CONCEPTUAL DESIGN OF AN AIRCRAFT TO MATCH THE MISSION PROFILE OF A MOBILE HOSPITAL FOR HUMANITARIAN SERVICE

by

Alvaro E. Hernandez

A thesis submitted in partial fulfillment of
the requirements for the degree of Bachelor
of Science with Honors and Distinction in
Aeronautical and Astronautical
Engineering

The Ohio State University

2010

Advisor:

Dr. James Gregory – Assistant Professor - Dept. of Aerospace Engineering

Committee:

Howard A. Werman, MD – Professor - Dept. of Emergency Medicine

THE OHIO STATE UNIVERSITY

College of Engineering
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ABSTRACT

Conceptual Design of an Aircraft to Match the Mission Profile of a Mobile Hospital for Humanitarian Service

Alvaro E. Hernandez

Advisor: Dr. James Gregory[1]

Committee: Howard A. Werman, MD[2]

Millions of people worldwide are unable to access medical care due to poverty and geographic isolation. Some locations, although being overpopulated, do not possess the infrastructure to find a solution to the ongoing medical problem. It is the objective of this thesis to design an aircraft capable of performing the mission profile of a flying hospital, thus providing life-saving treatments to these populations. The extensive equipment needed to sustain medical missions creates unique challenges in aircraft design, which are addressed by a systematic design build-up that uses the mission specifications as the main driver and therefore creates an aircraft specific to the mission. Aeronautical design of commercial aircraft must accommodate the crew, passengers, and baggage: However, the mobile hospital additionally requires operating, treatment, and recovery rooms. This specification brings with it a unique payload requiring weights and volumes atypical of most aircraft. The size of the aircraft needs to be chosen carefully in order to carry the necessary equipment while still maintaining the aircraft aerodynamically capable of servicing small, rough fields in the outskirts of places like Africa. Such requirements led to the design of a 413,000lb aircraft capable of servicing runways as short as 4,500ft in length. A surgical suite featuring 260ft^2 has been installed inside along with recovery and clinical areas. It has been estimated that a medical crew of 25 will be able to service deprived areas, helping up to 8,000 patients in a given 21-day mission. Ultimately, the solution is only a small step in the huge stride that is providing medical help to the impoverished areas of the world. Yet, the MedWing Project looks to do its part in creating a better world as well as in inspiring others to step up and work with and in the humanitarian field.

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ACKNOWLEDGMENTS

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In addition, my thesis advisor Dr. James W. Gregory, who provided me with timely, instructive comments and evaluation at every stage of the thesis process, allowing me to complete this project on schedule. *My expertise in this topic is solely due to your support and constant guidance.*

Next, I wish to thank Howard A. Werman, MD and Ayesha Khan, MD, who presented me, albeit having extremely busy schedules, with the most exceptional aid and advice needed to succeed in this project. *For your constant aid to the impoverished areas of the world, I congratulate you.*

In addition to the technical assistance above, I received equally important aid from family and friends. My parents, Tibisay & Alvaro F. Hernandez, and Maria de Lourdes & Guillermo Carrillo provided on-going support throughout the thesis process, as well as the education and desire needed to obtain my Bachelor’s degree. *To you I owe everything; my accomplishments will always be yours.*

NOMENCLATURE

Symbol	*Definition*
AR	Aspect ratio
b	Wingspan
$\mathbf{C_D}$	3D (Wing) drag coefficient
$\mathbf{C_d}$	2D (Airfoil) drag coefficient
CG	Center of gravity
$\mathbf{C_j}$	Blowing coefficient
$\mathbf{C_L}$	3D (Wing) lift coefficient
$\mathbf{C_l}$	2D (Airfoil) lift coefficient
$\mathbf{C_M}$	3D (Wing) moment coefficient
$\mathbf{C_m}$	2D (Airfoil) moment coefficient
c	Section chord
$\bar{c}$	Mean geometric chord (mgc)
D	Drag
E	Endurance
L	Lift
L/D	Lift-to-Drag ratio
$\mathbf{M_{ff}}$	Mission fuel fraction
$\mathbf{M}_\infty$	Freestream mach number
q	Dynamic pressure
R	Range
Re	Reynolds number
S	Area
T	Thrust
V	Velocity

NOMENCLATURE (CONTINUED)

Symbol	*Definition*
$\mathbf{W}$	Weight
Greeks	
$\boldsymbol{\alpha}$	Angle of attack
$\boldsymbol{\Lambda_{c/2_w}}$	Wing semi-chord sweep angle
$\boldsymbol{\Lambda_{HL}}$	Hinge line sweep angle
Subscripts	
CAR	Cargo
CREW	Crew
E	Empty
ff	Fuel fraction
F	Mission fuel
f	Flap
LD	Landing
max	Maximum
OE	Operating empty
PASS	Passenger
PL	Payload
r	Root
TO	Take-off
t	Tip
w	Wing
0	Zero Lift

NOMENCLATURE (CONCLUDED)

Acronyms

AEO	All engines operating
APU	Auxiliary power unit
AOA	Angle of attack
EET	Energy efficient transport
FAA	Federal Aviation Administration
FAR	Federal aviation regulation
LBL	Left buttock line
NACA	National Advisory Committee for Aeronautics
OEI	One engine inoperative
OR	Operating room
RBL	Right buttock line
SFC	Specific fuel consumption
STA	Weight station
STOL	Short take-off and landing
sls	Sea level standard
USB	Upper surface blowing

Introduction:

In 2003, nearly half a million children died of the measles. This disease is preventable; a thirty cent vaccination that has been accessible in developed countries for over forty years is unavailable to the populations that need it the most (1). Particularly, African people suffer from an underdeveloped healthcare system. In Congo, there are only 19.8 physicians per 100,000 people, while western countries average 17 times as many (2). Without proper medical attention, millions of people will continue to needlessly die of preventable or treatable conditions. Given the widespread nature of this health crisis and a lack of national resources and infrastructure, a mobile solution must be formulated. The posit solution is the design of *MedWing*, an aircraft capable of acting as a flying hospital, and the proposed research will concentrate on the design of this aircraft from the ground up to meet detailed mission requirements.

Aircraft design is an independent discipline within aeronautical engineering. It differs from the analytical disciplines such as aerodynamics, propulsion and structures. Design acts as a system integration, in which substantial knowledge, spanning all analytical disciplines, is required. There are two equally important aspects of aircraft design: Design Layout and Design Analysis. Design layout is the matching of a geometric description and solution to a mission profile or problem, while design analysis evaluates how well the solution or product matches the requirements and estimates the feasibility of such design (3). It is the goal of this thesis to perform both aspects of design, constructing a solution to the ongoing health problems of the world. Primary design parameters have been established using prior research of the problem. The requirement for the aircraft to be able to perform short take-offs and landings demands an extensive amount of work dedicated to the design of the main wing. Additionally, a mobile hospital aircraft will require a considerably large fuselage volume and a demanding payload carrying capability while still maintaining a flyable the size and weight of the aircraft. This constraint illustrates the importance of fuselage design in the project. The main objective of this research is to find a solution to the design problems of the mobile flying hospital using new technologies in aerospace design.

Surgical suite design has changed significantly over the past ten years and will continue to evolve over the next decade. The standard surgical suite has increased from 400ft^2 to 600ft^2 (4); however, a large aircraft, like the Boeing 747, exhibits a diameter of 21.3ft equaling an approximate feasible area of 450ft^2 (5). While it seems like such an aircraft would accommodate a surgical suite, it is important to note that the desired flying hospital needs to be significantly smaller and lighter in order to minimize drag and complete the mission profile. Special considerations must also be taken when designing the configuration layout of the aircraft. The overall arrangements and layout of the fuselage has a remarkable effect upon aerodynamic efficiency (3). A poorly designed fuselage can lead to disproportionate flow separation and drag, which may ultimately lead to the failure of the aircraft (6).

Therefore the key in aerospace design is to find a middle ground, between maximizing volume housed by the fuselage and minimizing drag, while maintaining structural integrity. The daunting challenge of this design is to achieve the necessary volume required by the mission while still producing an aerodynamically efficient aircraft. Thus, the goal of the proposed research is to develop a simple model of an aircraft capable of performing the mission concept of a mobile hospital.

Chapter 1 – The Problem and Mission Specifications:

Engineering design tries to find the solution to a problem. In this sense, aerospace conceptual design is not any different since it also tries to find a solution utilizing or comprising the atmosphere or space. Finding a good solution to a problem requires that the problem or conundrum be stated clearly. In the aerospace industry, problems are often displayed as mission profiles or mission specifications. In other words, the problem is displayed as a set of requirements that if met will ensure a successful mission which in turn will signified a solved problem. This chapter attempts to clearly state the requirements that will be utilized in the design and later in the analysis of such mobile hospital.

Out of the 20 countries with the highest mortality rates in the world, 16 of them are in Africa (7). In all sixteen countries, the number one killing disease is related to treatable illnesses caused by food or water contamination (7). This is a powerful statistic that begs for an answer. How can a treatable and preventable infection be Africa's greatest fear? When 72% of its population lives in slums, more than 40% are illiterate and only 32% have access to hospital and sanitation it becomes extremely hard to cure or communicate the danger of such diseases (2). These reasons along with many others are what determined the initial operation location or target of MedWing. In other words, this mobile hospital is being designed to target the preventable diseases of Africa by providing decontamination utensils, surgical and preventable care, but more importantly providing health education to the people.

The selection of Africa as the initial target for MedWing brings along a large problem. With only 37% of Africans living in an urban community, the amount of patients accessible by landing in normal paved airports is less than ideal (2). On top of that, most African cities that have an airport also have a hospital and therefore the need for such airplane diminishes. In order to actually target and help the impoverish people of Africa; MedWing must be able to travel to the location where they live. Said differently, the aircraft should be able to land near slums, rural villages, and outskirt communities regardless of whether or not they have a paved runway. Additionally, it can be assume that due to the geography of the continent, the areas that are flat, lengthy and unforested are scarce in nature. Therefore, MedWing should be able to land in any patch of land measuring less than 5,000ft which is significantly lower than today's industry's average.

The aerospace industry has always been favored from being on the top of the technology boom. Thanks to being able to create newer and more efficient technologies or methods of travel, the industry has always experience and needed large amounts of capital when it comes to newer developments. Unfortunately, the humanitarian industry has not been as privileged. In today's world, service and aid has always been a secondary front for most citizens and therefore finding capital to promote the required humanitarian missions has been a huge challenge. It is the job of this thesis to find a middle ground between the aerospace industry and the limited in resources humanitarian field. One of the methods to limit the amount of capital needed for a mission is to make the airplane fuel and operational efficient. Unlike the current airplanes in the humanitarian field, MedWing should be designed to be able to fly under the control of only two crew members therefore minimizing the amount of capital that must be used to hire flight personnel. Similarly, the passenger space should be maximized to allow a large hospital crew capable of servicing more patients per mission.

Another aerodynamic design driver that has been set in placed to minimize operation cost is the selection of a maximum range. MedWing should be designed with a range exceeding the 3,000nm in order to avoid refueling stops involving higher fuel prices charged at out-of-the-way stations. It is also necessary for the airplane to be able to fly across continents with ease, hence maximizing its worldwide usage.

Similarly to aerodynamic design drivers, there are also mission specifications that are determined by hospital needs. Hospitals tend to be city buildings that are not necessarily limited in size and therefore are often roomy and spacious within their facilities. A mobile hospital, however, does not have a large amount of square footage and therefore must choose carefully its arrangement. A separate study on hospital requirements by Douglas Gordon identified the areas of a surgical suite that are essential to the performance and the accomplishment of their mission. It was found that hospitals required an operating room with a minimum area of $250ft^2$ as well as sub sterile and recovery area to be able to perform required surgeries (4). MedWing mission requires that it able to accommodate such facilities and therefore volume allowances must be carefully studied.

Along with volume requirements, a mobile hospital also establishes some cargo weight requirements. Humanitarian missions must be able to bring all the required equipments and utensils needed during the mission, including its potable water. Current airplanes in the humanitarian field carry around 60,000lbs in medical cargo for every mission and therefore this was identified as the minimum required cargo allowance for MedWing (8).

Ideally, all the requirements highlighted above should be considered as the low margins for a successful humanitarian mission into places like Africa. It is desired that newer technology allows for a more complete aircraft capable of exceeding current standards and therefore creating a larger impact in the health of the people. With this on mind, Table 1 summarizes and highlights the desired mission specifications that are being implemented in the design of MedWing.

Table 1 Mission specifications

Mission Specifications	Required	Desired
Aircraft Requirements		
# of Crew Members	2	2
# of Passengers	25	40
Passenger Cabin Height	7 ft	7ft
Hospital Aisle Width	3.25 ft	4 ft
Cargo/Equipment Load	66,000 lbs	72,000 lbs
Maximum Takeoff Distance	4,500 ft	3,000 ft
Maximum Landing Distance	4,500 ft	3,000 ft
Cruise Mach Number	0.5	0.8
Range	3,000 nmi	3,500 nmi
Hospital Requirements		
Operating Room Relative Length	15 ft	18.25 ft
Operating Room Relative Width	10 ft	15 ft
Operating Room Area	(none)	250 ft^2
Sub Sterile Area	(none)	150 ft^2
Recovery Area	(none)	200 ft^2

Chapter 2 – Historical Background:

AIRCRAFTS IN THE HUMANITARIAN FIELD

Air medical transport became useful prior to the arrival of the first powered flight. Long before the Wright brothers had their amazing flight in Kitty Hawk; military units around the world were using hot air balloons to airlift wounded soldiers away from the front lines and into hospitals. As airplanes started to develop so did their uses and soon many aircrafts were being specifically designed to serve the mission of medical ambulances (8).

In 1970, Dr. David Patton envisioned using an aircraft as a mobile hospital to help the undeveloped countries fight sight illnesses. His idea called for the implementation of a mobile hospital and classroom that would be able to travel the world and provide humanitarian help to different people all year long. With the help of other humanitarian companies and United Airlines, Dr. Patton was able to obtain an old DC-8 which he converted into the first civilian mobile hospital and therefore giving birth to *ORBIS International* (8).

ORBIS International is one of the only companies that currently operate a civilian mobile hospital. They no longer use their original DC-8 but instead their current DC-10-10 has been traveling the world ever since 1994. This new aircraft contains in addition to a modern flight deck, a classroom, a laser treatment room, an operating room, and even a recovery room. Due to the mission of ORBIS International, bring sight to everyone in the world, the aircraft specializes in optical care instead of an all-around medical unit. However since their creation, they have been able to service more than 1,000 programs in 86 countries all while teaching and preparing local doctors to work and prevent blindness together (8). Actually, ORBIS International has been so successful in their humanitarian missions that late last year they began the process of expanding their fleet by converting a donated MD-10 into another flying hospital (9).

Similarly to the idea of ORBIS International, *Mercy Airlift* wanted to bring a fully equipped surgical hospital to the aerospace industry. In 1996, Mercy Airlift received a Lockheed L-1011 from Delta Airlines, which was successfully converted into the first full multiuse surgical air transport in the world. The airplane exhibits four completely self-contained operating stations, a pre/post operation recovery area for up to 12 patients, a pharmacy, diagnostic equipments and a waiting room/check-in area (10). In other words, the airplane was equipped with everything necessary to be able to carry a humanitarian mission targeting most illnesses encountered in today's medical missions. Unfortunately, the aircraft was unofficially retired in early 2001, but not prior to traveling the world and providing millions with humanitarian aid.

Although these aircrafts had a very different mission, they both became industry firsts which must be analyzed prior to designing any new mobile hospitals. Due to the similarities between the mission profiles of said aircrafts and the new mobile hospital, both the hospital versions of the DC-10-10 and the L-1011 will be used as key historical data. Yet, it is important to realize that as similar as these jets might be to the new MedWing; they have a key and important difference. Both of these mobile hospitals were converted versions of their civilian counterparts and therefore they were "slaves" to the aerodynamic characteristics of civilian aircrafts. MedWing is being design from the ground up to match the mission profile of a mobile hospital and therefore can exceed the current standards of both ORBIS International and Mercy Airlift.

HISTORICAL WEIGHT BREAKDOWNS

A critical part of the preliminary design stages constitutes the determination of the maximum gross takeoff weight, $W_{TO_{max}}$, of MedWing. This task must be performed first in the design process due to its impact on other systems, such as aerodynamic and propulsive characteristics. Due to the unique mission profile of MedWing, related historical weight data must first be acquired and analyzed to obtain a better understanding of the requirements of a mobile hospital.

ORBIS International's DC-10-10

ORBIS International's flying hospital is base on an interior modification of an original McDonnell Douglas DC-10-10. This is a three-engine widebody airliner that first entered production in the 1970s. It uses 3 GE CF6-6 engines that are mounted on underwing pylons and at the base of the vertical tail (11). ORBIS International decided to use this airplane due to its ability to perform medium range missions as well as its large fuselage which eases interior modifications (8).

ORBIS International's flying hospital mission only required that the DC-10-10 be modified internally. All aerodynamic aspects of the airplane were kept the same except the takeoff weight. The modifications required that the airplane be stripped of its entire airline interior and for it to be replaced with new walls, rooms, and equipment. Interior adjustments of this magnitude tend to cause significant changes to the weight distribution of the aircraft.

Table 2 Changes to the weight distribution of ORBIS International's DC-10

Weight Category	Airline Configuration	ORBIS Configuration	% Change
Max-TO Weight	430,000 lbs	455,000 lbs	6%
Empty Weight	239,571 lbs	246,758 lbs	3%
Flight Crew Weight	600 lbs	600 lbs	0%
Fuel Weight	95,000 lbs	95,000 lbs	0%
Passenger Weight	77,560 lbs	7,000 lbs	-91%
Cargo Weight	17,269 lbs	105,642 lbs	512%

Table 2 shows the changes in the weight distribution due to the hospital modification implemented by ORBIS (11) (12). It can be seen that although the change in the maximum gross takeoff weight is relatively small, the variation in the payload weights is significant. By lowering their passenger load from 277 passengers to the necessary 25 humanitarians needed per mission, the airplane passenger weight can be redistribute to accommodate more cargo such as medicines and equipment. Some hospital equipments, such as the surgical suite and x-ray machines, had to be installed to the structural frame for stabilization and support and therefore must be accounted as part of the empty weight of the aircraft. In the end, ORBIS International increased the gross takeoff weight of its airplane a 6% due to a 3% increase in empty weight and a 19% increase in payload weight. A graphical representation of the weight breakdown in percents of the maximum gross takeoff weight of each configuration can be seen in Figure 1 below.

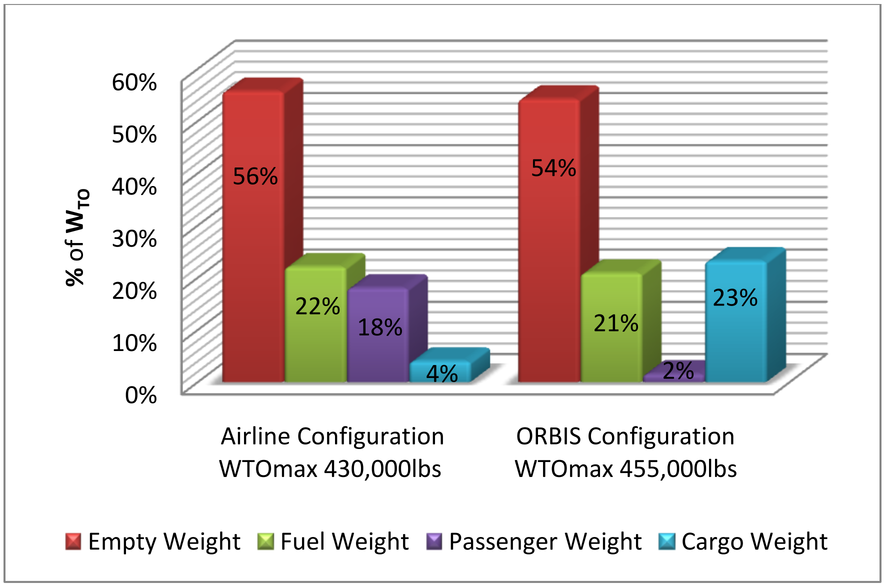

Figure 1 DC-10-10: Weight percentage comparison between configurations

Mercy Airlift’s L-1011-500

Similar to ORBIS International’s flying hospital, Mercy Airlift modified an existing airline transport’s interior to accommodate the medical facilities. They chose a Lockheed L-1011-500 as their baseline thanks to its long range capabilities. Like the DC-10-10, it is also a three engine wide body jet airliner which began production at the end of 1960’s.

