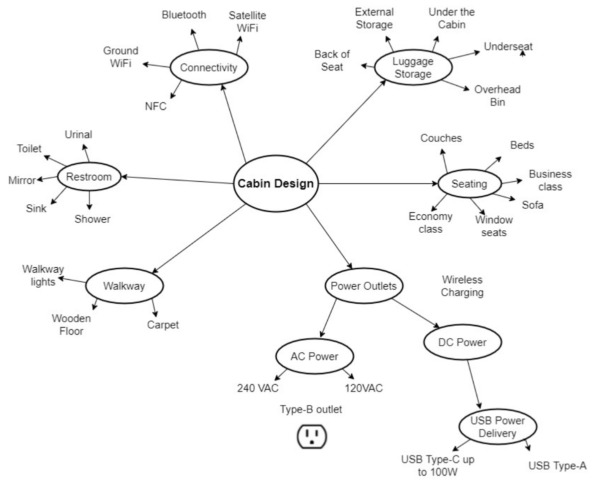


Fig. 8: Brainstorm/Mind-map of Cabin Design

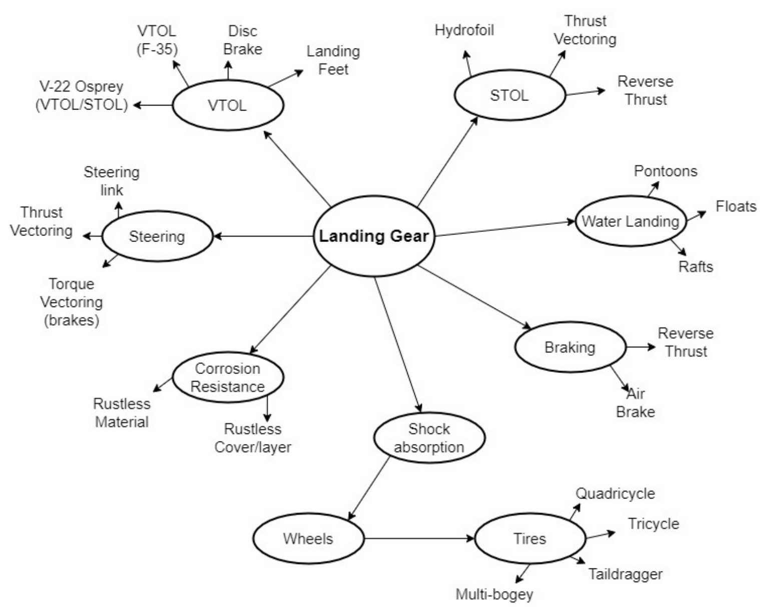


Fig. 9: Brainstorm/Mind-map of Landing Gear

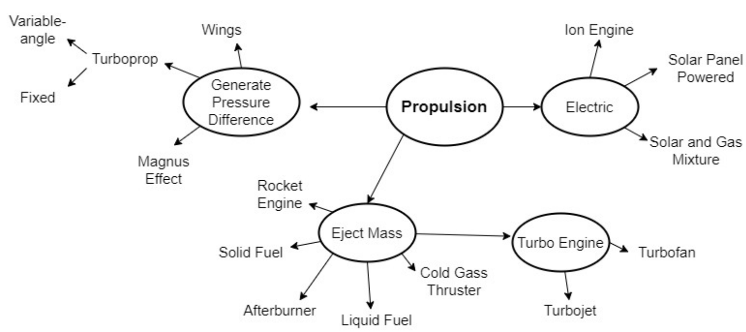
