DESIGN PLANS FOR A CONVENIENCE STORE TRANSPORTER

Final Report:

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for

ME4770 – AIRCRAFT DESIGN

By

Brian Joseph

Neil Pomerleau

1 March 2013

WPI

Table of Contents

List of Figures

List of Tables

Introduction

In our modern culture, where busy schedules demand quick and convenient products and services, convenience stores play a critical role. Serving anything from snacks and drinks to newspapers and cigarettes, convenience stores offer a wide variety of products on nearly every street corner, at prices that are high enough to make this business quite profitable for the companies that partake in it. And of course, one company in particular has profited quite well from their chain of convenience stores. With over 48,000 store locations around the world[1], 7-Eleven has emerged as the world's largest chain store[2], pulling in revenue of over $62 billion with worldwide retail sales in 2011 alone[3].

Not resting on their laurels, 7-Eleven is constantly developing new stores. According to 7-Eleven's corporate website[4], a new 7-Eleven store opens for business approximately every 2 hours. This is in keeping with their mission to "bring 7-Eleven's unique brand of convenience to even more guests by acquiring, developing, and maintaining world class 7-Eleven stores." The company has built a store nearly everywhere in the world there is land to build one, which is precisely why it has become clear that it's time for 7-Eleven to expand past the limitations of land to go where no convenience store has ever gone before.

This report details the conceptual design of an amphibian aircraft capable of transporting a modified, full-size 7-Eleven convenience store within its fuselage for flights between land and water, so that customers can enjoy the familiarity and convenience of a 7-Eleven store on land, in the air, and at sea. For the first time ever, off-shore customers will be able to enjoy such items as the Slurpee drink that can only be found at 7-Eleven, while frugal airborne customers will find great deals like freshly-brewed coffee for just $1 on Wednesdays. By taking the idea of a convenience store and putting it on an aircraft for the first time, the Boeing 7117 ("Seven Eleventy Seven") will take 7-Eleven to new heights, and beyond.

Caffeine Effects

By bringing a 7-Eleven convenience store within the confines of a transport aircraft for the first time, the Boeing 7117 allows passengers and crew to get very high while consuming caffeine, up to a flight ceiling of approximately 40,000 ft. However, this abundance of caffeine available at altitude introduces health and safety concerns that must be addressed.

Pilots of this new "caffeine-liner" might be tempted to substitute proper sleep with the consumption of coffee, due to the stimulating effects of the beverage. However, research by the Finnish Air Force has shown that this could pose a flight safety problem[5]. In a randomized, double-blind test, thirteen military pilots were given either 200 mg of caffeine or a placebo during 37 hours of sleep deprivation, before performing a flight mission in a simulator four times. The caffeinated pilots were observed to fly too "optimistically," leading the Finnish Air Force to recommend that caffeine pills not be used in military flight operations. In accordance with their recommendation, pilots and crew of the Boeing 7117 should also limit their caffeine intake and get proper rest for the safety of everyone on the aircraft. While other passengers should also be aware of the effects of caffeine products, they need not take additional precautions when compared to land- and sea-based consumers.

Second-Hand Tobacco Smoke

Like the land-bound convenience stores that 7-Eleven is famous for, the 7-Eleven within this aircraft will sell tobacco products. Of course, popular tobacco products such as cigarettes have many negative health effects, even on those who do not breathe the cigarette smoke directly. The World Health Organization has shown that second-hand smoke can lead to coronary heart disease, lung cancer, breast cancer, respiratory symptoms, and many other illnesses[6].

This effect is amplified in the cabin of an aircraft. Ronald Davis[7], a physician and epidemiologist who served as the former director of the U.S. Office on Smoking and Health, explained that “the exposure on airplanes would be much more intensive and much more serious and much more hazardous than the exposure in the home.” It is for these reasons that the FAA has banned smoking on all commercial flights within the United States, and it is why passengers will be asked not to use cigarettes purchased at the 7-Eleven until they have exited the aircraft.

Literature Review

Martin P6M SeaMaster

The P6M was an advanced sea-based jet bomber built by the Martin Aircraft Company for a naval contract[8]. It was and still is one of the few jet aircraft designed as a seaplane capable of high speed (Mach 0.8) flight. Although the airframe was very capable and the concept itself was sound, the project was eventually cancelled by the Navy due to a shift towards carrier and sub based weapon systems.