Mercy Airlift’s hospital vision used the current L-1011 and modified the interior to house the hospital as needed. Just like ORBIS International’s DC-10-10, the Lockheed airplane suffered a change in gross takeoff weight due to the internal modifications. Such changes are highlighted in Table 3 below. The Mercy Airlift mission requires 67 volunteers to be able to fly with the aircraft and therefore a total of 167 seats were removed from the aircraft, significantly lowering the empty weight. In correspond to their ORBIS counterpart; Mercy Airlift installed some hospital equipment directly to the structure of the aircraft therefore ultimately increasing the empty weight a total of 3%. The final takeoff weight was maintained constant across both configurations by carefully rearranging the allocation of weight fraction between cargo, passengers and empty weights.

Table 3 Changes to the weight distribution of Mercy Airlift's L-1011

Weight Category	Airline Configuration	Mercy Airlift's Configuration	% Change
Max-TO Weight	506,000 lbs	506,000 lbs	0%
Empty Weight	232,739 lbs	239,000 lbs	3%
Flight Crew Weight	600 lbs	600 lbs	0%
Fuel Weight	181,879 lbs	181,879 lbs	0%
Passenger Weight	65,520 lbs	18,760 lbs	-71%
Cargo Weight	25,262 lbs	65,761 lbs	160%

A graphical representation of the weight breakdown in percents of the maximum gross takeoff weight of each configuration can be seen in Figure 2.

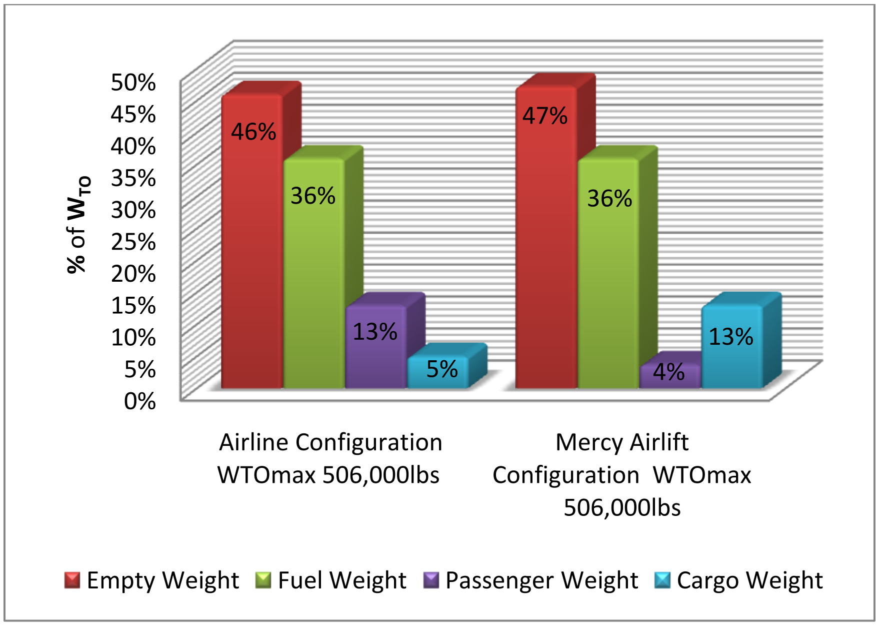

Figure 2 L-1011-500: Weight percentage comparison between configurations

Chapter 3 – Design Evolution:

Every aspect of MedWing has been designed based on how it would function on its humanitarian mission. Aspects such as the selection of the wing design, engine placement and even fuselage shape have been driven by primary or secondary requirements of the mission specifications. Throughout its design the airplane has been adapted from one configuration to another until finally reaching a final concept. Figure 3 has been included to ease the understanding of the changes implemented to the configuration of the aircraft. Said figure shows the different parts of the aircraft including control surfaces and their respective purposes. Changes to the design of MedWing have been kept under a close technological and time margin which ensures that all of its components will be ready for production by 2020. Figure 4 shows the initial concept design for MedWing.

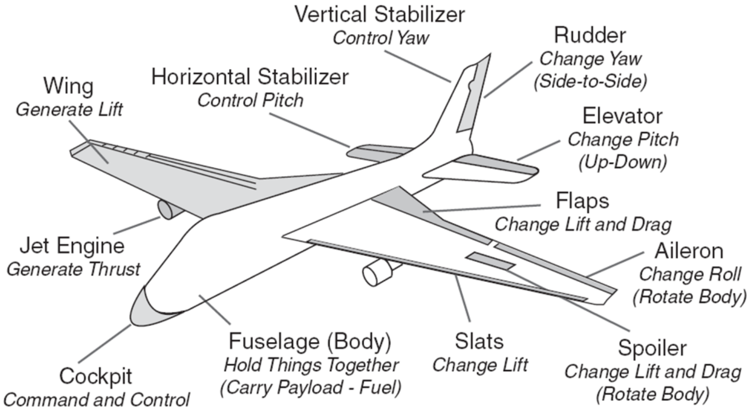

Figure 3 Airplane parts and control surfaces with their functions (13)

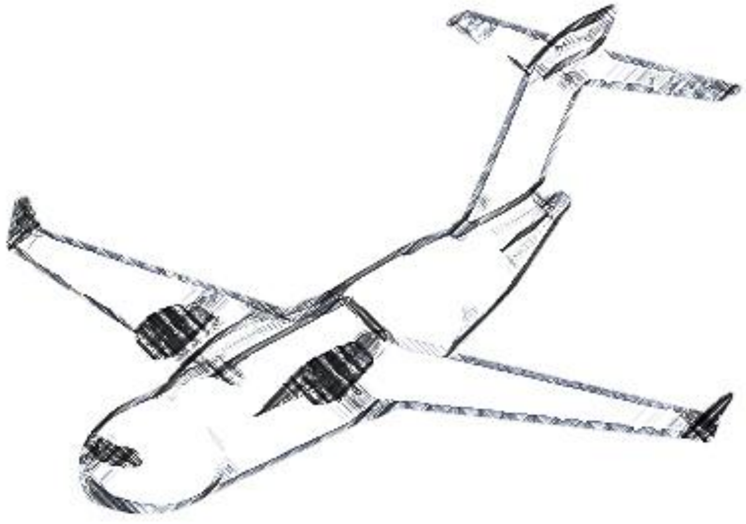

Figure 4 Preliminary concept for the MedWing

The initial concept shown in Figure 4 employs a high wing and a large T-tail. It is powered by two turbofan engines that are mounted above and semi embedded into the innermost or root leading edge of the wing for upper surface blowing. It has a very large fuselage meant to house the hospital and the robust landing gear.

The decision to use a high wing was driven by many mission factors. By placing the wing high above the ground, the fuselage can then sit closer to the terrain allowing therefore easy loading and unloading through a rear ramp. This was a primary driver from the mission since landing on unprepared fields means that the airplane must have a way to unload its cargo without the need of special airport equipment such as stairs or lifts. Landing on dirt fields also means that more debris or rocks will be kicked up by the tires and therefore could potentially hit and damage the leading edge surface of low mounted wings. For STOL aircrafts, high wings have the benefit of providing enough room for large flap systems as well as decreasing the undesirable ground effect on landing, making touchdown easier for pilots. One final driver for the selection of the high wing is related to the humanitarian operation rather than aerodynamic reasoning. Having a high wing allows for extra room and shade under the wing during the mission, potentially allowing the setup of external medical units housed under the canopy of the wing. The selection of the winglets or wingtips was driven by the STOL functions of the airplane. Said winglets allow for a higher effective wingspan, hence more lift (14). Figure 5 shows the planform view of the concept.

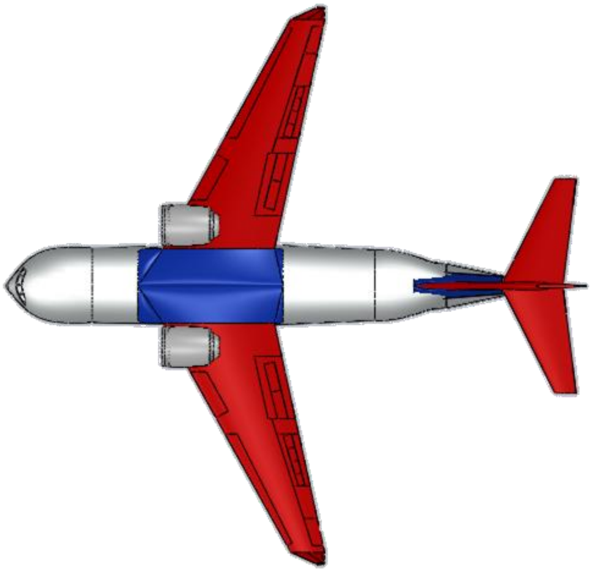

Figure 5 Top view of the MedWing concept

The unique angle or inclination of the wing with respect to the horizontal, as shown in Figure 6, is known as negative dihedral or anhedral. Its reasoning is due to the location of the wing. A high wing has a large amount of effective dihedral making it more prone to a large side-to-side motion involving yaw and roll. In order to counter this tendency a negative dihedral has been chosen to bring a more stable performance to the airplane (3).

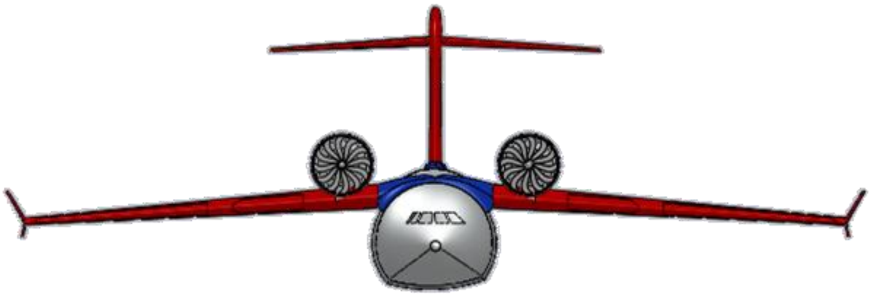

Figure 6 Front view of the MedWing concept

The location of the engines is key to the performance of the airplane. The engines we positioned above the wing and in front of the leading edge to take advantage of exhaust blowing over the top surface of the wing. USB helps increase the lift generated by the wing due to the coanda effect and therefore makes the airplane capable of performing from short fields (15). This location also protects the engine from flying debris due to using unprepared fields. Figure 7 shows the location of the engines with respect to the leading edge of the wing.

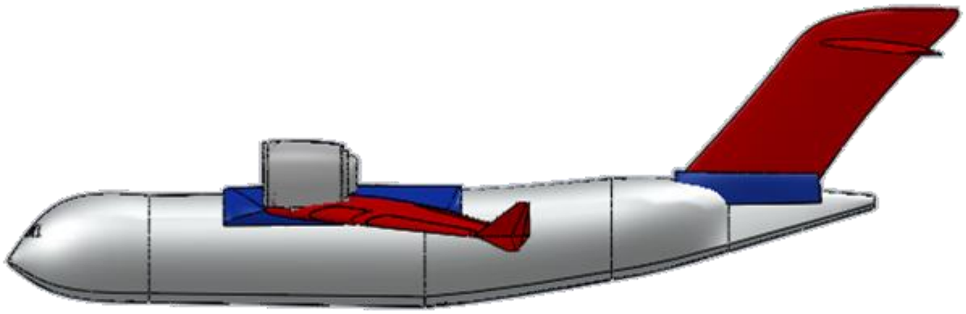

Figure 7 Side view of the MedWing concept

The T-tail of the aircraft was chosen due to location of the engines. Since the engines are so high in comparison to the fuselage, the tail must also be placed high to ensure clean airflow across its horizaontal stabilizers. It is undesired to have a tail surface impacted by exhaust flow from an engine since this leads to uncontrollable situations or performance during engine out operations.

Chapter 4 – Preliminary Sizing:

GROSS TAKE-OFF WEIGHT AND WEIGHT DISTRIBUTION

As it was explained before, W_{TOmax} is a very important characteristic of airplanes since it dictates how it will behave under many of its flight conditions. Therefore, preliminary conceptual design begins with the estimation of the aircraft weight using the mission specifications as the guideline. The gross take-off weight of the aircraft is the result of adding the required fuel weight, the payload weight, the crew weight and the empty or structural weight of the aircraft.

The payload weight of the MedWing has been established by the mission and therefore it can easily be used in the calculation of the $W_{TOmax.}$ In the case of MedWing, the payload has been divided into a required amount of passengers it must carry and an amount of medical equipment it must transport. According to the mission specifications, MedWing should be able to carry anywhere from 20 to 40 passengers during their missions. Similarly, it should be able to transport cargo weighting anywhere from 66,000lbs to 72,000lbs. Once the take-off weight is determined, sensitivity analysis can be performed to obtain an idea on how much fuel space or range would be lost by adding an extra passenger.

When it comes to crew weight, it can be determined using the mission specifications. Historically flight crew numbers has decreased over time as airplanes become easier to fly. The current standard calls for two flight pilots on board the aircraft while on operation. Due to the nature of the mission, flight attendants are not required. The total crew weight can be estimated using historical data for the weight of crew members. Assuming each pilot weighs a total of 300 lbs with their luggage, the total W_{CREW} was calculated to be 600lbs.

Aircrafts are designed to fly a given range with a set velocity while carrying a specified payload, and therefore burn an essential amount of fuel. When it comes to the fuel and empty weight of the aircraft, it can be shown that these values depend on the W_{TOmax} of the aircraft, hence using an iterative process to determine these values. The mission range specification of 3500 nm was used to determine the amount of fuel required. In order to calculate the amount of fuel needed, the mission was divided into smaller legs in which flight conditions were known. Figure 8 shows a schematic of the mission profile of MedWing. The typical mission of MedWing will consist of two cruise legs, a primary leg of 3,500nm to the mission location and a secondary leg of 500nm to a major airfield for refueling. At the refueling airfield, the airplane can either be fueled for a trip back to its home base or recondition for the next mission.

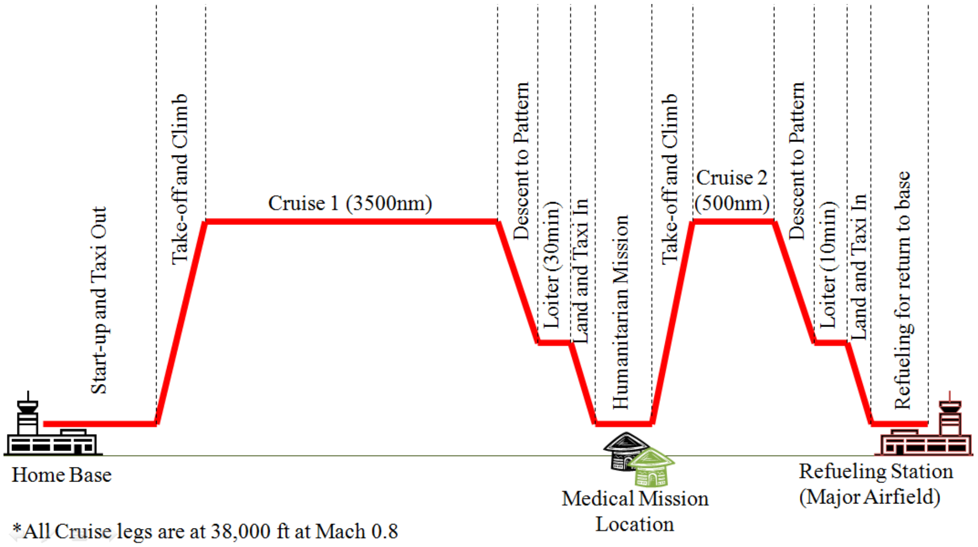

Figure 8 Schematic of the mission profile of MedWing

To calculate the fuel burned during such mission profile, the Breguet range and endurance equations for flight at constant angle of attack and historical data compiled by Roskam were used to estimate the fuel burned for a mission range of such magnitude (16). It was determined that MedWing will consume 138,367lbs of fuel in order to successfully complete the mission specified.

The empty weight of the aircraft was approximated using a combination of two techniques: historical data trends and the weight buildup method. Using the empty weight data of airplanes of similar mission profiles such as the ORBIS International’s DC-10, Mercy Airlift’s L-1011 and Boeing C-17, among others, it was possible to develop a linear regression of historical empty weights (16). This data was compared to the weight buildup highlighted above until a solution matching both curves was found. With the structural factor regression, the total empty weight of the MedWing was estimated to be 194,958lbs.

Once all the known weight fractions are known, it is possible to calculate a W_{TOmax} for the MedWing of 412,725lbs. Table 4 shows the weight breakdown of the MedWing and the distribution as percent of the gross take-off weight of the aircraft. It can be seen that 47% of the take-off weight of the aircraft is accounted by the structural buildup, which follows what was expected from the historical data as shown by Figure 9.

Table 4 Weight distribution of the MedWing

Weight Category	Value	% of W_{TOmax}
Max-TO Weight	412,724.8 lbs	-
Empty Weight	194,957.5 lbs	47%
Flight Crew Weight	400 lbs	<1%
Fuel Weight	138,367.3 lbs	34%
Passenger Weight	7,000 lbs	2%
Cargo Weight	72,000 lbs	17%

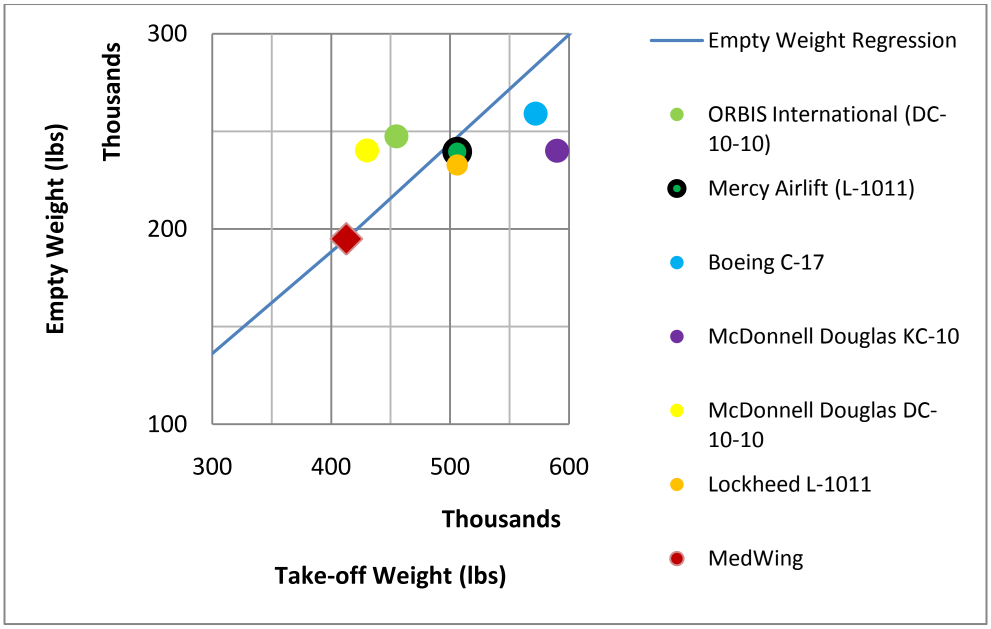

Figure 9 MedWing's empty weight versus that of other similar aircrafts

TAKE-OFF WEIGHT SENSITIVITY

It is evident from the previous section that the take-off weight is dependable from the chosen range and endurance requirements for the mission. The longer the range and loiter time, the heavier the aircraft. A heavy aircraft requires more fuel, making it inefficient and more runway length making it inaccessible. Choosing a good take-off weight is essential to the outcome of the airplane and therefore must be carefully selected. One method to carefully refine the takeoff weight is to study the sensitivity of the mission requirements on the actual $W_{TOmax.}$

It is possible to evaluate the sensitivity of the take-off weight to variations in payload by partial differentiation of the weight buildup equation by the payload requirement. For the MedWing which has a W_{TOmax} of 413,000lbs, when carrying 72,000lbs, it was evaluated that the growth factor due to payload, $\delta W_{TO}/\delta W_{PL,}$ is 7.12lbs/lbs. In other words, for each pound of payload added or subtracted the take-off grows weight will be increased or decreased 7.12 pounds respectively. The same procedure can be performed to obtain the sensitivity to range, empty weight, endurance, specific fuel consumption and lift-to-drag ratio. The results obtained have been tabulated and are shown in Table 5.