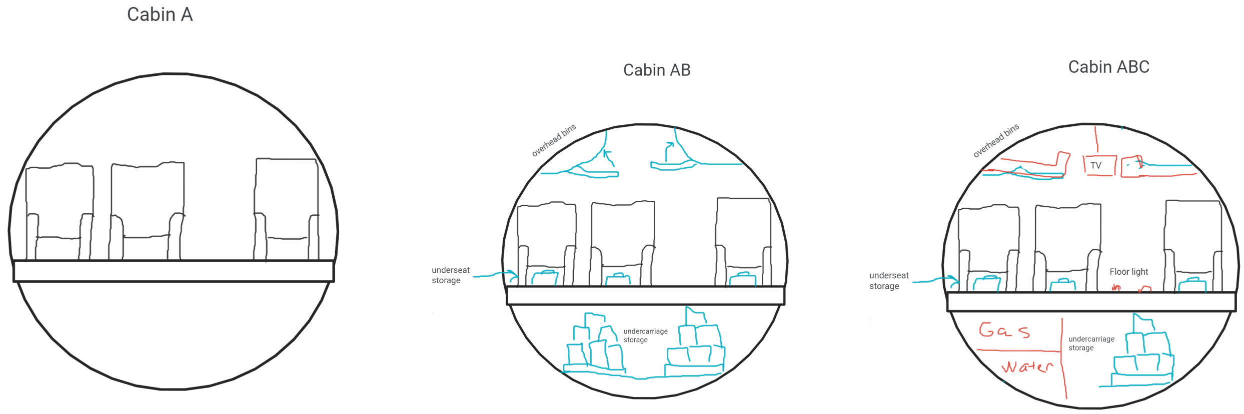
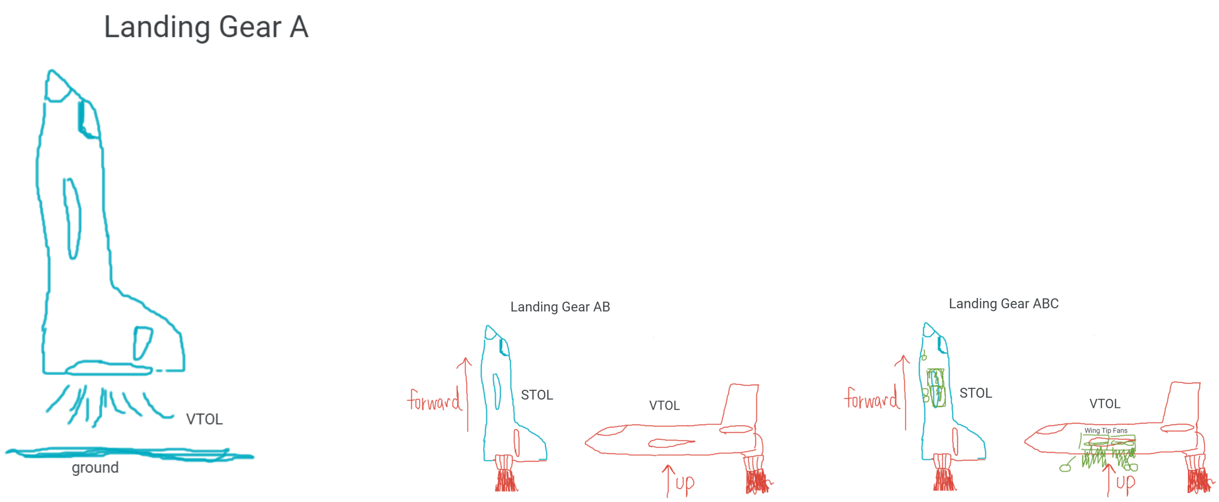


Fig. 10: Brainstorm/Mind-map of Propulsion



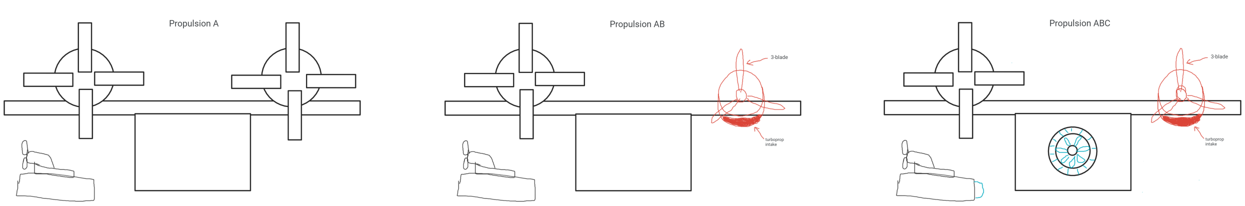
(a) Cabin - A (b) Cabin - AB (c) Cabin - ABC