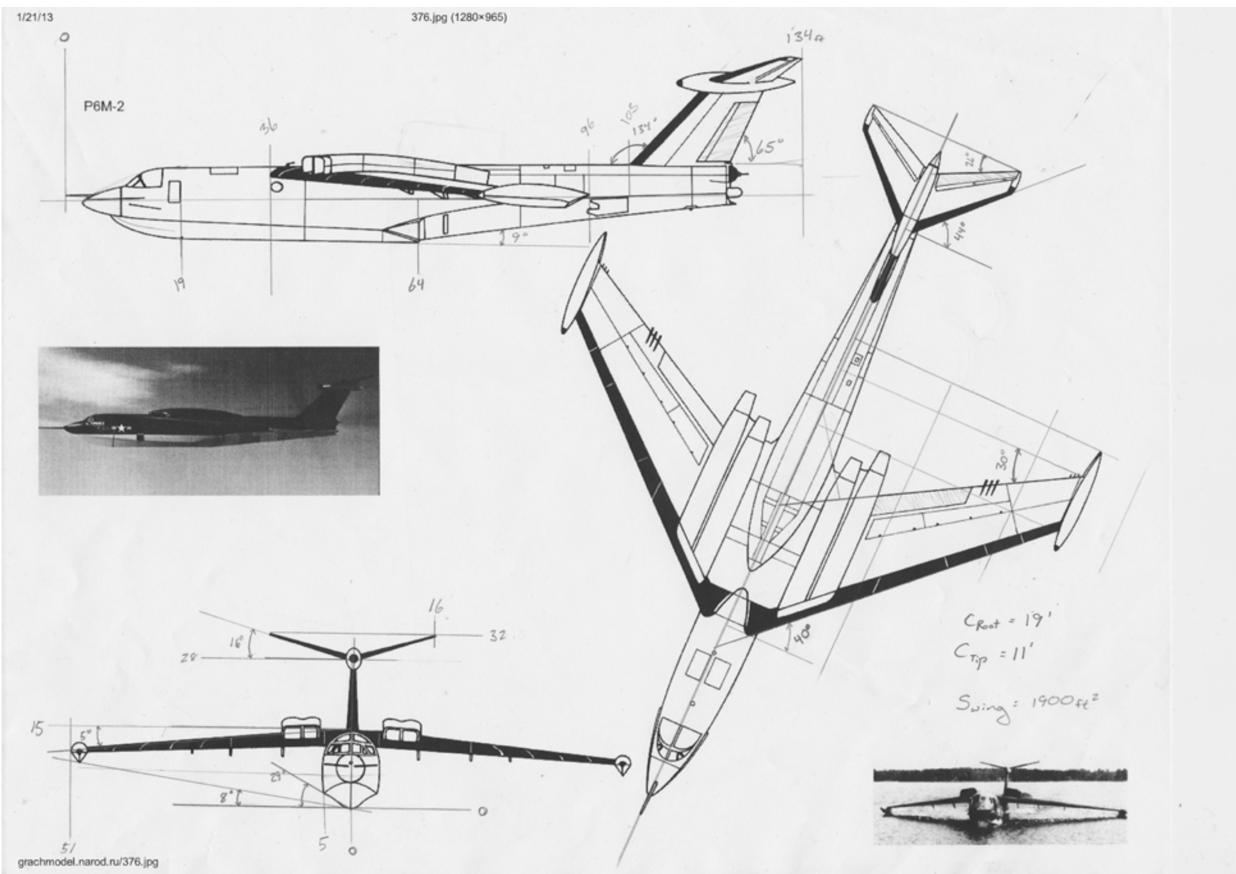


Figure 1: Design of the Martin P6M SeaMaster[9]

The high cruise speed meant the P6M had many unique design elements for a seaplane. To reduce drag and wetted area, the traditional wing floats seen on many seaplanes were replaced by floats at the tips of a negative dihedral wing. The wings themselves had a very high angle of sweep (40o) to allow for favorable flight characteristics at transonic speeds. The hull is also much more streamlined compared to similar prop driven designs and the engine nacelles are fully integrated into the wings and protected from spray to prevent corrosion. However, the characteristics that made the aircraft a good high speed jet bomber did not favor the high lift, low takeoff speed, and low speed stability needed for a good seaplane. The high wing sweep and thin wings increased the takeoff speed and made the plane much more difficult to fly at low speeds. This also necessitated the need for very powerful engines as seen by the 4 turbojets rated at 17500 lbf each that were used on the airframe. The low profile of the floats at the wingtips meant they could be accidentally submerged when maneuvering on the water, which was highly unfavorable since it would force the wing under the water. The statistics for the P6M are very similar to what we hope to achieve with our aircraft, while improving on its shortcomings at low speed and on the water.