Table 5 Growth factor sensitivity of the MedWing's take-off weight

Growth Factor		Value
Payload	$\delta W_{TO}/\delta W_{PL}$	7.12 lbs/lbs
Empty Weight	$\delta W_{TO}/\delta W_{E}$	1.93 lbs/lbs
Range	$\delta W_{TO}/\delta R$	126.8 lbs/nm
Loiter Endurance	$\delta W_{TO}/\delta E$	38757.3 lbs/hr
Engine SFC	$\delta W_{TO}/\delta SFC$	887,411.5 lbs/lbs/hp/hr
Lift To Drag	$\delta W_{TO}/\delta (L/D)$	-37170.2 lbs

ARRANGEMENT OF THE USEFUL LOAD

In aerodynamic terms the useful load of an airplane is the sum of the weight that the airplane structure can lift under maximum gross weight. In other words, it is the weight of the payload plus the weight of the fuel needed for a complete mission. Under the W_{TOmax} of 413,000lbs, the MedWing has a useful load of 217,767lbs.

By assuming a constant structural weight, the designer can freely arrange the distribution of the useful weight between the payload and the fuel. It is obvious that by deciding to add an extra passenger, the fuel on board must be decreased accordingly to the passenger weight and therefore the range must also be decreased since there is now less available fuel. Figure 10 shows the relationship between range and payload weight. It can also be seen that MedWing was designed to ensure that it can make the necessary 3,500nm which means it must carry 25 passengers.

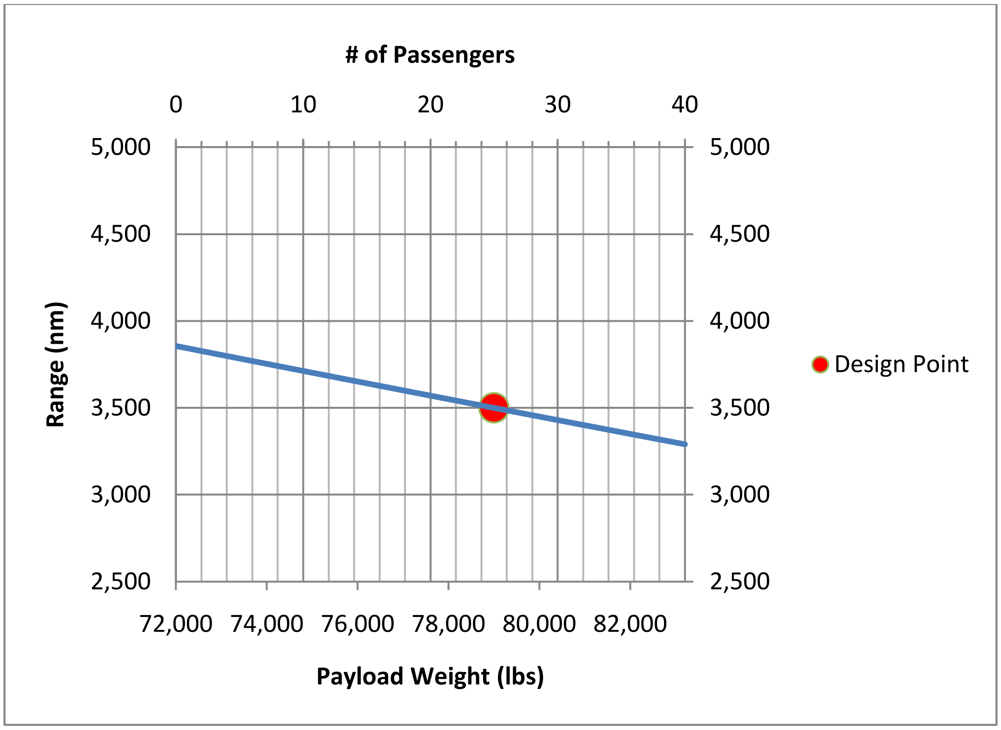

Figure 10 MedWing's range versus number of passengers and payload weight

SIZING TO PERFORMANCE

Once the empty weight of the aircraft has been determined, the design process continues in the estimation of the size of the aerodynamic components of the aircraft. The size of the wing defines many flight characteristics of the aircraft ranging from stall velocity to operations under one engine out emergencies. It is important to take into account all these aspects of flight when defining the wing size since any of these flight characteristics could occur during operation. The following performance characteristics are all either a function of the wing loading, the thrust loading or both quantities. In aerodynamics, wing loading is the amount of weight carried by each square foot of the wing and thrust loading is the ratio between the thrust generated by the aircraft and the weight of such.

The minimum steady flight speed at which the airplane can remain controllable is known as the stall speed. It is preferred that the stall speed of an aircraft be as low as possible to ensure that the airplane is controllable during a larger spectrum of flight velocities. The FAR 25 regulations do not specify a requirement for a maximum stall speed for the aircraft certified under its code. However, a minimum stall speed of 95knots has been established for the MedWing in accordance to historical data (16).

Performance during take-off is essential for the mission of MedWing. The take-off distance that MedWing will need is determined by its W_{TOmax}, the lift-off speed, the thrust available and the drag and friction forces. The takeoff analysis is performed assuming that the pilots are trained and capable of performing at the desired levels. The requirement of a maximum take-off roll of 4,500ft at sea level has been selected for the MedWing. A series of different $C_{L\text{-}TOmax}$ were studied to determine the minimum necessary lifting performance of the wing and aerodynamic package. It was verified that a maximum lift coefficient of 2.6 would ensure the required TO roll.

Similarly, the performance during landing is also important for the mission of MedWing. Once again the maximum landing roll has been selected to be 4,500ft during a sea level landing. To select the necessary aerodynamic package for the aircraft, a series of different $C_{L\text{-}LDmax}$ were chosen and studied. Unlike the TO roll, the landing performance is dependent of the approach speed and not the lift off speed. Using an approach speed derived from the stall speed it was determined that a maximum landing lift coefficient of 2.8 will ensure the required landing roll.

Another important performance mark that the aircraft must be able to meet is its maximum cruise speed. Although the aircraft is designed for efficient cruise at Mach 0.8, it should be able to meet a maximum cruise speed of Mach 0.83. This requirement has been selected in accordance to common jet transports and historical data. The relationship between wing loading and thrust loading define whether or not MedWing will be able to achieve such speed.

The FAR stipulates that every aircraft certified under Part 25 should be able to undergo a turn maneuver. The load factor that an aircraft experiences will increases during a turn. The sustained maneuvering capability of an airplane depends strongly on its maximum lift coefficient and on its installed thrust. The FAA dictates that the positive limit maneuvering load factor may not be less than 2.5 and not greater than 3.8. According to the weight of MedWing, it is required that the aircraft can hold a 2.5 load.

The final requirement that dictates the size of the wing and engines is the climb requirements. The FAR 25 climb requirements are given for two flight conditions: Take-Off and Balked Landing. A balked landing climb is also known as a go-around climb and it is performed during the approach to land if the pilot decides that the situation is not optimal for landing. Within the two flight conditions mentioned above, the FAA also requires that both conditions be met with one engine inoperative, OEI. Due to the complexity of the climb requirements, these have been summarized and tabulated in Table 6. All requirements estipulate the aircraft velocity at which it must be met but these have been omitted in order to save space.

Table 6 Performance climb requirements from the FARs

FAR	Engine	Climb Gradient	Flaps Position	Landing Gear Position	Aircraft Weight	Ground Effect	Climb Segment Description
25.111	OEI	1.20%	Take-Off	Retracted	W_{TOmax}	Inside	Initial
25.121	OEI	Positive	Take-Off	Extended	W_{TOmax}	Inside	Transition
25.121	OEI	2.40%	Take-Off	Retracted	W_{TOmax}	Outside	Second
25.121	OEI	1.20%	Retracted	Retracted	W_{TOmax}	Outside	En-route
25.119	AEO	3.20%	Landing	Extended	W_{LDmax}	Outside	Balked
25.121	OEI	2.10%	Approach	Extended	W_{LDmax}	Outside	Balked

As it was mentioned before, all of the performance requirements of this section are related to both or either wind loading or thrust loading. By graphing all of the requirements in one plot, it is possible to define a design point which meets and exceeds all of the requirements.

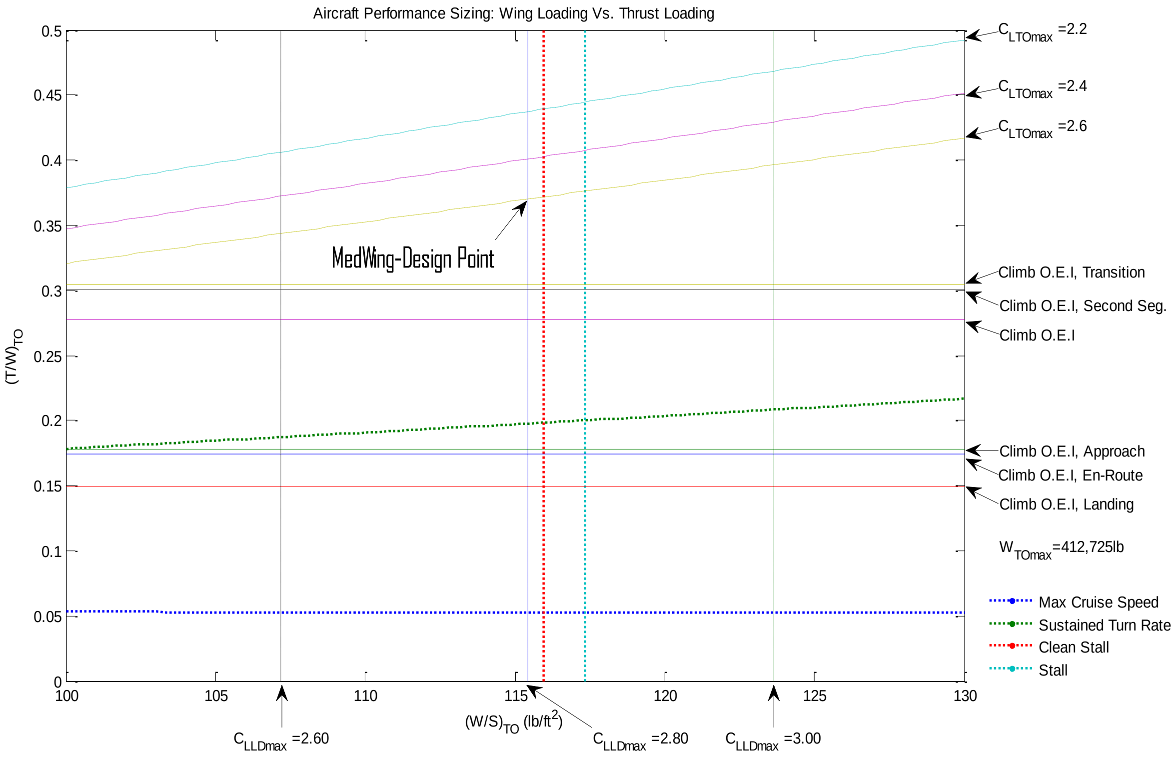

Figure 11 Aircraft performance sizing graph

Figure 11 shows the curves of each performance requirement as well as the design point chosen for the MedWing. It is important to highlight that the stall requirements establish a maximum wing loading unlike the other performance characteristics which establish minimum wing loading.

The design point highlighted in Figure 11 allows for sizing the configuration of the aircraft. Said results have been tabulated and summarized in Table 7. For the purposes of the table, take-off and landing field distance has been defined as the sum of both the ground roll and the air distance to clear a 50ft obstacle as dictated by the FAR 25.

Table 7 Performance sizing characteristic results

Characteristics	**Value**
Wing Loading	115.34 lbs/ft^2
Wing Area	3,578 ft^2
Thrust Loading	0.37
Thrust Available	153,057 *lbs*
Stall Speed	95 *kts*
$C_{L\text{-}TOmax}$	2.6
Take-off Field Distance	4,500 *ft*
$C_{L\text{-}LDmax}$	2.8
Landing Field Distance	4,500 *ft*

Chapter 5 – Aerodynamics:

Although the main purpose of a wing is to create the lift needed to sustain the airplane in the air, this is not the only requirement that the wings have to be able to fulfill. The wings normally have to be able to carry most if not all of the fuel needed to power the aircraft during its mission, hold the weight of the engines mounted on them and finally they must house most of the control surfaces of the aircraft. The main wing design must take into account all of these requirements when conceiving the platform shape of the wing.

AIRFOIL DESIGN

Wing design begins with the selection of the cross sectional shape of the wing or *Airfoil*. Said selection is derived from the aerodynamic requirements of the aircraft since airfoils dictate the aerodynamic characteristics of a wing. The airfoil affects either directly or indirectly the cruise speed and the stall speed, the takeoff and landing distances, the handling of aircraft and the overall efficiency during all the phases of the flight. However, an aircraft spends most of its mission during the cruise phase of flight and therefore airfoil design is based mainly in this range of flight.

The first consideration in the airfoil selection or main wing design is characterizing the design lift coefficient or C_l. Under the assumption that the wing's 3D lift coefficient will be equal to the airfoil's 2D lift coefficient and that at cruise condition the weight equals the lift, early approximations of the airfoil C_l can be calculated by,

$$C_l = \frac{1}{q}\left(\frac{W}{S}\right) \tag{1}$$

The previous equation is based on the wing loading during cruise, which is obviously a function of time since the weight decreases during the flight. However, since the C_l of an airfoil is a constant property, Equation 1 suggests that as the weight decreases, the dynamic pressure or q must change accordingly. There are two methods of changing the dynamic pressure experienced by the aircraft; either by lowering the flight velocity which is cruise inefficient or by increasing the flight cruising altitude in order to lower the density. This explains the reason why commercial aircrafts perform a cruise climb. Using Equation 1 it was determined that the MedWing requires an airfoil capable of having a lift coefficient of more than 0.59.

The stall characteristic of the airfoil was also studied to ensure that when the wing does stall, it does so from the trailing edge. The main reason behind this selection is the fact that trailing-edge-stall-airfoils tend to maintain a semi constant pitching moment as they approach stall. These airfoils also exhibit a gradual loss of lift instead of an abrupt change at stall which makes them more pilot-friendly. Trailing-edge-stall-airfoils tend to be thick, with a thickness ratio greater than 12%, which is why it was chosen that the MedWing airfoil should have a thickness of around 14%.

For the wing design, it was determined that a high-lift system was necessary to meet the mission requirement of short takeoff. It was also concluded that due to the cruising velocity of the MedWing, Mach 0.8, a supercritical airfoil capable of accelerating to such velocities was necessary. Supercritical airfoils are designed to delay the wave drag accompanied by cruising at transonic speeds. There are several designs that use a supercritical airfoil along with a high-lift system to accomplish mission requirements. One such airfoil was the Langley Energy Efficient Transport (EET) High-Lift Supercritical Airfoil, as tested at NASA Langley (17). It was decided that a similar airfoil as that used in the studies by Harry Morgan should be chosen for the MedWing (17). The airfoil chosen was the NASA SC(2)-0414, shown in Figure 12.

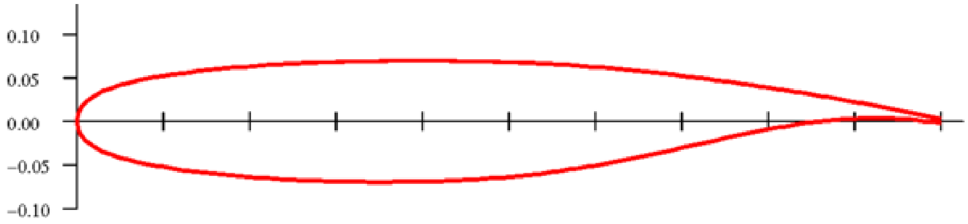

Figure 12 MedWing's main wing airfoil: NASA SC(2)-0414

Said airfoil was analyzed using virtual wind tunnels that utilize the vortex panel method. One of such analysis was performed with DesignFoil by

DreeseCode Software (18). The results of this analysis are shown in Figure 13 below.

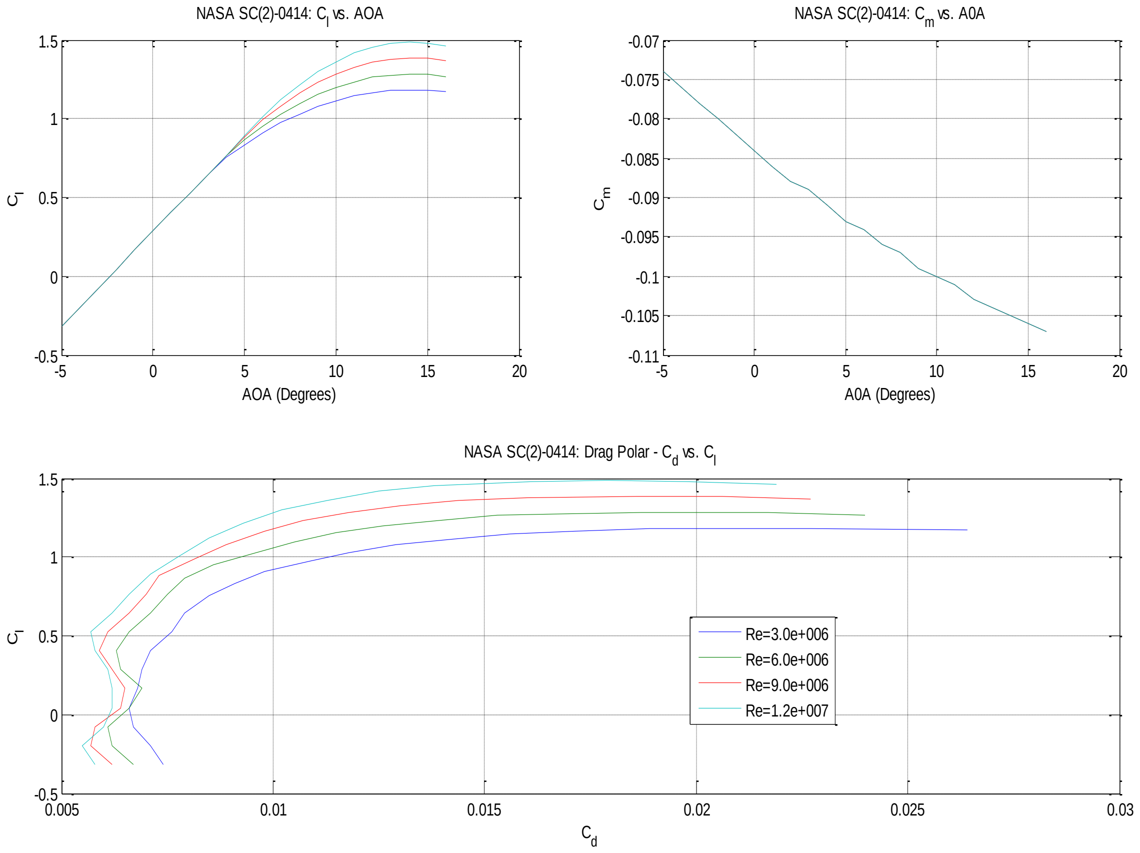

Figure 13 NASA SC(2)-0414 airfoil characteristics

The figure above shows the fundamental relationship between the C_l and the angle of attack of the wing. This graph is also known as the lift curve. This curve shows a linear part which is constant for all Reynolds numbers and a decaying curve depending on the flow's Reynolds number.