Fig. 11: C-sketch: Cabin design



(a) Landing Gear - A (b) Landing Gear - AB (c) Landing Gear- ABC

Fig. 12: C-sketch: Landing Gear



(a) Propulsion - A (b) Propulsion - AB (c) Propulsion - ABC

Fig. 13: C-sketch: Propulsion Systems

TABLE IX: Morphological Matrix

		Alternative Concepts					
Subfunction		**1**	**2**	**3**	**4**	**5**	**6**
Cabin		Layout 1	Layout 2	Layout 3	Layout 4		
Landing Gear	Steering	Steering Link	Thrust Vectoring	Flaps/Rudder	Brake Vectoring		
	Surface Contact	Floats/Pontoons	Taildragger	Multi-bogie	Tricycle	Quadricycle	Feet
	Braking	Disc Brakes	Drum Brakes	Air Brake (Flaps)	Reverse Thrust	Parachute	
Propulsion		Turbojet	Turbofan	Turboprop	Helicopter Rotor	Rocket engine	

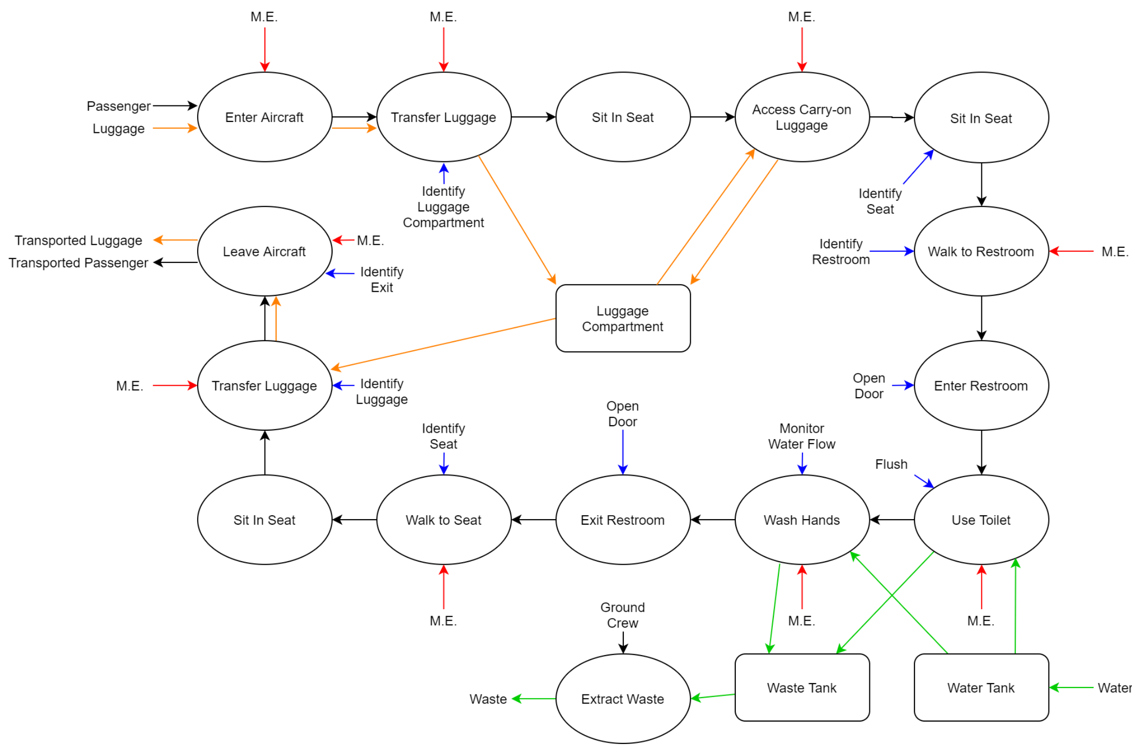


Fig. 14: Passenger Functional Decomposition

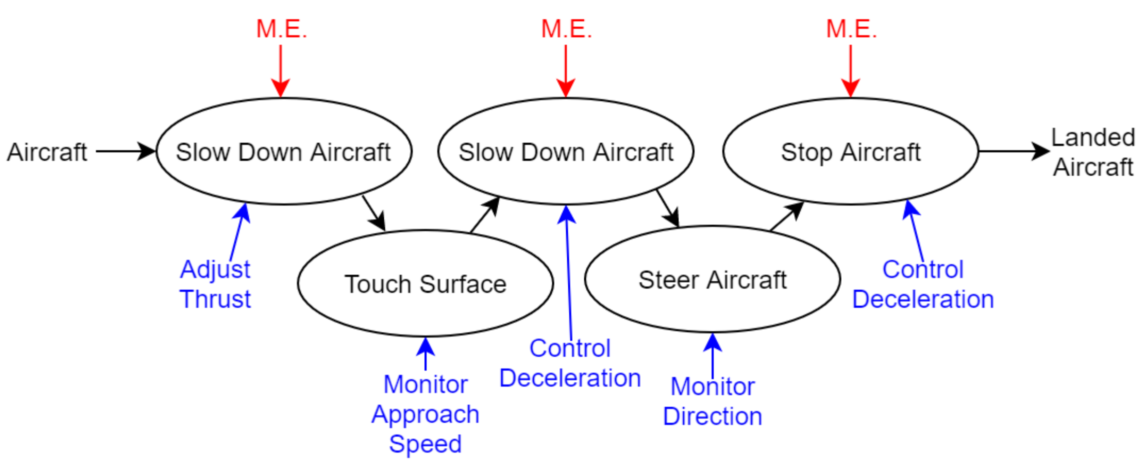


Fig. 15: Landing Functional Decomposition

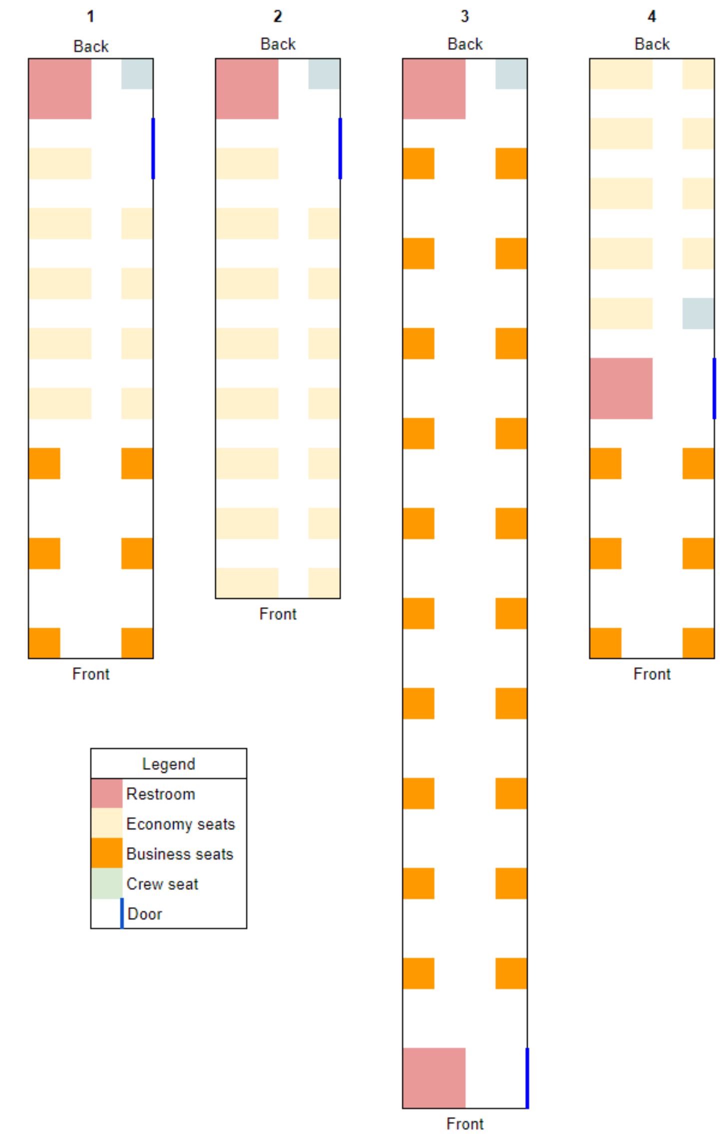


Fig. 16: Cabin Layouts

TABLE X: Cabin Layout Configurations

	Cabin Concepts			
	1	2	3	4
Restrooms Location	Front (1)	Front (1)	Front/Rear (2)	Middle (1)
# of Economy Seats	14	23	0	14
# of Business Seats	6	0	20	6
Crew Seat Location	Back	Back	Back	Middle
Door Location	Back	Back	Front	Middle
Length of Fuselage (ft) (Economy seat = 30in) (Business seat = 40in) (Restroom width = 24in)	57 ft	60 ft	69 ft	57 ft