Martin P6M SeaMaster	
Length:	134 ft
Wingspan:	102 ft
Airfoil:	NACA 63A210
Wing Sweep:	40°
Height:	32 ft
Wing Area:	1,900 ft^2
Dry Weight:	91,284 lb
Cargo Capacity:	30,000 lb
Max T/O Weight:	176,400 lb
Thrust:	70,000 lbf
Maximum Speed:	633 mph
Range:	2000 miles
Service Ceiling:	40,000 ft

Table 1: Specifications for the Martin P6M SeaMaster

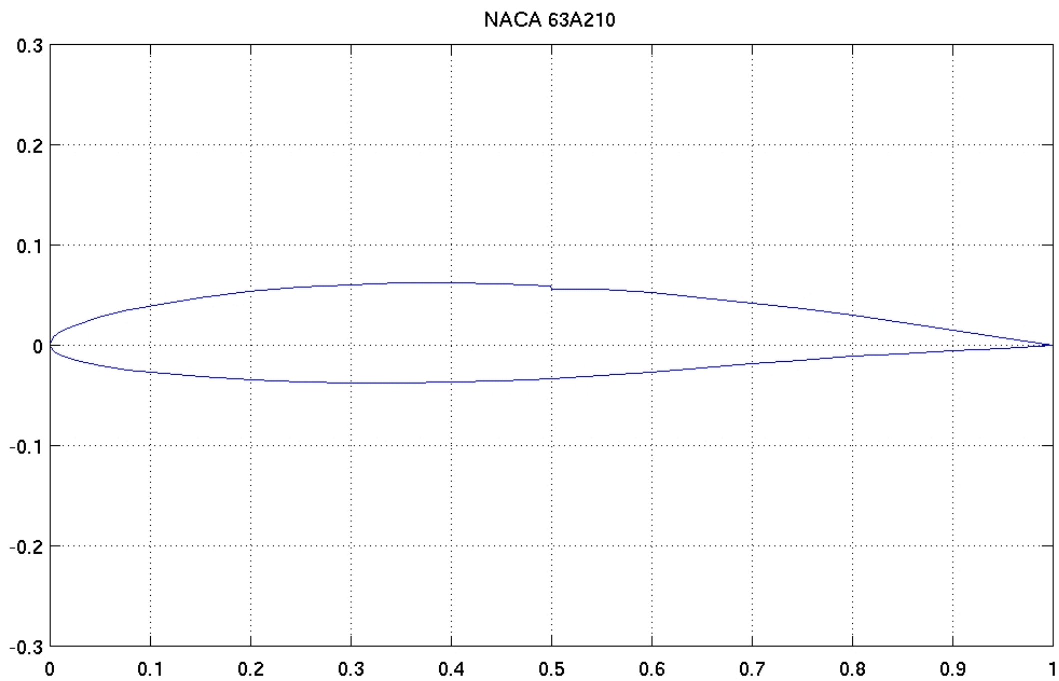


Figure 2: The NACA 63A210 Airfoil used in the Martin P6M SeaMaster[10]

Beriev Be-200

The Be-200 is a modern turbofan powered seaplane and is the latest in a lineage of similar Russian seaplanes designed for a wide variety of roles from bombers and transports, to search and rescue and firefighting aircraft[11]. The aircraft is very adept in the water and can be configured in a wide variety of ways to meet many missions. The configuration of the wing and engines is optimized for flight at speeds less than Mach 0.55 with a low sweep and high, rearward engine mounts. The wing is straight, with no dihedral to simplify the structure. The aircraft has a wide hull and roomy fuselage and uses standard wing floats inboard of the wingtips.