The linear part of the lift curve is of great importance because this is the range at which the airplane will normally operate. Aerodynamically speaking this range explains how the lift coefficient of the airfoil varies with changes in the wing's angle of attack. This part of the relationship of the lift curve can be approximated mathematically by,

$$C_l = C_{l_\alpha}(\alpha - \alpha_0) \qquad 2)$$

where C_{l_α} is the lift curve slope in *1/rad* and α_0 is the angle of attack for zero lift. Theoretically, the lift curve slope should approach *2π/rad* for very thin airfoils and the zero lift angle of attack should be a negative angle (19). The NASA SC(2)-0414 exhibits a lift curve slope of *2.18π/rad* and a zero lift angle of attack of -1.5°.

The nonlinear ranges of the curves show the characteristics of the airfoil as it approaches stall depending on the Reynolds number. Figure 13 shows that this airfoil exhibits a maximum lift coefficient ranging from 1.2 to 1.5 in the selected Reynolds numbers.

Figure 13 also contains a graph showing the relationship between C_l and C_d otherwise known as the Drag Polar. This graph provides two important quantities, the zero lift drag coefficient, C_{d_0}, and the lift to drag ratio, C_l/C_d. Both of these quantities are a function of the Reynolds number of the flow and therefore it is left for the reader to verify that this airfoil has lift to drag ratios from 100 to 300 and zero lift drag coefficients or mean drag of 0.006 to 0.0075 (60 to 75 drag counts).

Finally, the last graph of Figure 13 is the pitching moment curve which is the relationship between the C_m and the angle of attack. This graph shows how the magnitude of the moment of the airfoil decreases as the angle of attack increase. However, as it was explain before, it was necessary for this increase to not become sudden when the airfoil stalls, as shown by the figure. It is important to highlight that this moment is measured in accordance to the industry standard at the 25% chord.

MAIN WING DESIGN

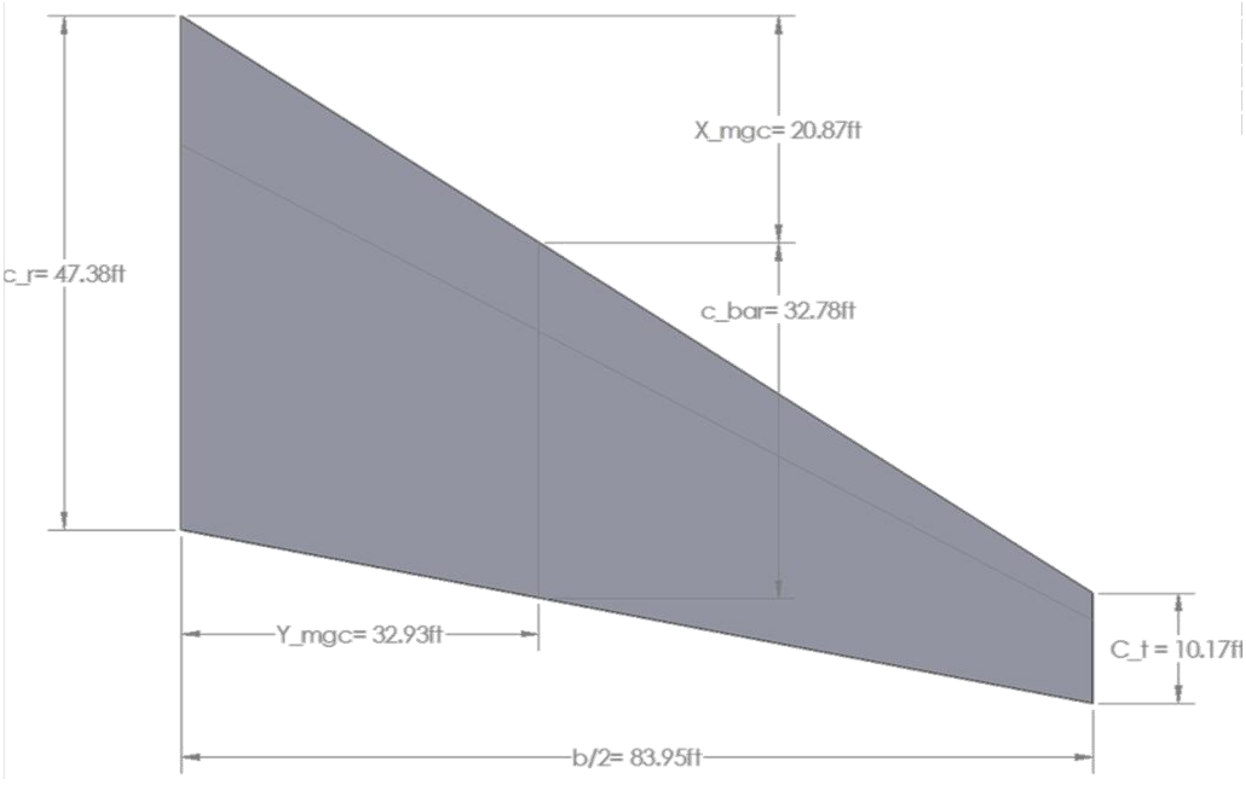

Figure 14 Dimensioned top view of the main wing

Due to the nature of the design objectives of the MedWing, the process for selecting a wing design was critical. The main wing design used the reference wing basic geometry of a trapezoid as the initial design. Said design can be seen in detail in Figure 14. After carefully studying and researching wing designs and control surfaces, it was decided that a high lift system with extensive control planform would be used in the design. This wing was based on the NASA EET. The study by Morgan in 2002 is based on an airfoil design, which NASA fits into a high efficiency wing design (17). Due to the fact that the airfoil selection for the MedWing is a supercritical airfoil, similar to the EET, this wing planform fits well with the airfoil and the mission requirements. After extensive adaptation, the wing was designed with an aerodynamic package consisting of inboard and outboard high lift flaps, low and high speed ailerons, wider and more extensive slats, and winglets.

Similar to the EET wing design, the high-lift flap for this model consists of a part-span double-slotted trailing-edge flap and a full-span leading-edge slat (17). The trailing-edge flap is a combination of a large-chord vane with a set of small-chord flap. Following development both by NASA and other aircraft manufacturers, this vane-flap combination will achieve a two-dimensional lift coefficient on the range of those achieve by heavier and more complex triple-slotted flap arrangements (17). The lift coefficient increase due to such arrangement can be found in the next section.

The high/low speed aileron combination will allow the airplane to be maneuverable at a wider range of speeds. Due to its design requirements, the high-speed aileron will allow the pilot to perform fast, and stable turns without increasing drag or creating large moments about the latitudinal axis of the aircraft. Meanwhile, the low-speed aileron will allow crucial control at low altitude and low speed approaches during the airplane's rescue missions to unprepared environments. The difference between the aileron groups also allows minimal wing twisting when the ailerons are deflected at high speeds, hence minimizing wing loading effect and possible material failure due to stress (20).

The winglet of the wing was designed with the idea of increasing the effective wing span without having to carry any additional weight (14). This is achieved by impeding the high pressure flow from reaching the low pressure area on top of the wing. This process increases the area of pressure differential of the wing, hence creating more lift, while also decreasing the size of the vortices or wake turbulence left by the airplane. This makes the airplane more airport-friendly and capable of landing in high traffic, small airports without causing destructive damage to nearby small airplanes.

The final component of the wing is the leading edge slats. These will enable the airplane to minimize takeoff and landing distance by increasing the maximum lift coefficient. On average, from historic trends, a leading edge slat will add an extra 0.4 to the maximum 2-D lift coefficient (3). In the case of the MedWing, the slats will be wide slats, allowing for a bigger deflection, hence decreasing stall speed and increasing wing area. The difference between normal slats and the wider kind possibly increases maximum lift coefficient by a total of an additional 0.2(20).

Historical data showing how the 2-D maximum lift coefficient of the airfoil increases due to high lift devices, can be found in the literature by Raymer (3). Table 8 shows the tabulated lift contributions of the high lift devices. These values of 2-D lift coefficient can be converted to wing (3D) lift coefficients using historical trends and the following equation (3),

$$\Delta C_{L_{max}} = 0.9\Delta C_{l_{max}} \left(\frac{S_f}{S_w}\right) \cos \Lambda_{HL} \qquad 3)$$

Table 8 Approximate lift contributions of high-lift devices

High Lift Device	$\Delta C_{l_{max}}$	c_f/c_w	$\Delta C_{L_{max}}$
Flaps			
Plain/Split	0.9	n/a	0.34
Slotted	1.3	n/a	0.49
Fowler	$1.3c_f/c_w$	1.3	0.64
Double slotted	$1.6c_f/c_w$	1.3	0.79
EET / Triple Slotted	$1.9c_f/c_w$	1.3	0.93
Leading Edge Devices			
Fixed Slot	0.2	n/a	0.08
Leading edge flap	0.3	n/a	0.11
Kruger Flap	0.3	n/a	0.11
Slat	$0.4c_f/c_w$	1.17	0.17

With this number of passive enhance lift devices, the MedWing will be able to land on and takeoff from short unprepared fields. The change in maximum lift coefficient, following data and research, is estimated to be in the order of 1.11. The final design of the wing can be seen in Figure 15.

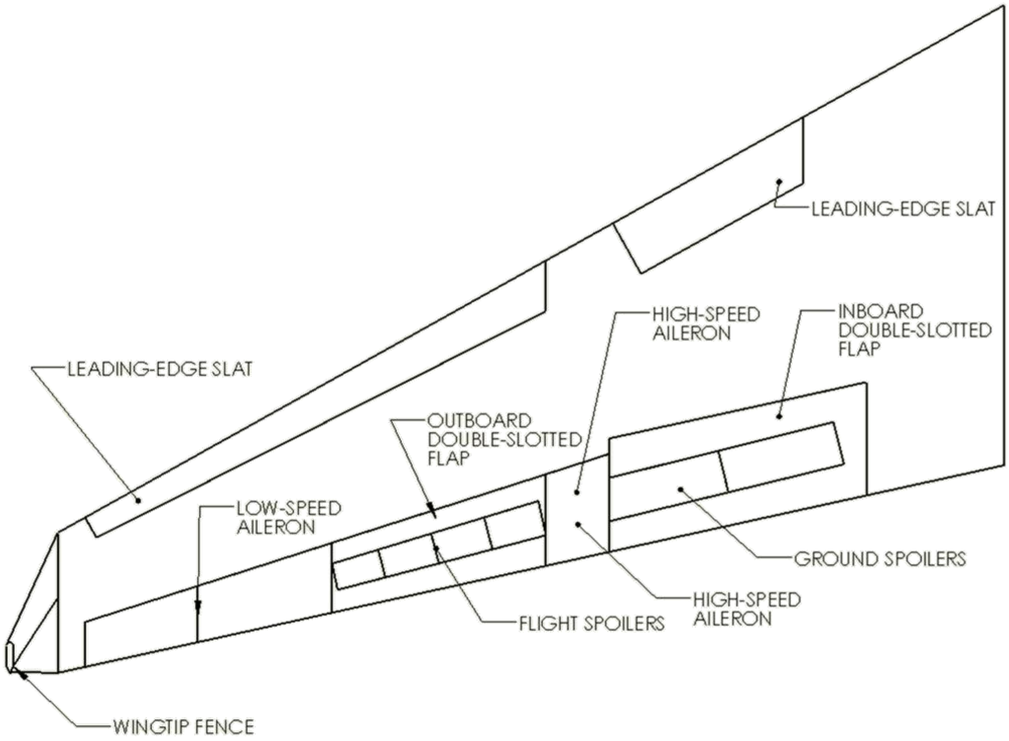

Figure 15 Top view of the high-lift package of the main wing

Table 9 provides the dimensions of each of the high lift devices installed in the wing as a function of the section wing chord and the half wingspan of the wing.

Table 9 Dimensions of the high lift devices

Device	Chord	Span
Inboard Leading Edge Slat	15.50%c	25%$\frac{b}{2}$
Outboard Leading Edge Flap	15.50%c	54.30%$\frac{b}{2}$
Inboard Double-Slotted Flap	30%c	28.70%$\frac{b}{2}$
High-Speed Aileron	30%c	6.70%$\frac{b}{2}$
Low-Speed Aileron	30%c	26%$\frac{b}{2}$
Ground Spoilers	11.50%c	26%$\frac{b}{2}$
Flight Spoilers	11.50%c	26%$\frac{b}{2}$

c= Section Wing Chord $\frac{b}{2}$=Half Wingspan

ESTIMATION OF THE PASSIVE LIFT OF THE WING

Once the airfoil and the wing planform have been selected, a series of approaches can be used to calculate the aerodynamic characteristics of the wing. The maximum lift coefficient, C_{Lmax}, the lift curve slope of the wing, $C_{L_{\alpha_w}}$, and the zero lift angle of attack of the wing, α_{0_w}, are of particular interest.

The maximum lift coefficient of the wing dictates the maximum lift that can be achieved by the wing at a given altitude and velocity. Like an airfoil, it occurs at a given angle of attack and it marks the point at which an increase in angle of attack will begin to stall the wing. The C_{Lmax} of a wing is a combination of the C_{lmax} of the airfoils of the wing, the planform of the wing and the incidence angle of each section of the wing. An accurate method to estimate the maximum lift coefficient of a wing is the Shrenk's

Approximation. The procedure determines the distribution of station lift coefficients across the span for a certain value of the airfoil lift coefficient and then scales this distribution up until at some point the section coefficient exceeds that of the airfoil (21). In other words, the approximation calculates the basic lift due to the airfoil and adds the additional lift created from the planform by averaging an elliptical (ideal) distribution. The total lift is then scaled up until a section of the wing stalls which by definition would be just after the $C_{Lmax.}$ Figure 16, below, shows the resulting lift distributions due to wing twist angle (basic lift) and the average lift distribution (additional lift), as well as the scaled up lift distribution to obtain the $C_{Lmax.}$ The final result for the $C_{Lmax,}$ $C_{L_{\alpha_w}}$ and α_{0_w} are shown in Table 10. The value for $C_{L_{\alpha_w}}$ and α_{0_w} were obtained following a detailed derivation by Roskam which leads to Equation 4,

$$C_{L_{\alpha_w}} = \frac{2\pi AR\, f_{gap_w}}{2 + \left\{\frac{AR_w^2 \beta^2}{k^2}\left(1 + \frac{\tan^2 \Lambda_{c/2_w}}{\beta^2}\right) + 4\right\}^{1/2}} \qquad 4)$$

where f_{gap_w} is the gap correction factor, β is the Prandtl-Glauert transformation factor and k is the ratio of incompressible sectional lift, all by Roskam (16).

Using the data compiled in Table 8 and the calculated clean C_{Lmax} for the wing, it is possible to figure out the final maximum lift coefficient due to passive high lift devices. It is important to realize that the exhaust from the turbofan will act as an active high lift device.

Table 10 Comparison between the 2D to the 3D passive aerodynamic data

	Airfoil	MedWing	
$C_{l_{max\ clean}}$	1.6	1.48	$C_{L_{max\ clean}}$
$C_{l_{\mathrm{max}\ \mathrm{f-passive}}}$	4.53	2.827	$C_{L_{\mathrm{max}\ \mathrm{f-passive}}}$
C_{l_α}	0.1199/°	0.0992/°	$C_{L_{\alpha_w}}$
α_0	-1.5°	-4°	α_{0_w}

Re=12x10^6

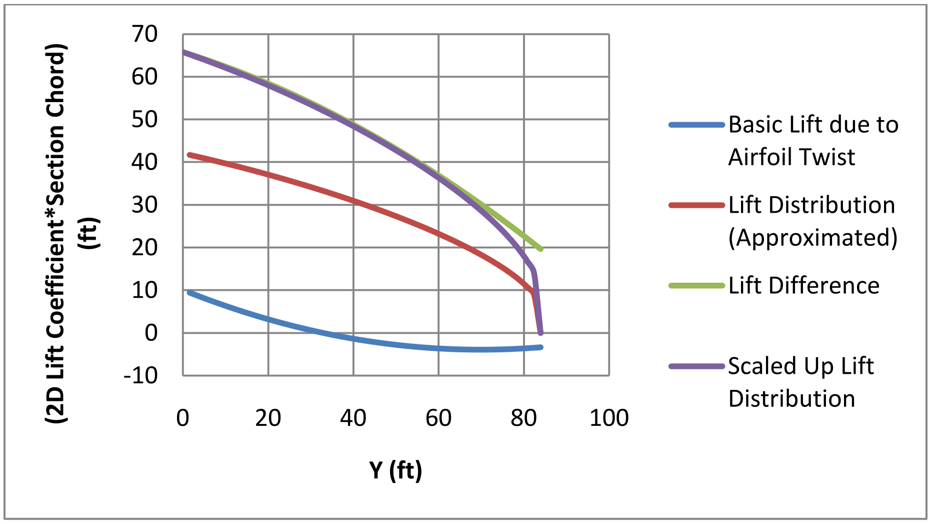

Figure 16 Shrenk's approximation lift distributions

ESTIMATION OF THE ACTIVE LIFT OF THE WING

For aircraft whose principle design driver is short take-off and landing (STOL), it is common that passive lift devices do not generate the needed increase in maximum lift coefficient. These cases require active flow control approaches to generate the desired extra lift. Some common approaches to active lift enhancements fall in three main categories: Upper Surface Blowing (USB), External/Internal Blown Flaps and Vectored Thrust (5). USB is the use of high velocity air stream being directed over the upper surface of the main wing to generate more lift. This requires for the engines to be installed above and forward of the wing. In addition to the aerodynamic lift gains of blowing high velocity air over the wing, USB also provides a downward component of thrust. The ability of a fluid to follow a curved surface such as a flap is known as the Coanda effect. Since the trailing edge of the flap points towards the ground, the air stream will follow the flap and separate at the trailing edge heading towards the ground and therefore producing downward thrust. Figure 17 shows the schematic of the USB lift enhancement showing the location of the engines as well as the theoretical flow path across the double slotted flaps.

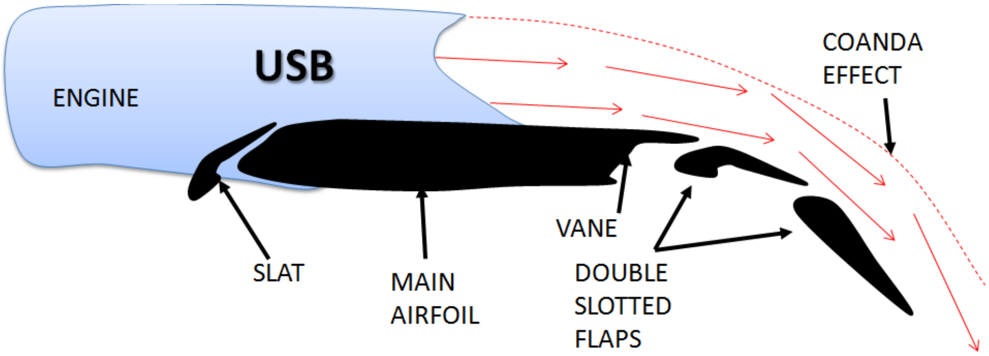

Figure 17 Schematic of active lift enhancement: upper surface blowing

The effectiveness of this active flow control can be quantified by using yet another coefficient; the blowing coefficient. The blowing coefficient is defined as

$$C_j = \frac{Thrust}{qS_w} = \frac{\frac{T}{W}\frac{W}{S}}{q} \qquad 5)$$

where *T/W* and *W/S* are the thrust loading and wing loading respectively. Using the data from Table 7, it is possible to calculate a blowing coefficient of 0.058 using sea level conditions at M_∞=0.7. In accordance to the data collected by Malmuth, et al. the blowing coefficient is related to an increase in C_L as shown by Figure 18, which states that a blowing coefficient of 0.058 means an increase in C_L of 1.10 (22).