APPENDIX C
CONCEPT SELECTION

		1	2	3	4	5	
		Alternatives					
Criteria	Weights (1-5)	Concept 1 Cabin 1 Tricycle Turbojet	Concept 2 Cabin 1 Quadricycle Turboprop	Concept 3 Cabin 2 Multi-Bogie Turbofan	Concept 4 Cabin 4 Taildragger Turboprop	Concept 5 Cabin 3 Floats Rocket engine	Concept 6 Cabin 1 Multi-Bogie Turboprop
Can take off and land from runways of dirt, grass, metal mat, gravel, asphalt, and concrete	5	–	0	0	–	– –	D
Can take off and land from fresh and saltwater	5	– –	– –	– –	– –	+ +	
Can fly in hot air or icing conditions	5	0	0	0	0	0	
At least 5000 lbs of payload	5	+	0	+	0	–	A
At least 500 nautical miles of range	5	+	0	–	0	+	
Restroom	3	0	0	0	0	+	
Two flight crew and one cabin crew	5	0	0	0	0	0	T
At least 20 passengers with 28-32 inches of seat pitch	5	0	0	+	0	0	
Comfortable cabin	4	0	0	–	+	+	
Fast cruise speed	4	+ +	0	+	0	+ +	U
WiFi Connectivity	4	0	0	0	0	–	
Disability Access	3	0	0	+	+	–	
Luggage Capacity	3	0	0	–	0	–	M
Low Cost of Ownership	4	–	0	–	+	– –	
	Totals	0	-2	-2	0	-1	
	Rank	1	3	3	1	2	
	Weighted Totals	-1	-10	-9	-4	-3	
	Weighted Rank	1	5	4	3	2	

Fig. 17: 1st Iteration of Pugh Chart

		1	2	3	4	5	
		Alternatives					
Criteria	Weights (1-5)	Concept 1 Cabin 1 Tricycle Turbojet	Concept 4 Cabin 4 Taildragger Turboprop	Concept 5 Cabin 3 Floats Rocket engine	Hybrid 1 Cabin 1 Floats Turbojet	Hybrid 2 Cabin 4 Float/Tricycle Turboprop	Concept 6 Cabin 1 Multi-Bogie Turboprop
Can take off and land from runways of dirt, grass, metal mat, gravel, asphalt, and concrete	5	–	–	– –	– –	–	D
Can take off and land from fresh and saltwater	5	– –	– –	+ +	+ +	+ +	
Can fly in hot air or icing conditions	5	0	0	0	0	0	
At least 5000 lbs of payload	5	+	0	–	0	0	A
At least 500 nautical miles of range	5	+	0	+	+	0	
Restroom	3	0	0	+	0	0	
Two flight crew and one cabin crew	5	0	0	0	0	0	T
At least 20 passengers with 28-32 inches of seat pitch	5	0	0	+	0	0	
Comfortable cabin	4	0	+	+	0	+	
Fast cruise speed	4	+ +	0	+ +	+	0	U
WiFi Connectivity	4	0	0	–	0	0	
Disability Access	3	0	+	–	0	+	
Luggage Capacity	3	0	0	–	0	0	M
Low Cost of Ownership	4	–	+	– –	–	– –	
	Totals	0	0	0	1	1	
	Rank	2	2	2	1	1	
	Weighted Totals	-1	-4	2	5	4	
	Weighted Rank	4	5	3	1	2	