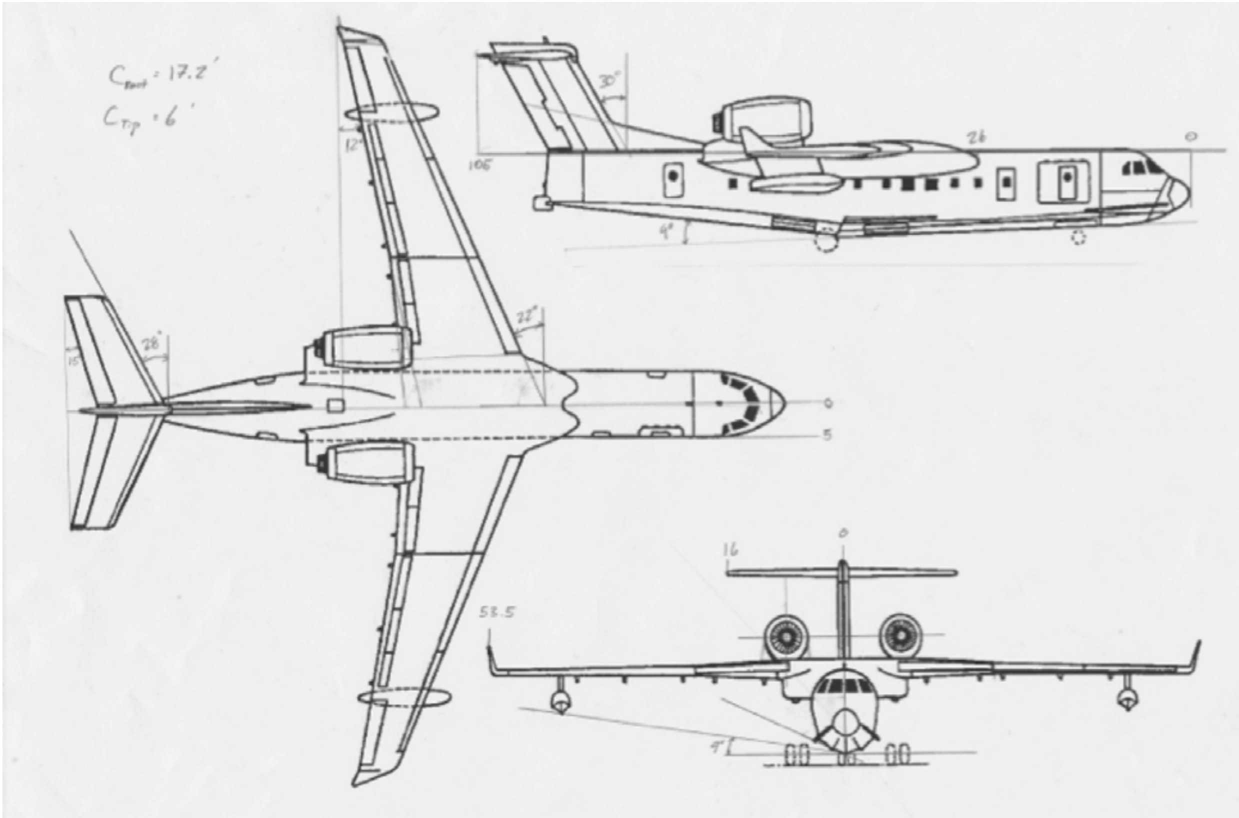


Figure 3: Design of the Beriev Be-200[12]

The simplicity and flight and water characteristics of the Be-200 are favorable to our design, however, we want a plane capable of international travel, so the range and cruise speed are far too low. However, the aircraft is a perfect example of modern seaplane design utilizing high-bypass turbofans.

Beriev Be-200	
Length:	105 ft
Wingspan:	107 ft
Airfoil:	Tsagi 16%
Wing Sweep:	22°
Height:	29 ft
Wing Area:	1,264 ft^2
Dry Weight:	60,850 lb
Cargo Capacity:	16,530 lb
Thrust:	33,068 lbf
Maximum Speed:	435 mph
Cruise Speed:	348 mph
Landing Speed:	124 mph
Takeoff Speed:	137 mph
Stall Speed:	98 mph
Range:	1305 miles