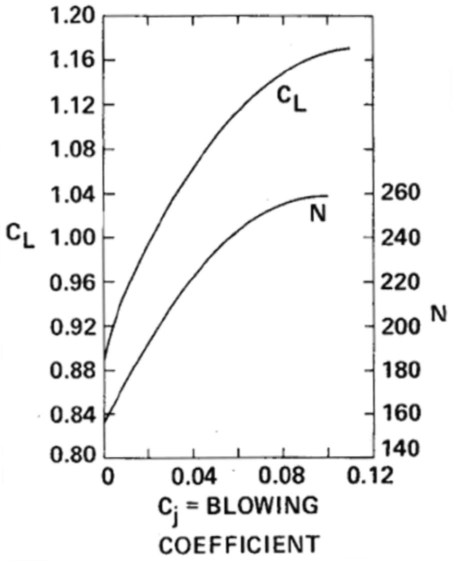

Figure 18 Variations of C_L as a function of blowing coefficient at flow Mach number of M_∞=0.7, α=0° (22)

By using the data tabulated in Table 10 and the calculated active lift coefficient contribution it is possible to see that the MedWing can generate a $C_{L_{\max f-\text{active}}}=3.927$ which is significantly higher than the required for a

4,500ft takeoff roll. This leads to the conclusion that the MedWing can decrease its takeoff roll significantly if it employs all its lift enhancements.

Chapter 6 – Interior Hospital Design:

Very rarely does aerospace design have to actively design a complex interior layout such as that of a hospital. As it was previously discussed, a mobile hospital requires some key instruments and areas to be able to function. Some of these areas are a surgical suite, a clinic, a pre/post sterilization room and a recovery room. Hospitals also require a good source of electricity, surgical gases, and water. It is obvious how these equipments require a large amount of space which is foreign to many airplanes and how therefore such design is extremely complex. This section will provide a sample layout of the interior of the MedWing giving detailed dimensions of the different areas of the aircraft.

Trends of primary healthcare show that new hospitals are being design around the principle of group practices (23). Group practices are the combination of a group of doctors with different specialties all working with a shared staff and premises. The design of hospitals around this principle is to provide consultations, treatment diagnosis, minor surgery and health education all in the same location. MedWing is being designed following such idea and therefore, maximizing the amount of treatment available but minimizing the area required. However, there are some requirements other than space and treatments which must be addressed in the design of hospitals. The location of the hospital is of great importance. Hospitals should be at places that are convenient in relation to the people it serves. There is no way that a hospital can do its mission if the people it is supposed to serve are not in the vicinity of the healthcare center. Fortunately, the main objective of the MedWing is to address this precise problem. Capable of flying to meet its patients, MedWing will always be at the location where it is needed regardless of how remote it can be, that is providing that it has access to flat fields ranging 4,500ft or more.

The design of the facility should also be able to provide easy circulation within the building for patients in wheelchairs, people with disabilities and patients with need of stretchers. This necessity was addressed with the mission specification which required that the hospital aisle or corridor width of at least 3.25ft.

Another important aspect of hospitals is their security. With the rising cost of medical care and the availability of drugs, hospitals have become targets of a lot of crimes by drug addicts. In foreign soil, medical crimes are so common that lately traveling for humanitarian doctors have become a predicament. Humanitarian organizations have resulted to the point of making doctors have to carry their own medicines and instruments as part of their carry-on when traveling in order to ensure that the equipment will make it pass customs (24). MedWing has been developed to partially solve this kind of problems. Since, the aircraft will carry its own equipment onboard; it will be able to clear foreign customs as a whole, therefore limiting third party contact and reducing the chances of medical related crimes. During its mission, MedWing will protect itself against crime by carefully screening all personnel coming onboard the aircraft as well as using a complex internal video recording system.

A hospital must also provide both privacy and confidentiality to its patients. Although, the current trends in hospital design are moving towards the preference of two or more beds per room due to the decreasing length of patient stay, new hospitals have developed methods to efficiently provide the needed privacy (23). In the case of MedWing, a hospital without a residential area, the rooms will be able to provide limited privacy by implementing curtains and dividers in between the recovery beds.

Finally, the last necessities which the interior design must address consist on the arrangements of the rooms itself. The best way to arrange a hospital can be determined by studying the typical needs of an incoming patient. Architectural data has been collected which states how different rooms and equipments must be connected for the successful handling of a medical mission (23). This data has been tabulated and can be found in Table 11, below. The table differentiates the needed connectivity between the hospital areas into four categories ranging from a very good connection to no connectivity need.

Table 11 Connectivity between hospital areas (modified from (23))

	Operating	Sterilization	Laboratory	Examination	X-Ray	Recovery
Nursing				Δ	○	Δ
Operating		Δ	○			Δ
Sterilization						Δ
Laboratory				□		□
Examination					○	
X-Ray						○
Recovery						

Δ= Very Good Connection Required
○= Good Connection Required
□= Connection Desirable

OPERATING THEATER

Historical trends in surgical department design show that these have been often planned within hospitals as a centrally located examination and treatment unit for the use of various special departments (4). This way they provide better utilization of the space, equipment and staff. It also helps maintain a clean suite since having the surgical suite centered in the hospital provides longer distances from contaminants.

To understand the design of said department, it is necessary to understand its purpose. The surgical suite is where patients whose conditions have been diagnosed but cannot be cured solely with medications receive treatment. In accordance to this purpose and Table 11, it can be seen how the surgical suite needs to be close to the sterilization area, the recovery area and if possible the laboratory.

Additional aspects that affect the design of the operating suite are derived from the needs of the surgeries themselves. Now more than ever, doctors have available technological instruments that allow for better and safer surgeries. These instruments often are large in size and heavy, both characteristics which are not appreciated by aeronautical engineers. Table 12 shows some of the typical equipment found in operating rooms as compiled by ORBIS International (9).

Table 12 Various typical operating room equipment (9)

Operating Room (OR) Devices	Quantity Needed	Estimated Unit Cost ($)	Estimated Weight (lbs)
Surgical Microscope	1	$ 75,000.00	510
Anesthesia Machine	1	$ 53,000.00	430
Anesthesia Monitor	1	$12,000.00	25
Transilluminator	1	$ 2,000.00	10
Diode Laser	1	$ 32,000.00	37
Monopolar Cautery	1	$ 6,000.00	11.5
Bipolar Cautery	1	$ 6,000.00	4
Wall Suction unit	1	$ 600.00	1
Infusion Pump	1	$ 1,200.00	2
Fiber Optic Headlight	1	$ 1,500.00	18.2
Overhead OR Lights	2	$ 3,000.00	50
Freestanding Halogen OR Light	1	$ 1,200.00	40.5
Ophthalmoscope	1	$ 5,000.00	2
TOTAL		**$ 198,500.00**	**1,141.20 lbs**

Among the equipment tabulated above, surgeons also require surgical gases such as oxygen, ozone and nitrous oxide. Transporting these gases is extremely hard due to their volatility, weight under compression, as well as the rapid decay of ozone into diatomic oxygen (25). MedWing will be design to carry oxygen and ozone generators. Oxygen concentrators or generators are common in the medical and aerospace industries. In the aerospace industry, oxygen is often concentrated by chemical reaction generators which are used in case of sudden cabin decompression. These generators are used only in emergencies and are therefore only effective for short time (20-30mins) intervals. MedWing will need to use medical class generators which provide a constant stream of oxygen upon request. For emergencies, the aircraft will carry oxygen bottles which can be used should the generator fail. The ozone generator to be used is a Corona Discharge Tube which will produce ozone from ambient air and create nitrogen oxide as a by-product (25). This is of great used since anesthesia machines use nitrous oxide as a working gas. Both gas generators will be located in the cargo level towards the center of the aircraft to minimize CG displacement.

Federal regulations also estipulate requirements such as that the surgical theater be isolated from the rest of the hospital rooms. This requirement is set forward to maintain the hygiene and sterilization of the area. MedWing will accomplish the following by placing the surgical suite in the top level and towards the center of the vehicle. This will maximize the distance that contaminants need to travel to enter the surgical suite. The Air conditioning system will be used as a passive *clean room technology* by using it as a low turbulence displacer to move germs out of the room (23). The air conditioning will also filter, dilute and compress the air prior to exhausting into the surgical suite. The surgical suite will be constructed using a hermetic sealing which will ensure no uncontrolled inward air flow from neighboring rooms. In addition, all the sterile areas of the hospital will use protective pressurization to ensure clean air. Protective pressurization is the act of pressurizing areas to higher than normal pressures such that when the doors leading to or from these areas are open, the air will escape in the outward direction, not letting air come into the room. Rooms will be pressurized as follows: highest pressure in the operating theater, followed by the anesthesia/sterilization room and the lowest pressure in the auxiliary rooms. This will create the required pressure gradient which will move the air outwards from the theater to the areas requiring less protection.

As a consequence of all the requirements highlighted above, the surgery room design was given priority in the interior design. It was decided that due to the weight of the equipment it contains and its need for stability, that the surgical room would be located in the center of the plane near the center of gravity. Following the idea, of using the aircraft also as a classroom to teach the community to help itself, the surgical room was designed to have two windows for people to observe the surgery. Said windows would be placed facing to the outside corridor and the conference/administration room. In addition the surgical theater will be equipped with a remote control audio visual system which will allow the broadcast of the surgery throughout the aircraft should the mission call for it.

The operating theater also possesses two entry methods. The main entry method is a set of electrical sliding doors heading towards the sterilization room. These doors are operated by foot switches for hygiene reasons. In the other corner of the room, a small doorway to the outside corridor has been designed. The main objective of this door is to allow personnel to exit the theater shall they not need to use the sterilization room. During surgery, this door will be sealed from the inside as to prevent intrusion of non-personnel as well as contaminants.

In order to maximize the cabinet space of the operating theater, this one has not been fitted with exterior windows. Artificial lighting will provide the required light needed for surgery. According to medical regulations, the provided light should provide a minimum of 1000lux (4). It should also be able to be moved to provide light without shadows depending on the surgical incision. It has been chosen that the MedWing will use a mobile ceilingpendant operating light equipped with large number of halogen lights as well as auxiliary small directional lights.

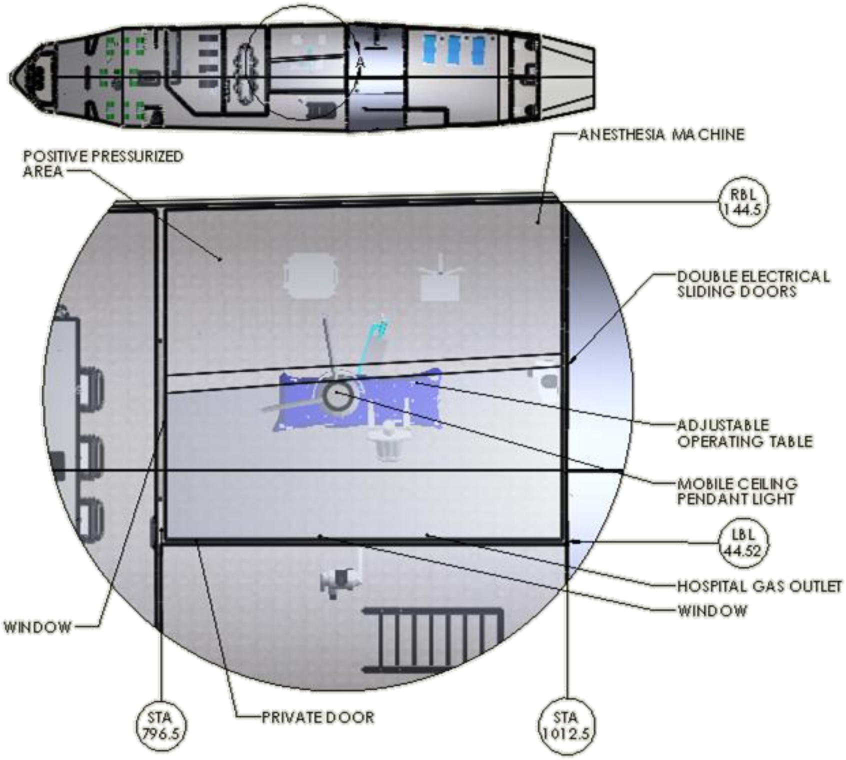

Figure 19 Detailed view of interior design of the surgical suite

Finally, the surgical room will be connected to two separate power supplies which will be located in the cargo deck of the aircraft. Both APUs will be used during the whole mission; however, one will be used as a slave of the other in order to minimize the amount of fuel needed to run these electrical generators while maximizing the power output.

Figure 19 shows the final design of the surgical suite in a schematic drawing. It has been dimensioned by stations and buttock lines. It also has been noted to show the key features of the room. Some of the equipment has been modeled in CAD to ease the identification of the room, however much of the equipment is not shown. Figure 20 shows a virtual rendering of the surgical suite.

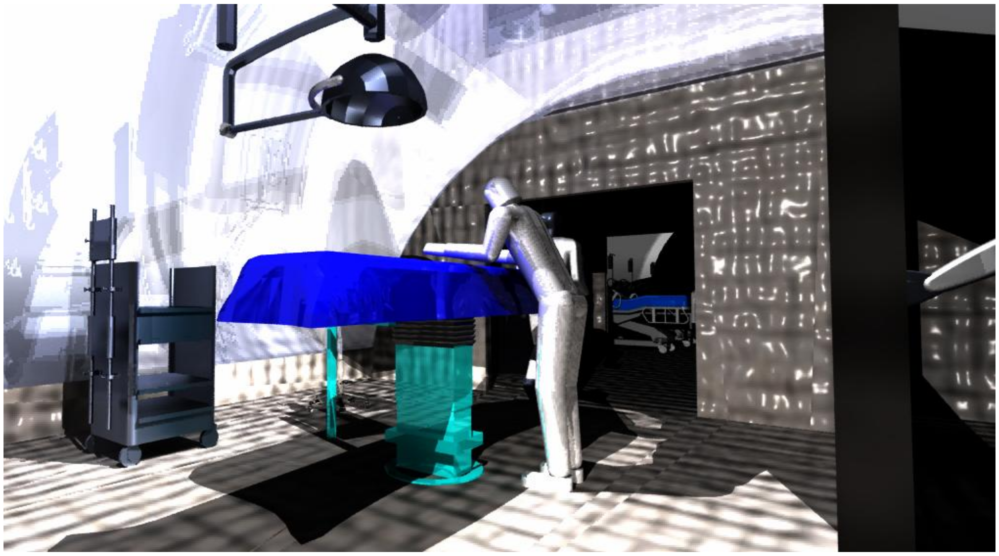

Figure 20 Virtual rendering of a surgical scene in the operating theater

PRE/POST OPERATION ROOM

It is obvious that surgeries are delicate processes that require highly hygienic areas due to their nature. However, just like the actual procedure, the pre and post surgery actions are highly important to the success of a good surgery. This is to the point that special rooms or areas are designed for said procedures. In hospitals, where space is not a significant constraint, the surgical department has a set of sterile rooms ranging from an anesthetics room to a separate washroom.

The anesthetics room is the last preoperative area that the patient enters before the surgical theater. In this room, the patient receives either local or general anesthesia to numb the body and minimize pain felt during the procedure. There are various different types of anesthetics that can be used and the choice depends on the actual procedure being performed. The choice of anesthetic also defines the equipment required to administer it. However, the medical hospital should be prepared with all the necessary equipment to successfully numb a patient. In addition to an anesthetic room, largo hospitals also have an anesthetic discharge room which is identical to the anesthetic, but it is used for post operative procedures. Both of these rooms should have access to a refrigerator, a draining sink (sluice), rinsing lines, cannulas, connections to the anesthesia gases and emergency power. Due to the space requirements of the MedWing, it will be impossible to have a separate room for the purpose of anesthesia only. Instead, MedWing will use part of the surgical theater as a pre-operative area where anesthesia can be administered.

Surgical departments also include a small room designated the washroom. The washroom is the room the surgeons use both immediately prior and immediately after the operation. This room is often divided into clean and non clean subareas to preserve a more hygienic environment. However, from the hygiene point of view a single large room is also adequate (23). This room should include non-splash wash-basin with foot controls and sterilizers or autoclaves to ensure the equipment remains sterile until the surgery. The door leading into the operating theater should have inspection windows and ideally be electrical also operated with foot controls (23). Swing doors can be used if cost saving is a priority (4).

A final room that is often attached to the surgical theater is the sterile goods room. This room is flexible in size but it must contain all the equipment that is ready for the surgical procedure. It often contains small autoclaves which are used for instrument sterilization although major sterilization occurs in a separate room away from the theater (23).

Given that the MedWing is an aircraft which by nature has limited space and volume, it has been decided that all the previous room will be combined into one pre/post-operation room. This room will serve as the hospitals washroom, sterile good, small equipment storage, and substerilization room. Since the operating theater has been placed in the center of the second floor (main cabin) of the aircraft, the Pre/Post-operation room will also be placed in the same level. It will be place towards the rear of the aircraft to allow room for the recovery room and the clinic.

In view of the fact that the Pre/Post-operation room has been placed in the second floor, a method to get surgery patients into the room must be design. It was decided that a small elevator, capable of lifting a patient in need of a stretcher or wheelchair, would be fitted to the room. The elevator will take the patient from the ramp at the cargo deck to the Pre/Post-operation room where the patient would be received and admitted into the hospital. The room also includes two sets of electrical sliding doors operated with foot controls. The first set is the doors leading to the operating theater and the second leads to the recovery room.

The Pre/Post-operation room will house a lot of equipment and instrument since it is a multipurpose area. Some of the equipments needed by the Pre/Post-operative room are highlighted in Table 13 from an equipment list compiled by ORBIS International (9).

Table 13 Various typical pre/post operation room equipment (9)

Pre/Post Operation Devices	Quantity Needed	Estimated Unit Cost	Estimated Weight (lbs)
Tuttnauer Autoclave	2	$ 5,500.00	100
Ultrasonic Cleaner	2	$ 1,200.00	17.5
Flash Autoclave	1	$ 6,000.00	50
Reverse Osmosis System	1	$ 1,000.00	100
Scrub Sink	1	$ 1,200.00	220
Refrigerator/ Freezer	1	$ 3,000.00	150
Surgical Microscope	1	$ 10,000.00	5
A/B ultrasound Scanner	1	$ 12,000.00	21
Patient Monitor	1	$ 12,000.00	10
TV monitor	1	$ 4,000.00	40
Ophthalmoscopes	3	$ 6,000.00	1
Incubator	1	$ 150.00	100
Diode laser	1	$ 55,000.00	20
Portable Cryo	1	$ 3,500.00	10
TOTAL		**$139,250.00**	**964.00 lbs**

Figure 21 below shows the final dimensioned model and design of the Pre/Post operation room. It shows the two separate areas: wash and soiled. It also shows the location of some of the key instruments and equipments installed in this room.