Fig. 18: 2nd Iteration of Pugh Chart

	Criteria	Raw Weight (1-5)	Relative Weight	Concept Variants					
				Hybrid 1 Cabin 1 Floats Turbojet		**Hybrid 2** Cabin 4 Float/Tricycle Turboprop		**Concept 5** Cabin 3 Floats Rocket engine	
				Raw (1-100)	Relative	Raw (1-100)	Relative	Raw (1-100)	Relative
1	Can take off and land from runways of dirt, grass, metal mat, gravel, asphalt, and concrete	5	0.08	0	0.00	50	4.17	0	0.00
2	Can take off and land from fresh and saltwater	5	0.08	90	7.50	80	6.67	90	7.50
3	Can fly in hot air or icing conditions	5	0.08	50	4.17	50	4.17	50	4.17
4	At least 5000 lbs of payload	5	0.08	80	6.67	75	6.25	50	4.17
5	At least 500 nautical miles of range	5	0.08	70	5.83	80	6.67	50	4.17
6	Restroom	3	0.05	60	3.00	60	3.00	80	4.00
7	Two flight crew and one cabin crew	5	0.08	80	6.67	80	6.67	80	6.67
8	At least 20 passengers with 28-32 inches of seat pitch	5	0.08	70	5.83	70	5.83	80	6.67
9	Comfortable cabin	4	0.07	60	4.00	65	4.33	75	5.00
10	Fast cruise speed	4	0.07	80	5.33	65	4.33	100	6.67
11	WiFi Connectivity	4	0.07	50	3.33	50	3.33	40	2.67
12	Disability Access	3	0.05	65	3.25	70	3.50	80	4.00
13	Luggage Capacity	3	0.05	70	3.50	70	3.50	50	2.50
14	Low Cost of Ownership	4	0.07	60	4.00	85	5.67	15	1.00
	Totals	60	1.00		**63.08**		**68.08**		**59.17**
	Relative Rank			**2**		**1**		**3**	

Fig. 19: 1st Iteration of Decision Matrix

	Criteria	Raw Weight (1-5)	Relative Weight	Concept Variants					
				Hybrid 1 Cabin 1 Floats Turbojet		**Hybrid 2** Cabin 4 Float/Tricycle Turboprop		**Concept 5** Cabin 3 Floats Rocket engine	
				Raw (1-100)	Relative	Raw (1-100)	Relative	Raw (1-100)	Relative
1	Can take off and land from runways of dirt, grass, metal mat, gravel, asphalt, and concrete	5	0.13	0	0.00	50	6.58	0	0.00
2	Can take off and land from fresh and saltwater	5	0.13	90	11.84	80	10.53	90	11.84
	Can fly in hot air or icing conditions	0	0.00						
3	At least 5000 lbs of payload	5	0.13	80	10.53	75	9.87	50	6.58
4	At least 500 nautical miles of range	5	0.13	70	9.21	80	10.53	50	6.58
5	Restroom	3	0.08	60		60		80	
	Two flight crew and one cabin crew	0	0.00						
	At least 20 passengers with 28-32 inches of seat pitch	0	0.00						
6	Comfortable cabin	4	0.11	60	6.32	65	6.84	75	7.89
7	Fast cruise speed	4	0.11	80	8.42	65	6.84	100	10.53
	WiFi Connectivity	0	0.00						
8	Disability Access	3	0.08	65	5.13	70	5.53	80	6.32
	Luggage Capacity	0	0.00						
9	Low Cost of Ownership	4	0.11	60	6.32	85	8.95	15	1.58
	Totals	38	1.00		**57.76**		**65.66**		**51.32**
	Realtive Rank			**2**		**1**		**3**	

Fig. 20: 2nd Iteration of Decision Matrix

Appendix D
Concept Improvement

TABLE XI: TRIZ Improvement Ideas - Cabin Design

Features to Improve	Features to Preserve	Solution	Improvement Ideas
2: Weight of Stationary	8: Volume of Stationary	5: Merging	Integrated seat rows [28]
			Flipped seat for more shoulder room [29]
		35: Parameter Changes	Compact seat alternative, e.g. standing seats [30]
		2: Taking Out	Removable seats
	14: Strength	2: Taking Out	Generatively-designed cabin structures [31]
		27: Cheap Short-lived Objects	Disposable seat covers [32]
		28: Mechanics Substitution	Automatic sink faucet / soap dispenser [33]
	16: Durability of Non-moving Object	19: Periodic Action	Dynamic cabin lighting (time-of-day / flight-stage dependent) mitigates always-on lighting [34]
		6: Universality	Universal cargo seat for additional cargo capability without removing seats [35]