Table 2: Specifications for the Beriev Be-200

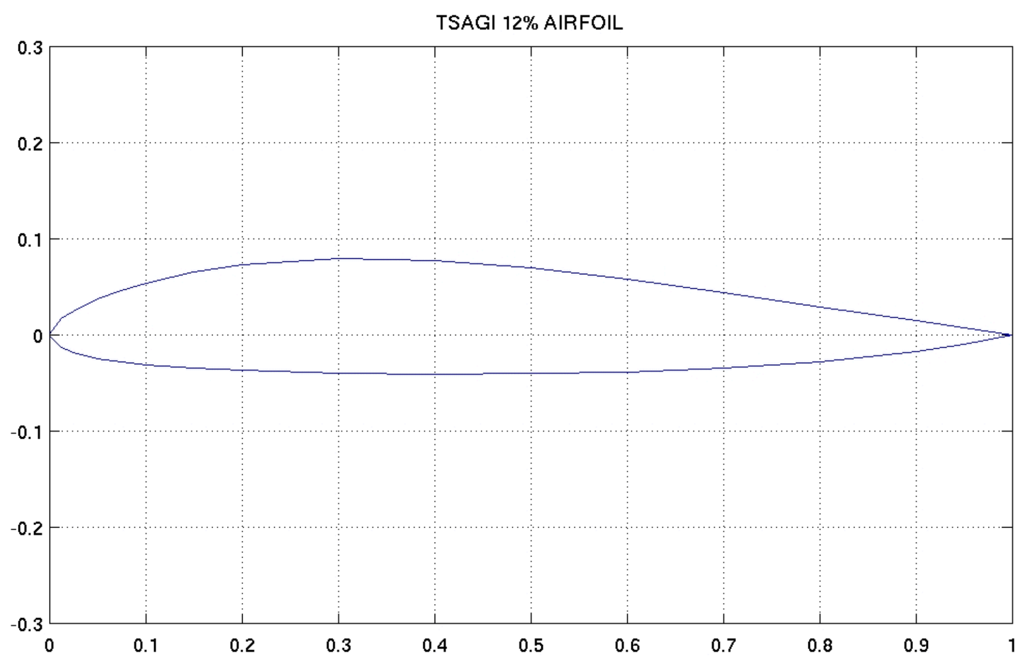


Figure 4: The Tsagi 12% Airfoil used in the Beriev Be-200[10]

Boeing C-17 Globemaster III

The Boeing C-17 Globemaster III is a large military transport aircraft capable of carrying a payload of 160,000 pounds for over 2,400 nautical miles[13].

Figure 5: The Boeing C-17 Globemaster III, in flight[14]

It achieves enough lift to transport this immense payload by using a supercritical airfoil on the wing with flaps that are fixed-vane and double-slotted. The wing also has a relatively low sweep angle, at only 25°. The aircraft uses a mix of an anhedral high-wing with a dihedral T-Tail. The shape of the fuselage is useful for carrying volumetrically large payloads, with a cargo floor length of 68.2 ft, a loadable width of 18 ft, and a loadable height of 14.8 ft aft of the wing (or 12.3 ft under the wing). Though the C-17 is not capable of landing on water, it can land on rough terrain and is useful for transporting people and resources into remote locations. The geometrically large fuselage and the ability to transport a heavy payload are characteristics that will be important for the design of the Boeing 7117 aircraft.

Boeing C-17 Globemaster III	
Length:	174 ft
Wingspan:	169.8 ft
Airfoil:	Supercritical
Wing Sweep:	25°
Height:	55.1 ft
Wing Area:	3,800 ft^2
Dry Weight:	282,500 lb
Cargo Capacity:	170,900 lb
Max T/O Weight:	585,000 lb
Thrust:	161760 lbf
Maximum Speed:	515 mph
Range:	2785 miles
Service Ceiling:	45,000 ft

Table 3: Specificatons for the Boeing C-17 Globemaster III

Comparison of Existing Aircraft

The following table draws comparisons between the key parameters for the three aircraft discussed in this section. Note that the maximum takeoff weight of the C-17 is much higher than that of the seaplanes, supported by its much larger size.

	P6M	Be-200	C-17
Crew	4	2	3
Maximum T/O Weight	176,400 lb	90,390 lb	585,000 lb
Range	2000 mi	1305 mi	2785 mi
Maximum Speed	633 mph	435 mph	515 mph
Length	134 ft	105 ft	174 ft
Wingspan	102 ft	107 ft	170 ft

Table 4: Comparison of Specifications for Similar Aircraft

Specifications

First and foremost, the Boeing 7117 must be able to transport one 7-Eleven convenience store within the fuselage. According to the National Association of Convenience Stores (NACS), a convenience store can only be defined as such if it has the following properties[15]:

1) *Size of less than 5,000 square feet* – The convenience store placed within the Boeing 7117 will be much less than 5,000 square feet, at a reasonable size of 600 square feet (10 feet wide by 60 feet long, with an 8-foot ceiling).
2) *Off-street parking* – Boats will be able to approach and "park" near the Boeing 7117 while it is serving off-shore customers on the water. Off-shore parking is certainly far enough off-street to satisfy this constraint.
3) *Extended hours of operation* – The Boeing 7117 will have both exterior and interior lights so that it can be operated safely at any time of day.
4) *Stock at least 500 SKUs* – Within the convenience store within the fuselage, the aircraft will also be transporting a wide variety of products, particularly the products customers would expect from a typical 7-Eleven location.
5) *Grocery type items, beverages, snacks, and tobacco* – As part of the variety of items required in the previous constraint, the cargo must include items from these four specific categories of items.