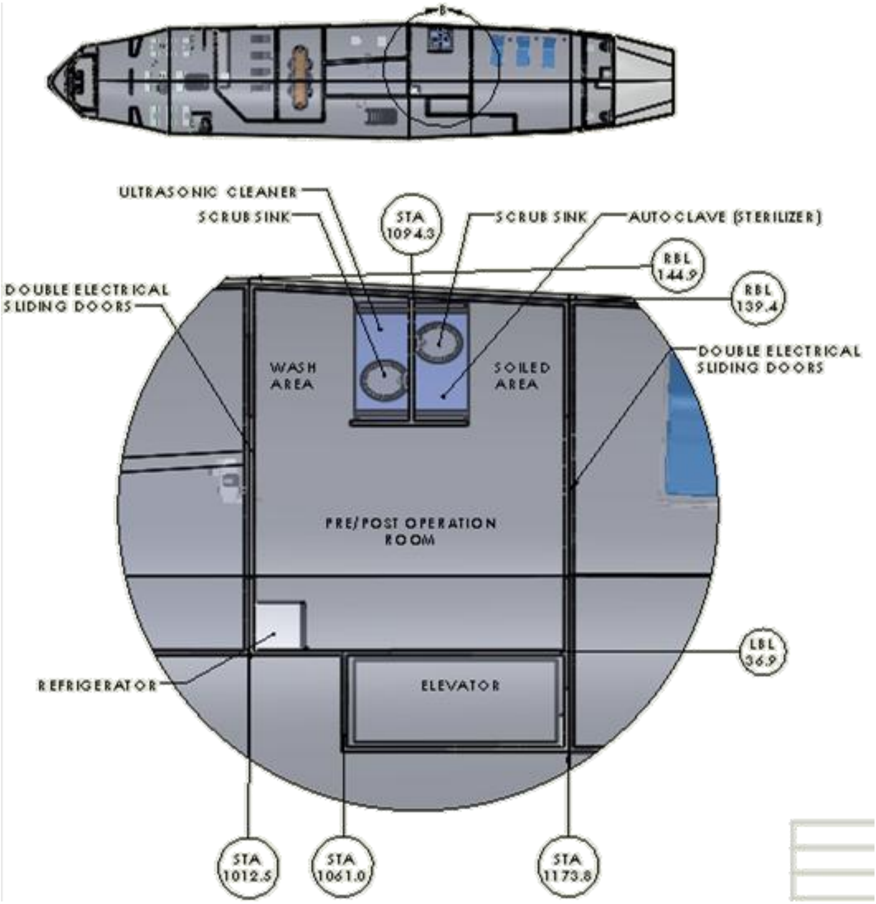

Figure 21 Detailed view of interior design of the pre/post operation room

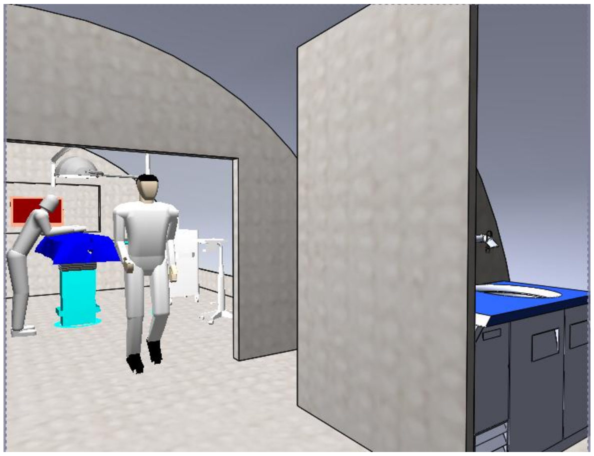

Figure 22 Virtual rendering of the pre/post operation room

RECOVERY ROOM

The recovery room design is much simpler than the operating room since it has fewer requirements than the latter. The fewer requirements are due to the nature of the procedures that occur in this area. The recovery area, like the name implies, is the area where patients recuperate from surgical procedures. Not all patients need to spend time in the recovery room, and the amount of time that they will require depends solely on the person and the surgical procedure. In accordance with Neufert, recovery rooms must accommodate all the post-operative patients from all the operating theaters. Fortunately for the MedWing, it only has one operating theater, meaning that the recovery room only has to accommodate 2 beds (23). However, it is important to highlight that although the architectural data says that 2 beds per surgical suite are enough; this is under the key assumption that the hospital also has a residential area for patients to spend the night. In the case of the

MedWing, the recovery area is the only place for patients to stay if they require any source of overnight attention. Following this idea, the place should be design to fit a least twice the amount of beds required.

Fitting four recovery beds into the recovery room can be challenging given that there are space requirements which state the minimum spacing between beds to ensure the safety of the patients. Recovery beds must not be too close together to prevent the anesthetist or his equipment from reaching at least three sides of the bed (23). Recovery rooms also often experience the presence of awkward equipment such as sublimation stands which require large amount of space.

The final requirements for the design of the recovery room are the fact that the recovery room should have access to clean water and lavatories as well as the nurses' lounge. The water and lavatories are required since the amount of time that patients might spend in this room is unpredictable. Nurses have to be available in the recovery room because often doctors can't be available the whole time and the nurses who are qualify to maintain the patients can help these recover.

Along with all these requirements, there are also the requirements set by the connectivity between areas table highlighted before. It is important that the recovery room be accessible by doctors, anesthetist and nurses fairly easy.

That said, it is also a good idea to have the recovery room separate from the surgical theater to prevent the spread of diseases.

When it comes to equipment of the recovery room, it often encompasses large amounts and different types of equipment since recovery rooms can have many different patients each with a different situation and need. Table 14 tabulates some of the common instruments and equipments found in a recovery room.

Table 14 Various typical recovery room equipment (9)

Device Name	Quantity Needed	Estimated Unit Cost	Estimated Weight (lbs)
Direct Ophthalmoscope	1	$ 500.00	2
Defibrillator	1	$ 6,400.00	14.5
Nerve Stimulator	1	$ 500.00	1
Ear Thermometer	1	$ 100.00	0.25
Oral Thermometer	1	$ 100.00	1
Glucometer	1	$ 100.00	0.5
Oxygen Monitors	3	$ 12,000.00	14
Portable Suction Unit	1	$ 600.00	9
Wall Suction Unit	3	$ 600.00	2.5
TOTAL		**$ 46,100.00**	**77.75 lbs**

The space needed to house all this equipment is limited. A detailed platform view can be seen in Figure 23 below along with key dimensions and equipment. It is important to highlight that the shower depicted in the female changing area is only for emergency purposes. Clean water is a precious item for the MedWing and the shower can only be used for emergencies. Doctors will sleep and shower in the community they are serving.

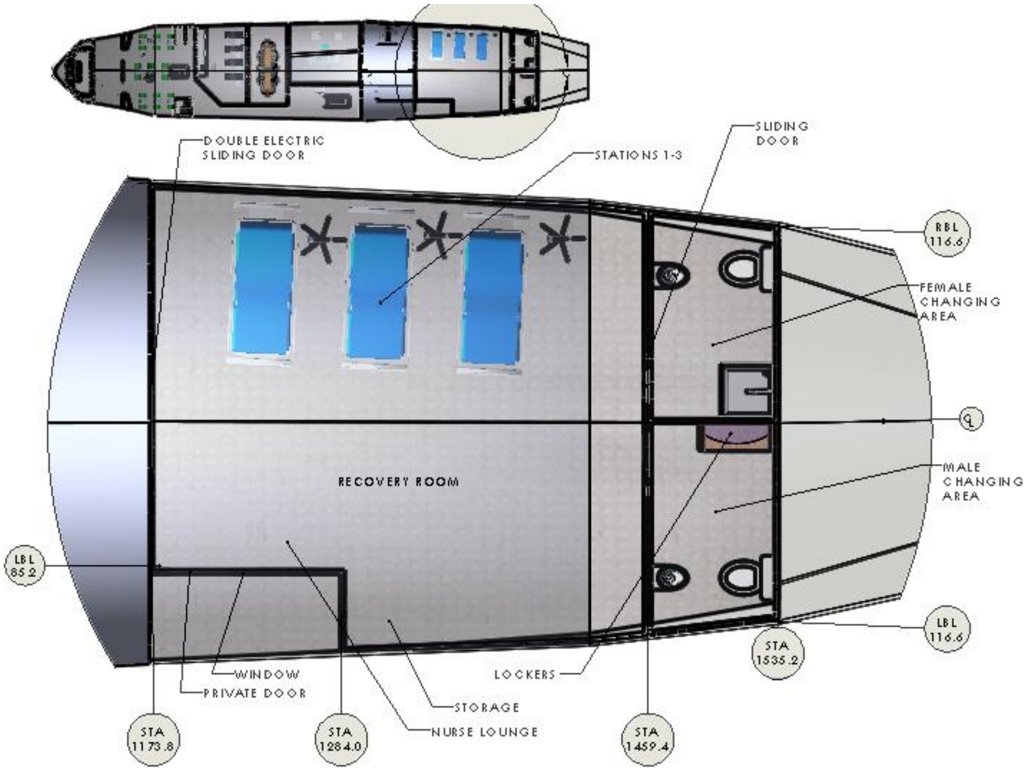

Figure 23 Detailed view of interior design of the recovery room

A rendering of the recovery room has been modeled and can be seen as Figure 24 below. This schematic shows three recovery beds in order to not clutter the image. In the back it is possible to see the changing areas as well as the emergency shower. The nurse lounge and the nurse storage are not depicted in the rendering.

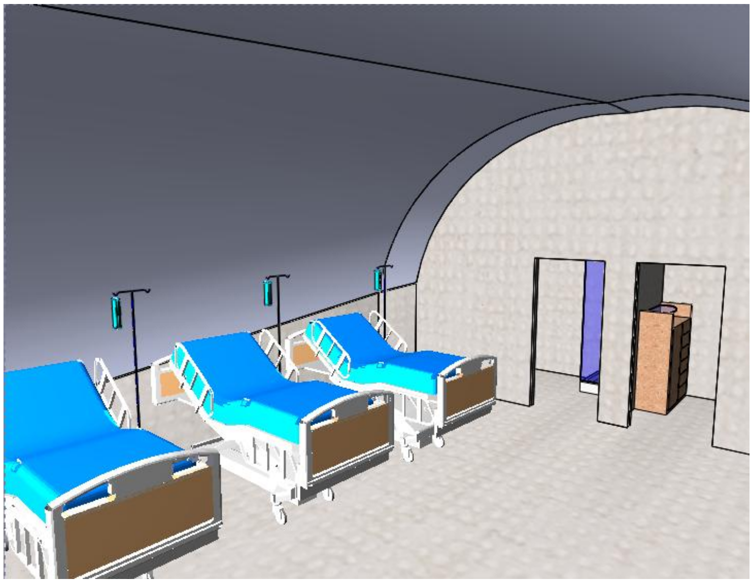

Figure 24 Virtual rendering of the recovery room

COMMUNICATIONS AND A/V ROOM

A cockpit is to an aircraft as the communications room is to the hospital side of the MedWing. That is, the Communication and A/V Room is the heart of the operations of the hospital. All administrative procedures can be done from inside this room, including controlling the closed loop video system. This room has been setup as a conference room which can be used for meetings between key personnel or for personalized instruction of the community in need.

In order for the room to serve as personalized classroom, it must contain visual access to the surgical theater both physically and through audio visual displays. The room has been fitted with a large window which faces to the inside of the operating suite and a 42in flat screen monitor which allows viewing of other angles using the closed loop video system.

The room will also serve as the A/V command center. This room has been fitted with the control panel of the closed loop video system which will allow users to select which cameras can be observed at any of the monitors aboard the MedWing. In other words, this room can serve as a small TV station for the hospital airplane, allowing community medical leaders to learn how they can also help their community.

Figure 25 shows a virtual rendering of the Communications and A/V room. The figure clearly shows the window facing towards the surgical theater as well as the door leading to the outer corridor. In addition, it is possible to see the A/V controls on the left side walls.

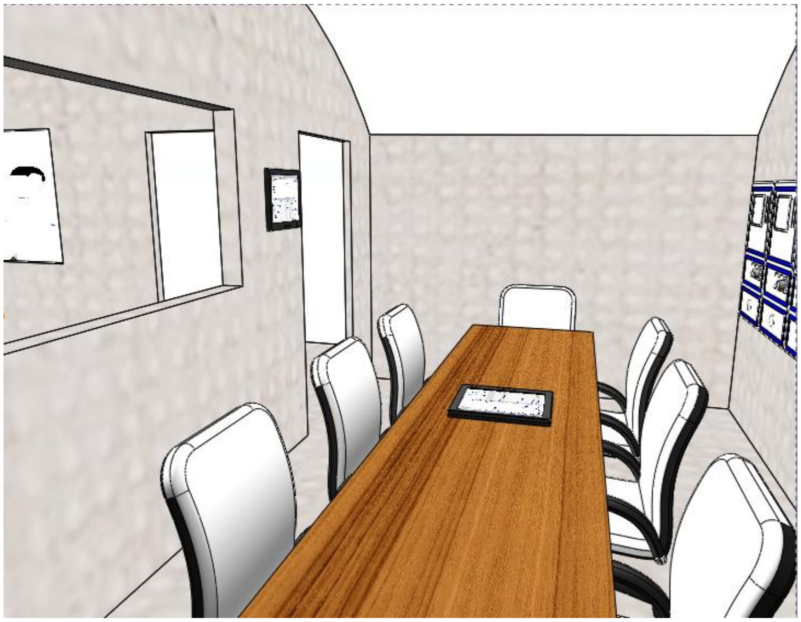

Figure 25 Virtual rendering of the communications and A/V room

A dimensioned schematic of the communication room has been included for reference as Figure 26. It also shows the locations of some of the key equipment found in said room. It is important to highlight that the chairs of the room, although modeled as regular desk chairs, they will need to be custom made to lock on place during flight and to contain seatbelts if this room is to be used during flight.

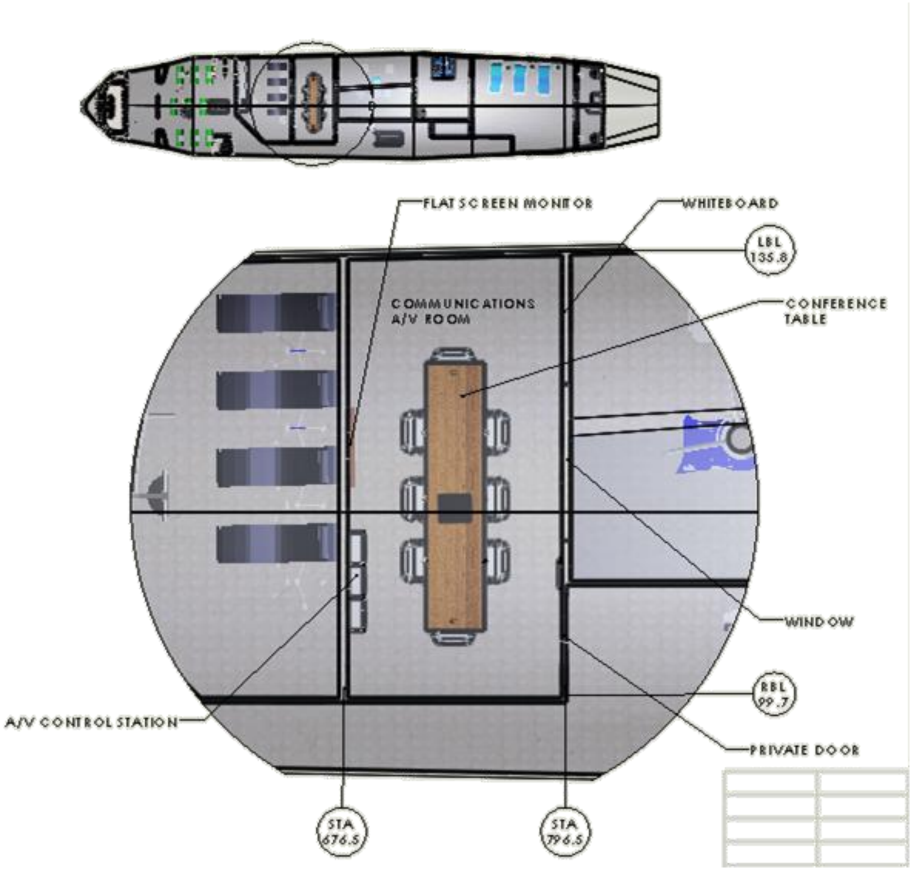

Figure 26 Detailed view of interior design of the communication and A/V room

CLINIC

A clinic is often a small private or public health institution serving mostly outpatients. Although some clinics are as large as hospitals, they always tend to be smaller in size and personnel. Very often, hospitals include some sort of clinical area where small procedures which do not required any surgical treatment can be performed. It was decided that a clinic should be included in the internal arrangement of the MedWing. Said clinic will maximize the amount of patients that can be helped while minimizing the use of the surgical theater.

The function of clinics is different depending on the community they are trying to help. For example, clinics in the USA range from free clinics which provide healthcare to people without insurance, to sexual clinics which provide solutions to sex-related problems. The MedWing has been designed to include a general out-patient clinic offering general diagnoses or treatments without an overnight stay. The clinic will also act as a polyclinic since it will need to provide various different types of treatments depending on the given mission.

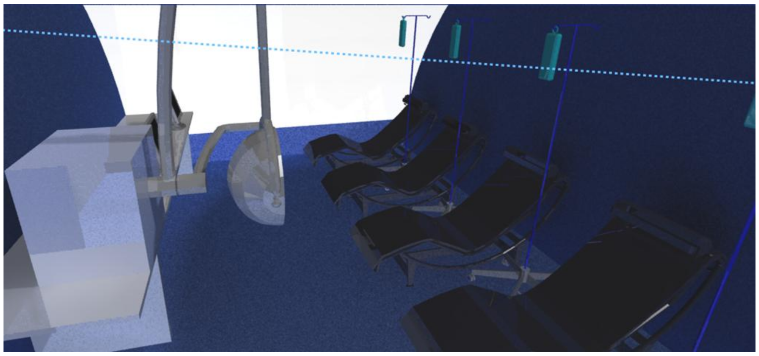

Figure 27 Virtual rendering of the clinic

Figure 27 shows the original rendering of the clinic of MedWing. In the image it is possible to see up to four workstations which can be each used for different procedures. The clinic has been designed to allow procedures such as blood diagnostics, stool diagnostics, x-ray and general checkup as well as quick non-invasive treatments.

A detailed schematic showing the dimensions and equipment locations of the clinic is shown as Figure 28. The stations labeled 1-4 will be used depending on the need of the patient. They can be used for either diagnostics or for application of treatments. The figure also shows the proximity between the clinic and the front stairs leading to the Biolab which will be use to process results from the diagnostic tests.

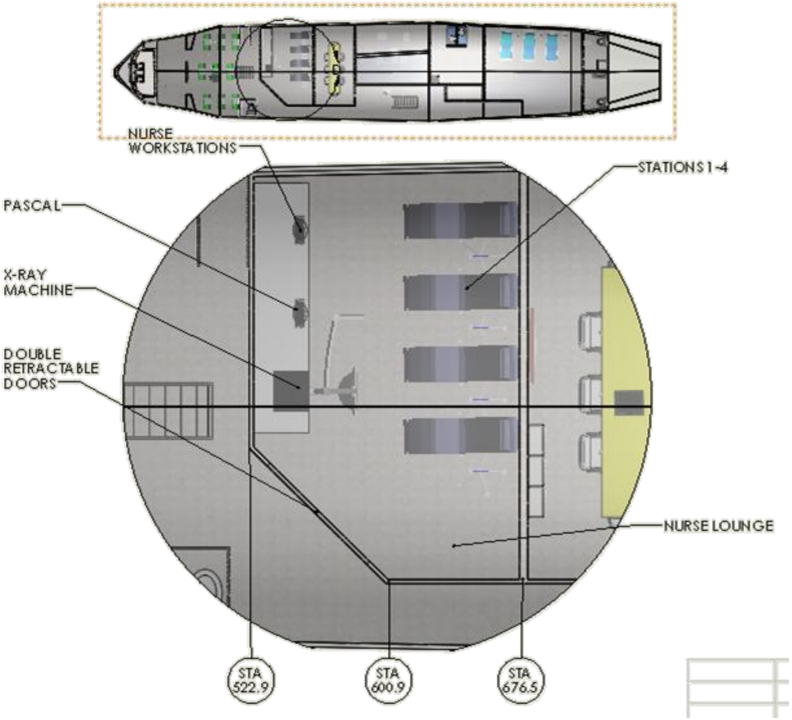

Figure 28 Detailed view of interior design of the clinic

PASSENGER CABIN / CLASSROOM

All rooms in the interior of the aircraft are being designed in accordance to regulations dictated both by the FAA and the American Hospital Association. The design of most rooms is not necessarily affected by the FAA regulations since the hospital is being certified for ground-usage only. That said, the passenger cabin is the only room where personnel will be while the aircraft is in-flight and therefore is heavily affected by the FAA regulations.

Following FAA regulations, the cabin has been designed such that during an emergency, no passenger will need to jump over more than three seats to get to an aisle. In order to seat the required 25 passengers, 27 seats have been placed in 3 sets of 3 seats abreast, each separated by an aisle. Regulations also dictated the number of emergency exits available for the passengers. For a seating configuration of 20 to 40 seats, there must be at least two exits in each side of the fuselage. The MedWing has been designed with two main exits in the front of the cabin and two in the back prior to the clinic. For the ease of the passengers, a lavatory and a small galley have also been installed in the rear of the cabin.