References

[1] *Seat Pitch Guide.* (n.d.). SkyTrax. Retrieved December 6, 2020 from https://www.airlinequality.com/info/seat-pitch-guide/

[2] Paur, Jason. (2013, September 5). *Airline Passengers Want Wi-Fi so Badly They'd Trade Legroom for it*. Wired. https://www.wired.com/2013/09/airline-wifi/
[3] *Air travellers see inflight broadband as an essential freedom*. (n.d.). Inmarsat Avaiation. Retrieved December 6, 2020 from https://www.inmarsataviation.com/en/benefits/passenger-experience/air-travellers-see-inflight-broadband-as-an-essential-freedom.html
[4] *Traveling with a Disability*. (2020, June 18). U.S. Department of Transportation. Retrieved December 6, 2020 from https://www.transportation.gov/individuals/aviation-consumer-protection/traveling-disability
[5] *Everything you need to know about food and drink on flights (and what you're allowed to carry on)*. (n.d.). Skyscanner. Retrieved December 6, 2020 from https://www.skyscanner.net/news/food-and-drink-on-planes-during-coronavirus
[6] Investopedia. (2020, September 24). *Can I Afford a Private Jet?* Investopedia. https://www.investopedia.com/articles/investing/081015/can-i-afford-private-jet.asp#: :text=You%20can%20charter%20a%20jet,million%20to%20over%20%24100%20million
[7] *These Large Cabin private jets have the most room for your baggage*. (n.d.). Private Jet Card Comparisons. Retrieved December 6, 2020 from https://privatejetcardcomparisons.com/these-large-cabin-private-jets-have-the-most-room-for-your-baggage/
[8] *Cockpit Automation - Advantages and Safety challenges*. (n.d.). Skybrary. Retrieved December 6, 2020 from https://www.skybrary.aero/index.php/Cockpit_Automation_-_Advantages_and_Safety_Challenges#Other_Potential_Improvement_Options
[9] *Short-haul Economy Class Comparison Chart*. (n.d.). SeatGuru. Retrieved December 6, 2020 from https://www.seatguru.com/charts/shorthaul_economy.php
[10] *Cessna SkyCourier*. (n.d.). Textron Aviation. Retrieved December 6, 2020 from https://cessna.txtav.com/en/turboprop/skycourier
[11] *Broadband Speed Guide*. (n.d.). Federal Communications Commissions. Retrieved December 6, 2020 from https://www.fcc.gov/consumers/guides/broadband-speed-guide?contrast=
[12] Wu, Jimmy. (2019, May 1). *How sanitary is it to use the lavatory in flight?* LinkedIn. https://www.linkedin.com/pulse/how-sanitary-use-lavatory-flight-jimmy-wu/
[13] *Determining the seat width for a wheelchair.* (n.d.). Karman Healthcare. Retrieved December 6, 2020 from https://www.karmanhealthcare.com/determining-the-seat-width-for-a-wheelchair/#: :text=Standard%20wheelchairs%20widths%20are%2016,seats%20from%2028%E2%8
[14] Tigar, L. & Diamond M. (2020, December 2). *Airline Carry-on Luggage Size Restrictions: What You Need to Know.* Travel + Liesure. https://www.travelandleisure.com/style/travel-bags/airline-carry-on-luggage-size-guide
[15] Mark, Rob. (2018, August 13). *How Seaplane Floats Work*. FlyingMag. https://www.flyingmag.com/how-seaplane-floats-work/
[16] Werth, John. (2014, December). *Airborne Weather Radar Limitations*. Weather.gov. https://www.weather.gov/media/publications/front/14dec-front.pdf
[17] *How much electricity am I using?* (n.d.). Centre for Sustainable Energy. Retrieved December 6, 2020 from https://www.cse.org.uk/advice/advice-and-support/how-much-electricity-am-i-using
[18] Warner, Jennifer. (2006, November 26). *Sit Back, It's Better for Your Back*. WebMD. https://www.webmd.com/back-pain/news/20061129/back-pain-eased-by-sitting-back