The estimate the weight of this 7-Eleven convenience store, we can take the requirement of 600 square feet and multiply by the average weight of a one-story building[16] at 50 lb/ft^2 to get 30,000 lb. To include the weight of the various products and devices found within a 7-Eleven convenience store, an additional weight of 5,000 lb results in a final cargo weight estimate of 35,000 lb. The aircraft will be operated by a pilot, co-pilot, and a store manager, who will serve approximately two customers. The pilot and co-pilot will share duties within the store while the aircraft is on the ground or water. Five people at an average weight of 155 lb results in a total crew weight of 775 lb. In short, the aircraft should be able to carry the modified 7-Eleven convenience store with the given weight and dimensions over a long range to both land and water-based destinations. The initial specifications for this aircraft design are summarized in the table below.

Cargo Weight:	35,000 lb
Crew Weight:	775 lb
Range:	3000 mi
SFC (Cruise):	0.5 hr^{-1}
Velocity:	650 mph
L/D:	15
Endurance:	0.5 hr
SFC (Loiter):	0.4 hr^{-1}
A:	1.05
C:	-0.055

Table 5: Initial Specifications for the Boeing 7117

Key Design Parameters

	Boeing 7117	Historical Trends
Range (R)	3000 mi	1500 – 5000 mi
Endurance (E)	0.5 hr	3 – 5 hr
Initial Weight (W_0)	162150 lb	120,000 – 300,000 lb
SFC_{cruise}	0.5	0.5
SFC_{loiter}	0.4	0.4
T/W	0.308	0.2 – 0.3
L/D	15	13 – 18
AR_{wing}	7	6 – 8
AR_{tail}	5	4 – 6
W/S	95.7 lb/ft^2	100 – 120 lb/ft^2
Airfoil Type	Supercritical	Supercritical
Stall Speed	115 mph	130 mph
λ_{wing}	0.4	0.4 – 0.5
λ_{tail}	0.4	0.3 – 0.6
$\Lambda_{wing, LE}$	25°	20° – 30°
Wing Dihedral	-5.7°	-5° – 0°

Table 6: Key Design Parameters

Initial Weight Estimate

To calculate the initial weight of our aircraft, an iterative approach was used based around the equation for initial weight:

$$W_f = W_{crew} + W_{payload}$$

where the crew weight and payload weight are specified in the previous section. The empty weight and fuel weight are then a function of the range and endurance. Manipulating the above equation for fuel weight and empty weight fractions yields:

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - \frac{W_e}{W_0} - \frac{W_f}{W_0}}$$

From the specifications, the mission outline can be split into five separate legs:

1. taxi and takeoff
2. climb
3. cruise
4. loiter
5. land

The weight fractions for each of these legs was determined either from a historical data approach or from calculations based on the aircraft specifications. Raymer[17] provides suggested values for takeoff, climbing, and landing legs that were used as a first estimate. The weight fraction for the cruise leg is determined using a manipulation of the range equation:

$$\frac{W_3}{W_0} = e^{-\frac{RC}{V\left(\frac{L}{D}\right)}}$$

This takes into account the specified range, specific fuel consumption of a high-bypass turbofan, velocity at cruise, and a crude L/D value based on historical data from the textbook. For the loiter leg, a similar approach was used applying a manipulation of the endurance equation:

$$\frac{W_4}{W_0} = e^{-\frac{EC}{\frac{L}{D}}}$$

The product of these weight fractions yields an overall weight fraction for the mission. To calculate the fuel weight fraction, the following relation was used:

$$\frac{W_f}{W_0} = 1.06 * \left(1 - \frac{W_{final}}{W_0}\right)$$

where 1.06 is a fuel safety factor. The weight fraction results (W_i/W_{i-1}) for our aircraft design are presented in the table below.