A passenger cabin would become useless space once the aircraft lands at its destination and therefore this space would be inefficient. In order to better use the space and to maximize the aid being provided to the community, said cabin has been designed to allow it to be used as a classroom during the mission. Every seat in the cabin has been intentionally located such that the occupants can easily see the flat screen monitor installed in the front of the cabin. Two white erase boards have also been installed in the side walls to allow for a better learning experience. The community members that use this classroom will be able to see everything that happens in the airplane thanks to its audio visual system controlled from the conference center. Figure 29 shows a digital rendering of the compartment showing sample seats and the lavatory in the back.

Figure 29 Virtual rendering of the passenger compartment

Figure 30 shows a schematic of the passenger deck with dimensions and key equipment highlighted. The stairwell shown in the figure leads to the Biolab located below the passenger compartment.

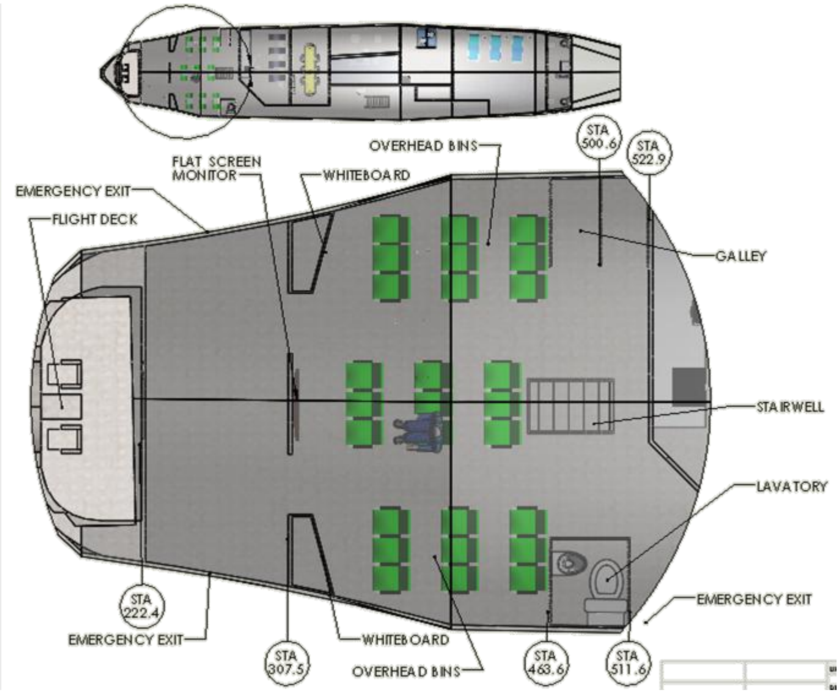

Figure 30 Detailed view of interior design of the passenger compartment

CARGO DECK AND BIOLAB

All the primary rooms have been placed on the second or upper deck of the aircraft; however, the mission would be impossible without the space for a cargo deck. The cargo deck is the primary hold space for all the payload, medicines and mobile equipment that will be used during the mission. Said space also holds all the required apparatus to operate the hospital such as the surgical gases and potable water. Although the internal arrangement of the cargo deck is not of particular importance, it is necessary to look into its design since it will greatly affect the location of the center of gravity.

A Biolab, installed in the front of the aircraft, is for diagnostics performed by the doctors. This room is a small place which can be used for processing of biomed materials. It housed equipment needed for the study of blood and stool samples as well as other biological substances. A set of internet workstations have been installed inside the room to allow doctors to connect with other doctors not in the mission to discuss particular cases of interest. This will allow the physicians to help the community by obtaining support and advice from specialist in the United States.

Passed the Biolab, a space has been left for the cargo hold. This space will be where all the medicines and payload will be kept during the mission. It will be fitted with cargo equipment such as modular rollers and crane actuators to help the loading and unloading of said equipment. It is estimated that this section will be very heavy and therefore it has been placed towards the middle of the aircraft to minimize CG displacement.

The next section of the cargo deck is the required hospital apparatus. As it was explained before, the hospital's operating theater requires a large amount of surgical gases which due to their weight and flammability are improper for flight. Generation equipment for these gases has been installed towards the center of the aircraft followed by a large water tank. The water tank will hold enough water for the duration of the mission. It is important to highlight that the aircraft will only carry enough water for medical reasons, not for personal hygiene of the personnel. The following compartments passed the water tank are the auxiliary power units. Two APUs have been installed towards the center of the cargo department to allow for constant and reliable electrical power during surgery.

The elevator shaft and loading ramp have been left towards the rear of the cargo deck. The elevator shaft location is dictated by the second floor location of the Pre/Post Operation room. The ramp placement is to minimize the angle of the ramp itself during deployment as well as to maximize the efficiency of said loading method. The ramp is to be operated from within the aircraft by a loading master engineer who will ensure that all loading and unloading keeps the center of gravity within its margins for safe flight. Figure 31 shows two schematic views of the cargo deck and Biolab.

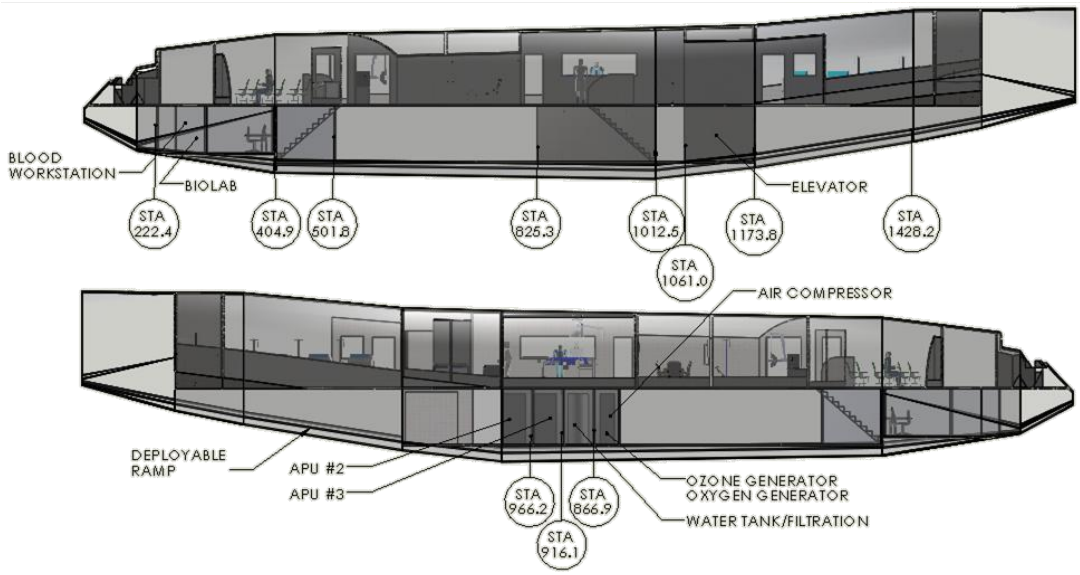

Figure 31 Detailed view of interior design of the cargo deck and Biolab

Chapter 7 – MedWing Impact Study

The main objective of Project MedWing is to maximize the access of people to healthcare. This thesis has shown some of the process that was involved in the conceptual design of a flying hospital, however, the whole project is based on the assumption that having a shorter takeoff and landing roll maximizes the accessibility of the aircraft. This chapter looks to explore this previous idea.

Due to the difficulty of estimating every landing site that MedWing can service, Africa has been chosen as a case study for the purpose of the impact study. Furthermore, this study will only compare reported runway accessibility of MedWing to that of the current solutions, ORBIS International and Mercy Airlift International. For this purpose, only reported landing airfields in Africa will be studied for length and runway conditions.

According to CIA World Fact Book, there are currently 3,401 recorded airports in the continent of Africa(7). This number includes all airports regardless of whether they are paved or unpaved and regardless their runway length. To put this number in perspective, the United States of America has a total of 15,095 airports and measures only 33% of the size of Africa(7). From the 3,401 airports, the Aircraft Charter World has detailed information of 1,900 total African airports (26).

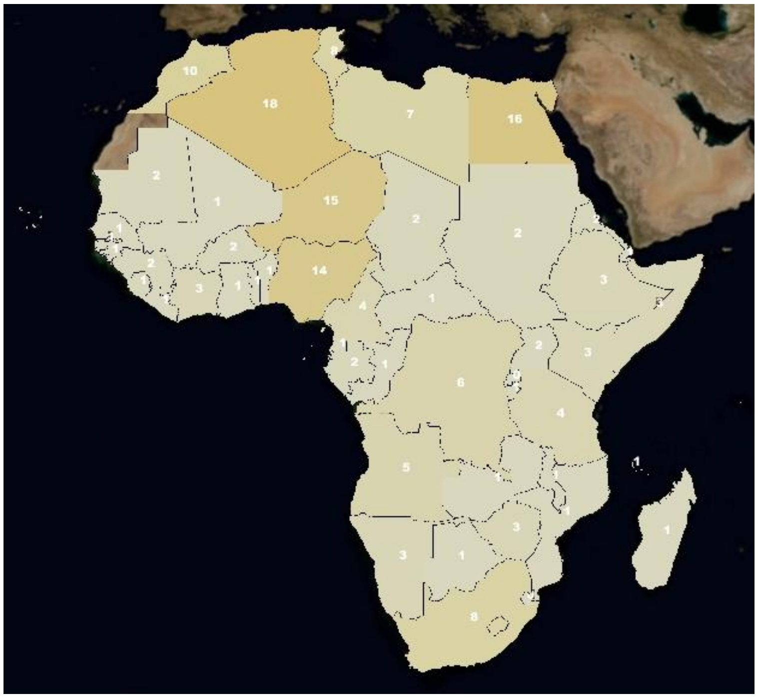

Figure 32 Number of African airports that ORBIS and Mercy Airlift International can service given their runway requirements

Figure 32 shows the number of African airports that currently are being served by ORBIS International and Mercy Airlift International. Given their required runway length of more than 8,000ft and paved, these organizations can only serve 206 airports or 10.8% of the available airfields. It is important to highlight that most of these 206 airports are located in major cities of Africa, however, as it was shown before, only 37% of the population of Africa lives in a city. These facts show how ORBIS International and Mercy Airlift cannot serve all the countries in Africa and certainly at most 37% of the population.

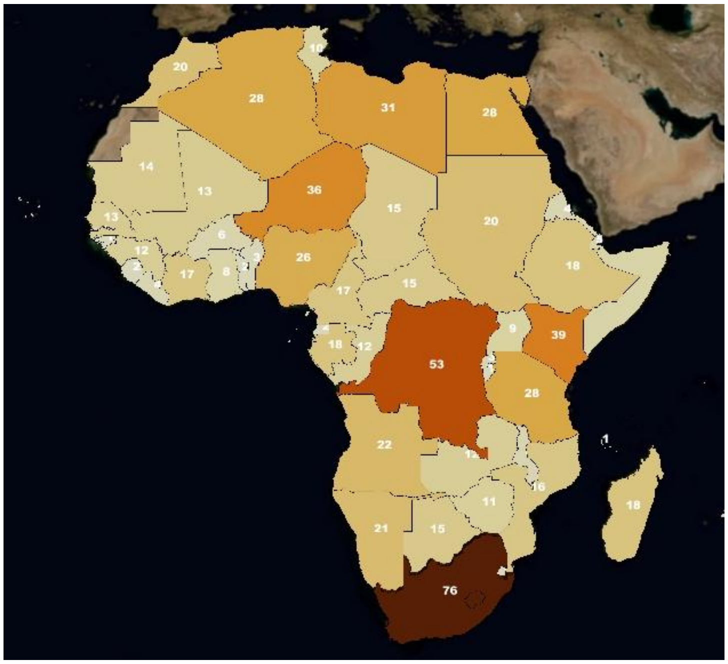

Figure 33 Number of African airports that MedWing Conceptual Design can service given its runway requirements

Figure 33 shows the number of airports serviceable by MedWing. Requiring only 4,500ft of unprepared runways, makes the concept more accessible and helpful. MedWing can currently serve up to 39.5% or 754 of the reported fields of Africa. The figure shows how much more of the region can now be accessible to humanitarian organizations thanks to MedWing. However, it is important to highlight that the figure does not include all the unregister fields which can also be used as landing sites whenever the MedWing pilots decide on doing so.

A simple comparison between Figure 32 and Figure 33, shows that the assumption that the shorter the runway length required the more people can have access to the healthcare aid, is in fact correct. MedWing can access and help 548 more reported airfields than Mercy Airlift or ORBIS International can.

Conclusion:

It is obvious that the world's healthcare system is in immediate need for help. Uneven distributions of wealth and resources have created less than ideal health situations in places like Africa. This thesis presented some of these problems and proposed a conceptual solution to what can be Africa's greatest fear. The objective of this analysis is to verify the possible design of MedWing, a short takeoff and landing aircraft capable of housing a full hospital to service both the urban and rural communities in need of healthcare aid. The analysis of the conceptual design of said aircraft allowed for numerous conclusions to be drawn about the posit solution:

Investigation of the problem led to the discovery of some humanitarian organizations that have chosen to use aeronautical vehicles as a method of providing healthcare to the populations that needed the most. Although these groups have been quite successful, it was determined that their need for paved, prepared, and long runways makes them only accessible to 37% of the African population.

An aircraft capable of servicing the mission of a mobile hospital requires that it be capable of housing an operating theater, a pre/post operation room, a recovery room, a clinic and a biological laboratory. Each of these rooms has specific requirements that enlarge the amount of payload that the aircraft must carry. It was determined that for an aircraft capable of performing the mission profile highlighted in Figure 8, under the mission specifications stated in Table 1 and able to carry the equipment highlighted in Chapter 6, must have a maximum takeoff weight of 413,000lbs. Said aircraft would require a wing with an area of 3,578ft^2 and engines capable of generating at least 153,000lbs of thrust.

In order to maximize the amount of patients that MedWing can access, the maximum runway length for both takeoff and landing was limited to 4,500ft. Performance modifications show that the aircraft can accomplish said task with a $C_{L_{max}}$ of 2.8. However, aerodynamic design of the wing states that the MedWing can generate up to $C_{L_{max}}$ values of up to 3.54. It can be concluded that due to this extra aerodynamic ability, MedWing can have a takeoff role smaller than 4,500ft.

A preliminary study of the African region airports allowed for an impact study of the design. It was determined that with the current solutions, ORBIS International and Mercy Airlift International, only 10.8% of the region's airports can actually be targets for the humanitarian mission. However, by cutting the takeoff roll to 4,500ft and giving the aircraft the ability to land in unprepared unpaved fields, the exposure of the mission can increase to about 40% of the African airports. It is important to highlight that the preliminary study only focused on reported runways of the continent and did not take into account the ability of MedWing to land anywhere not necessarily in reported airfields.

Finally, this thesis proves that the concept of a flying hospital is possible both from the aerodynamic design of the aircraft and from the healthcare system point of view. The fact that there are already organizations flying civilian mobile hospitals formulates the conclusion that it is possible to operate a humanitarian flying hospital.

In conclusion, it was determined that although the world is in desperate need of healthcare help, there are many different solutions that can help solve the problem. It is recognized that a flying hospital, although being an effective aid, is also a large financial burden which will bring along other kind of problems. To this last aspect, Project MedWing asks, “What is the price of one human life? What is the price of saving one more human being?” The main objective of Project MedWing is to do its part in creating a better world as well as in inspiring others to step up and work with and in the humanitarian field. All it takes to change the world is for all of us to want to change it.