[19] Park, Michael. (2018, May 7). *These are the Healthiest Planes in the Sky.* The Points Guy. https://thepointsguy.com/news/the-healthiest-planes-in-the-air-today/
[20] Griff, Zach. (2020, May 15). *Sorry, aisle-seat fans: The window seat is the best in the air.* The Points Guy. https://thepointsguy.com/news/why-window-better-than-aisle-seat/
[21] *Cessna Caravan.* (n.d.). Textron Aviation. Retrieved December 7, 2020 from https://cessna.txtav.com/en/turboprop/caravan
[22] *Twin Otter Technical Specifications.* (n.d.). Viking Air. Retrieved December 7, 2020 from https://www.vikingair.com/twin-otter-information/technical-description
[23] *Kodiak 100 Series II*. (n.d.). Kodiak.aero. Retrieved December 7, 2020 from https://kodiak.aero/wp-content/uploads/2018/05/KodiakBigBrochure2018.pdf
[24] *Private Single Enginer: Cessna 208 Caravan.* (n.d.). Aircraft Compare. Retrieved December 7, 2020 from https://www.aircraftcompare.com/aircraft/cessna-caravan/
[25] *Textron Launches Cessna SkyCourier with 100-Plane Deal.* (n.d.). AINonline. Retrieved December 7, 2020 from https://www.ainonline.com/aviation-news/business-aviation/2017-11-28/textron-launches-cessna-skycourier-100-plane-deal#: :text=A%20long%2Dtime%20customer%20of,the%20%245.5%20million%20list%20price
[26] *Business & Commercial Aviation*. (2017, May). Assets.Informa. Retrieved December 7, 2020 from https://assets.informa.com/digitaleditions/BCA/BCA_201705.pdf
[27] Bergqvist, Pia. (2018, August 29). *We Fly: Quest Kodiak 100 Series II.* Flying Magazine. https://www.flyingmag.com/quest-aircraft-kodiak-100-series-2-reviewed/
[28] Davies, Alex. *This Neat Design Could Make a Plane's Middle Seats Tolerable*. WIRED. https://www.wired.com/story/neat-design-make-planes-middle-seats-tolerable/
[29] *Original document: WO2015083088 (A1) — 2015-06-11*. Espacenet. Retrieved December 9, 2020 from https://worldwide.espacenet.com/publicationDetails/originalDocument?CC=WO&NR=2015083088A1&KC=A1&FT=D&ND=3&date=20150611&DB=EPODOC&locale
[30] Im, Jimmy. *This company wants you to travel 'standing' on your flight—and it could save you money*. CNBC. https://www.cnbc.com/2019/04/25/avioninteriors-designed-standing-seats-for-airplanes.html
[31] Micaleff, Ken. *Airbus Continues to Innovate Bionic Design for Future Sustainable Flights*. Autodesk. https://redshift.autodesk.com/bionic-design/
[32] *FreshFlight - Disposable Airplane Seat Cover*. Fresh Brands USA. Retrieved December 9, 2020 from https://freshbrandsusa.com/products/fresh-flight-disposable-seat-cover
[33] Harmon, Alyssa. *DO AUTOMATIC WATER FAUCETS ACTUALLY SAVE WATER?*. California State University. https://www.csus.edu/experience/innovation-creativity/sustainability/_internal/_documents/ir-faucet.pdf
[34] *True plug-and-play programmable LED Mood Lighting*. STG aerospace. Retrieved December 9, 2020 from https://www.stgaerospace.com/products/main-cabin-lighting
[35] Gavine, Adam. *Universal Cargo Seat developed to help the fight against Covid-19*. Aircraft interior international. https://www.aircraftinteriorsinternational.com/news/industry-news/universal-cargo-seat-developed-to-help-the-fight-against-covid-19.html
[36] *Turboprop*. (n.d.) Wikipedia. Retrieved December 9, 2020 from https://en.wikipedia.org/wiki/Turboprop#: :text=Compared%20to%20 turbofans%2C%20turboprops%20are,of%20the%20fuel%20per%20passenger.