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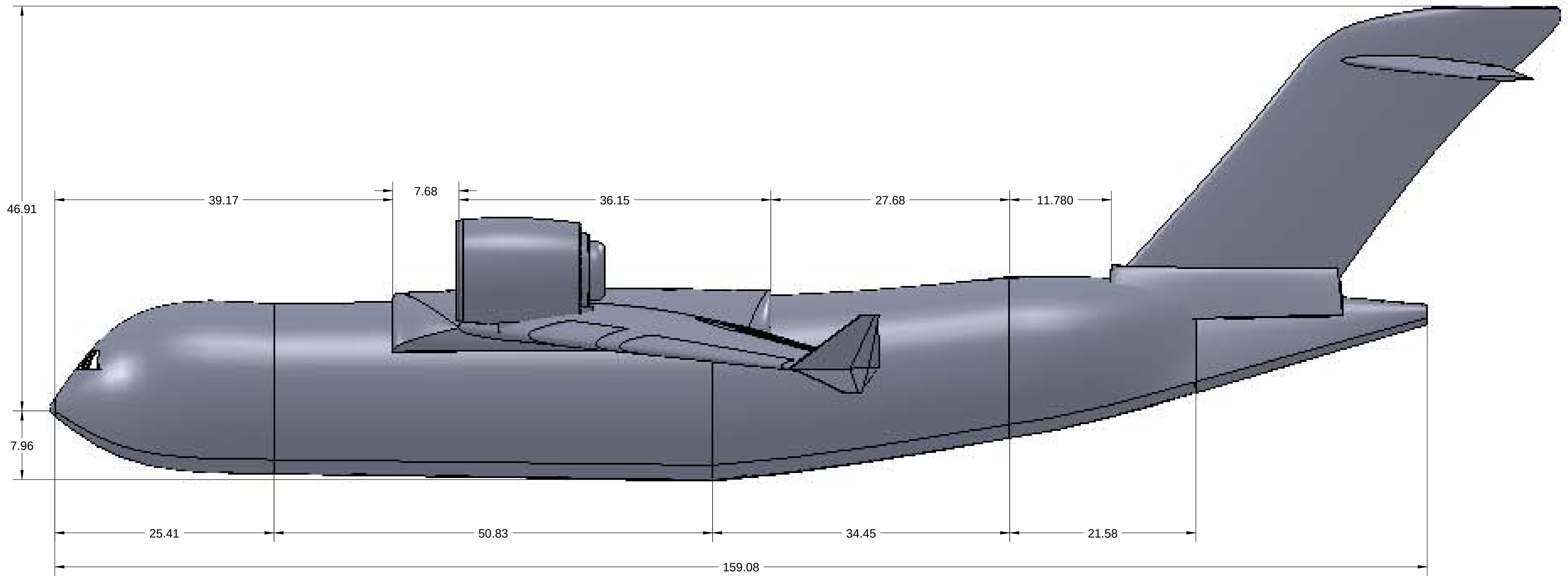
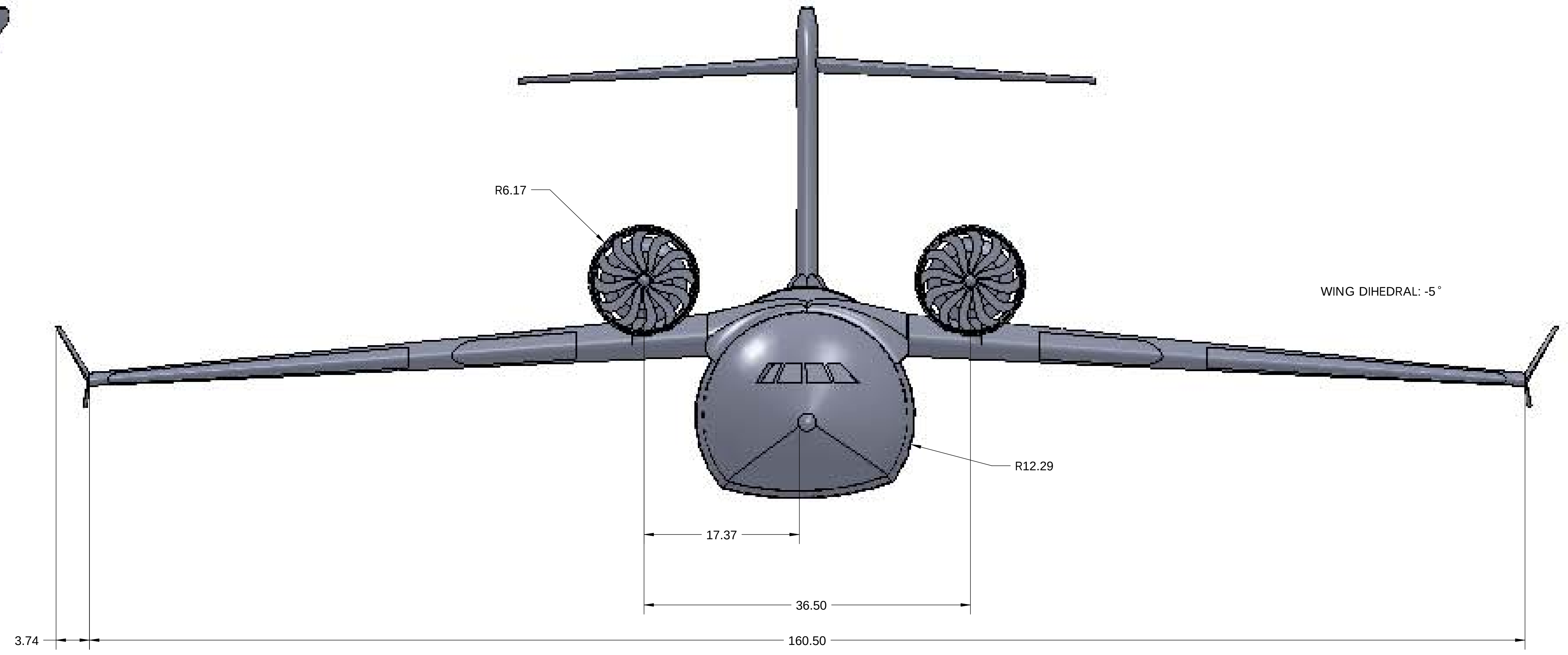
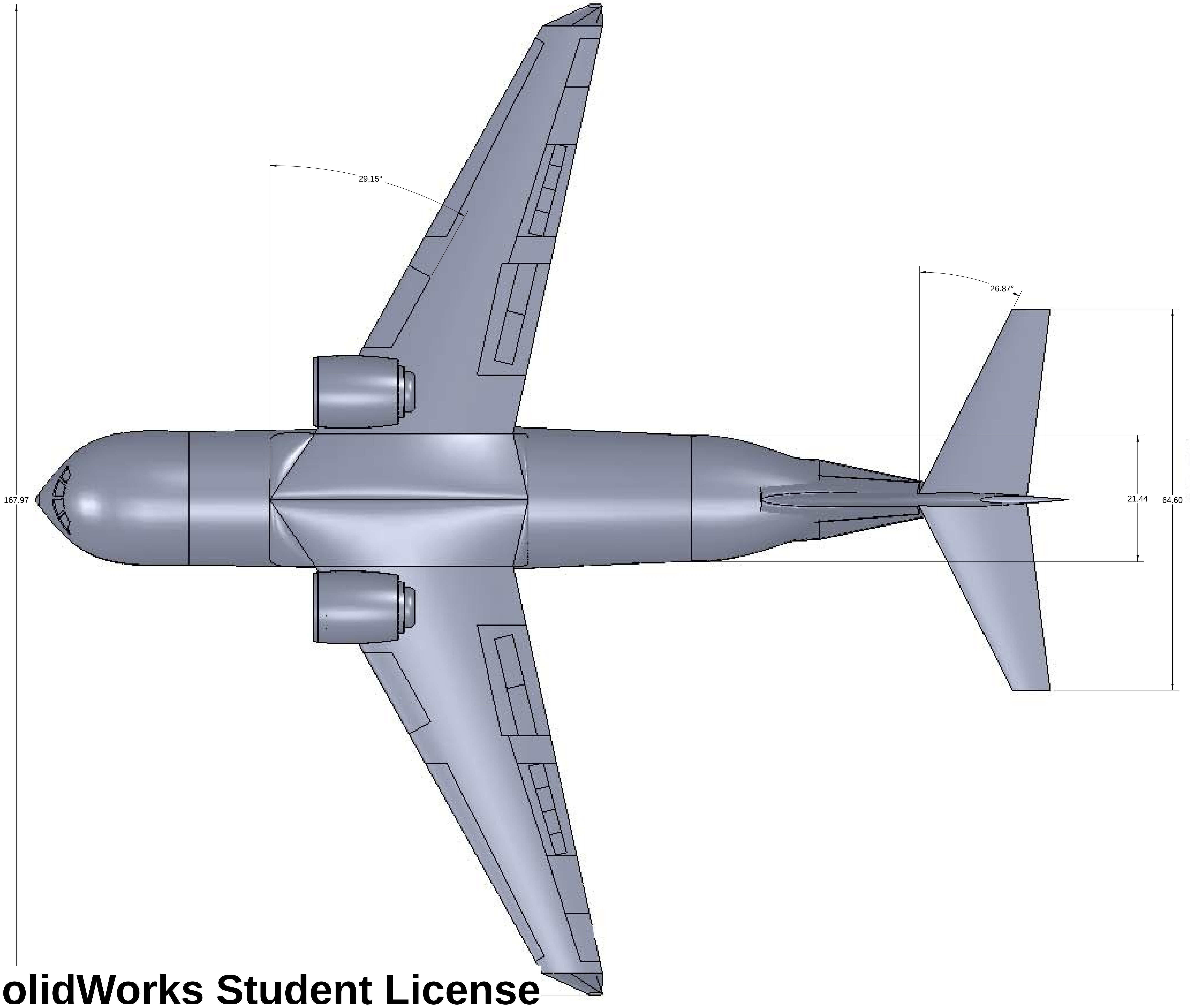
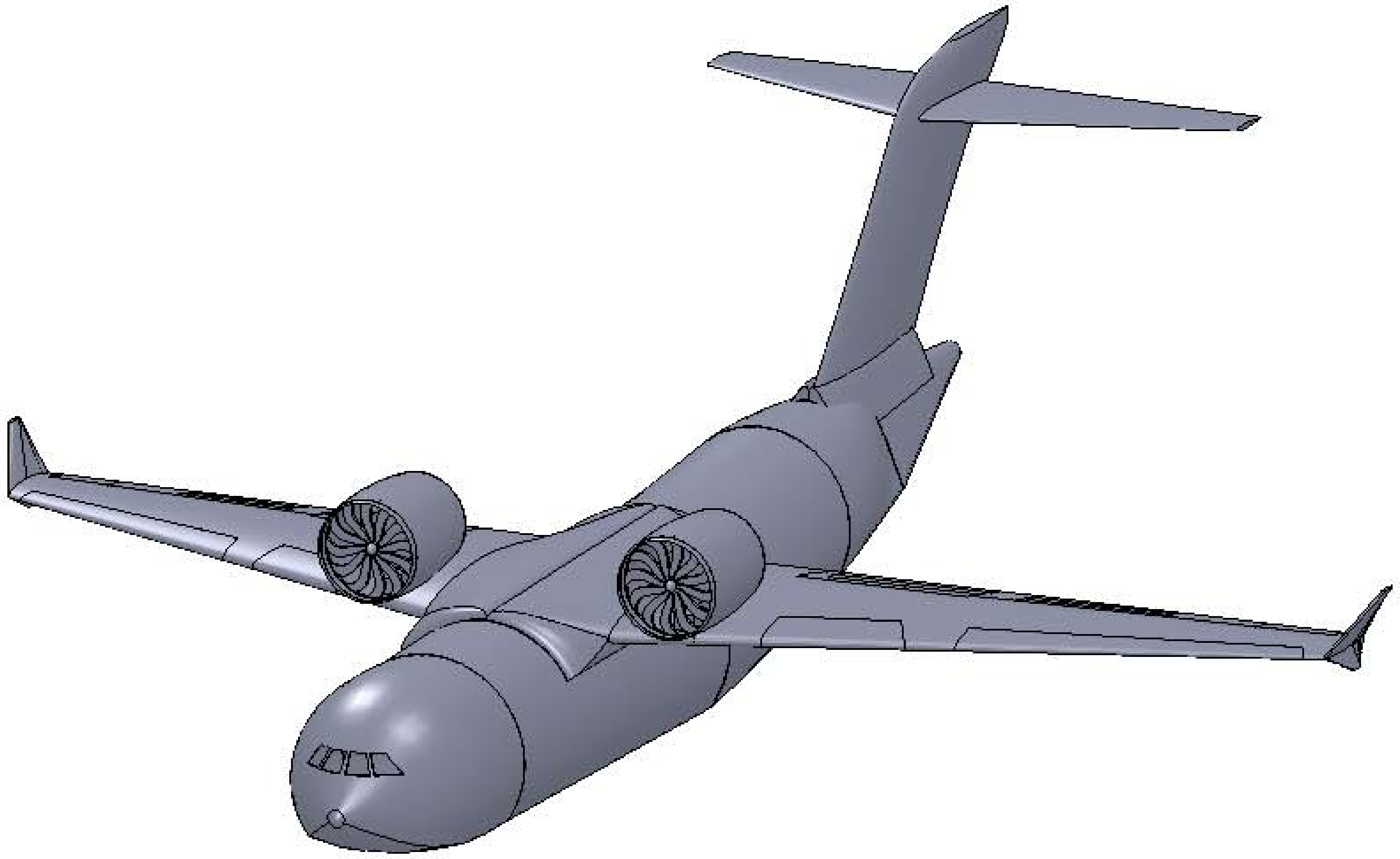
Nachiket Deshpande (left) and Alvaro Hernandez (right), creators of the MedWing Project – Integrating Aerospace with the Humanitarian Industry.









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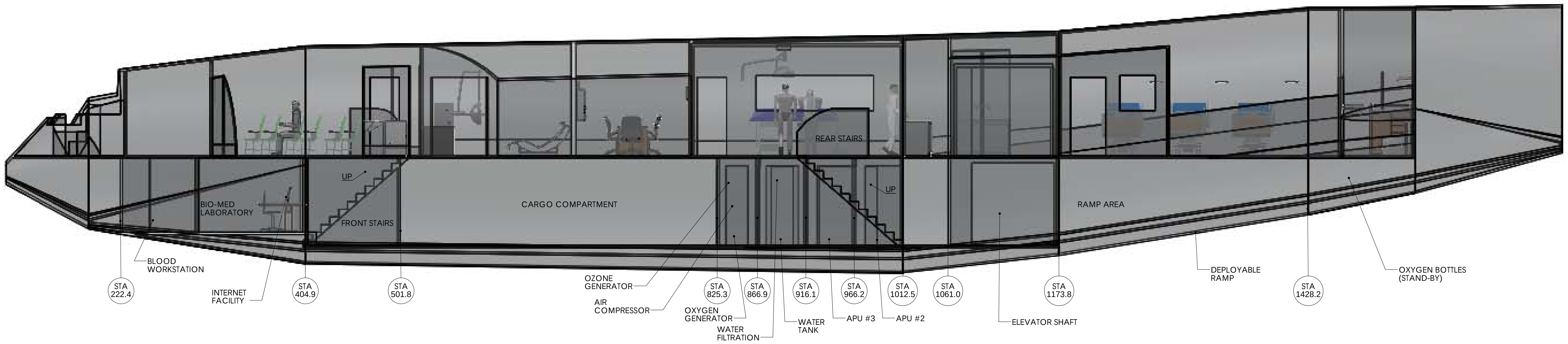

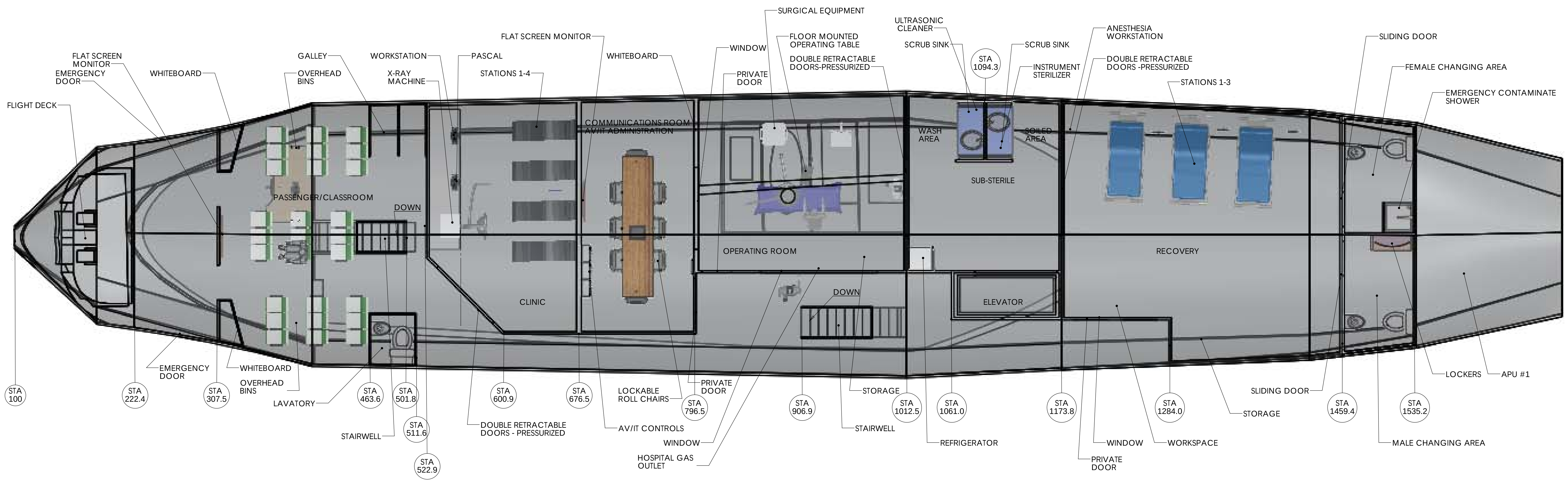

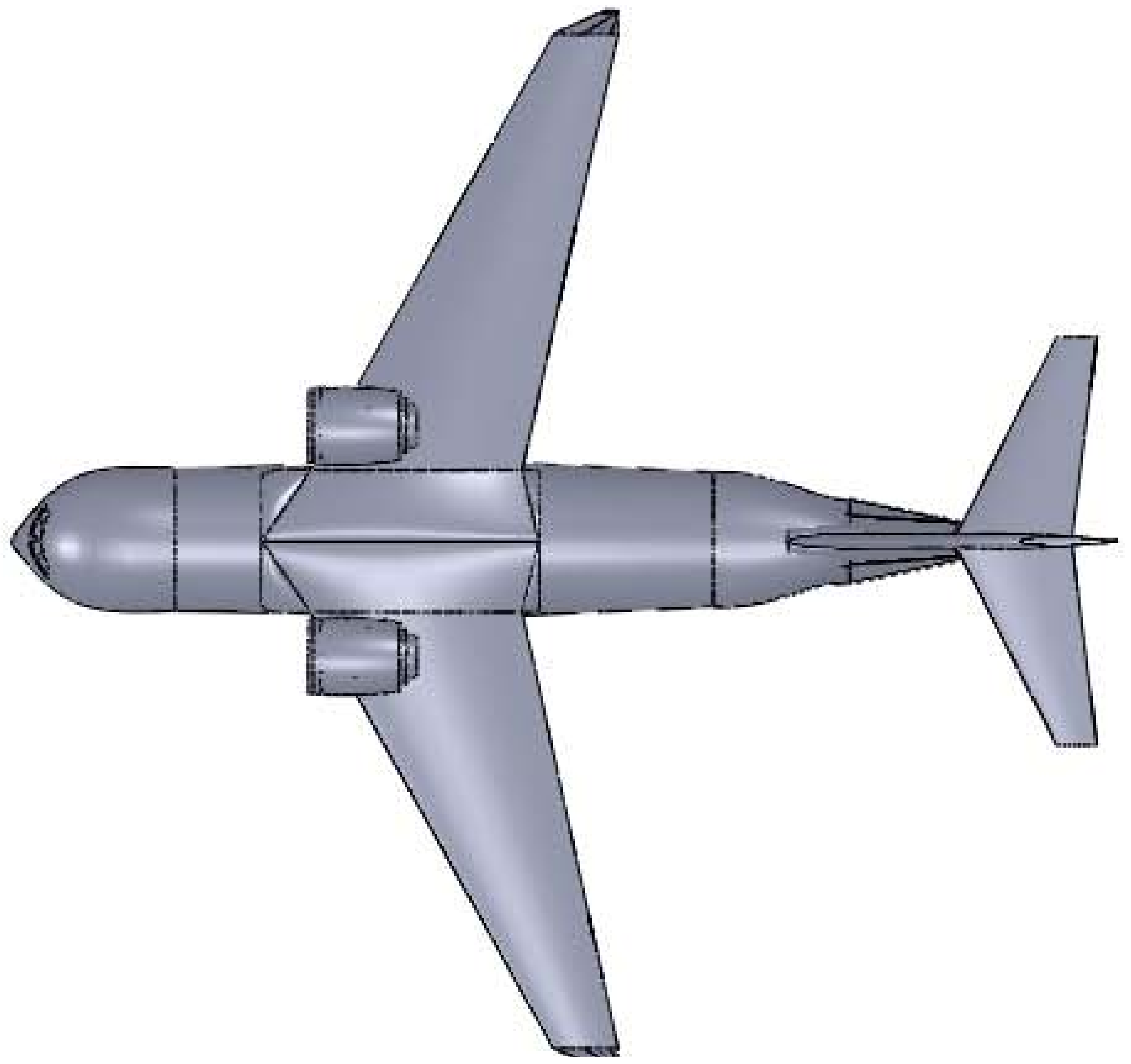

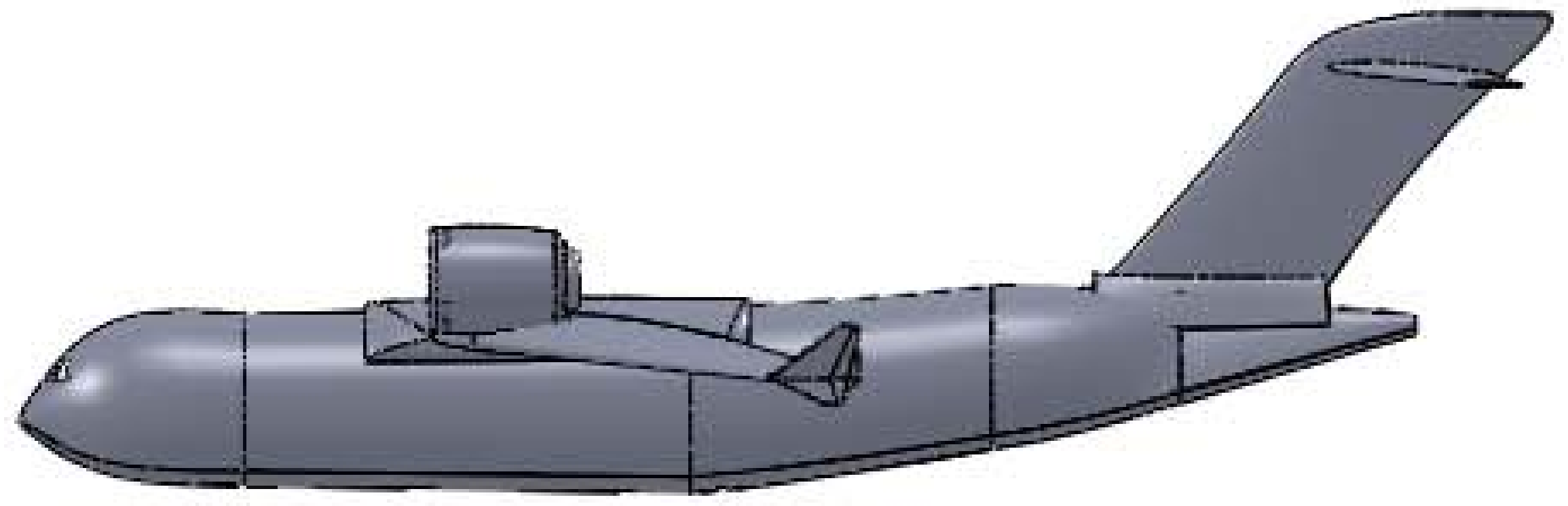

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