Warmup/Takeoff:	0.970
Climb:	0.985
Cruise:	0.857
Loiter:	0.987
Landing:	0.995
Mission Weight Fraction:	**0.804**
Fuel Weight Fraction:	**0.207**

Table 7: Weight Fraction Results for the Boeing 7117

From the fuel fraction, an empty weight can be approximated using the values found in Raymer Table 3.1 and the equation for empty weight fraction:

$$\frac{W_e}{W_0} = AW_0^C K_{vs}$$

where K_{vs} is a constant for variable wing sweep aircraft and doesn't apply to our aircraft, so it is equal to 1. The values for A and C are derived using Raymer Table 3.1 and can be found in the specifications table for this design. The iteration between an intial weight guess and a comparison to calculated initial weight fraction, as calculated using Excel, is shown in the table below.

W_0 Guess (lb)	W_e/W_o	W_e	W_o Calculated (lb)	% Diff
100000	0.557	55743	152140	0.521
152140	0.545	82872	144334	-0.051
144334	0.546	78848	145260	0.006
145260	0.546	79326	145147	-0.001

Table 8: Iterative Calculation of the Initial Weight

Range Trade-Off Study

The following is a study of how increasing the range affects the takeoff weight of the aircraft.

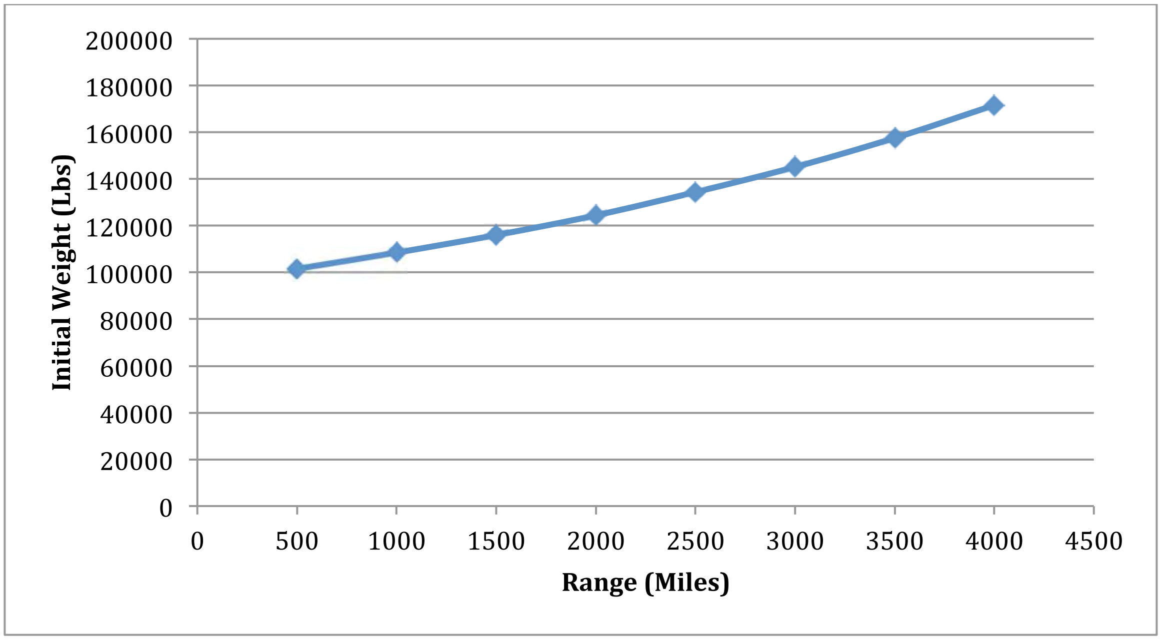


Figure 6: Range vs. Initial Weight

The curve found is dependent on the change in fuel weight fraction and consequently empty weight fraction. It follows that as range increases both fuel weight and empty weight must increase resulting in an exponential increase of takeoff weight as range increases. Our aircraft is going to operate at remote locations, so it is important to understand the effects of this tradeoff and design our aircraft accordingly.

Initial Airfoil Selection

Our aircraft must be efficient at a high-speed cruise while maintaining a high C_L and favorable flight characteristics at low speeds to enhance safety when landing on water or a short runway. For these reasons, we are investigating a supercritical airfoil design that will minimize the wing sweep required for high-speed efficiency that in turn will have favorable effects on low-speed maneuvering and stability when landing. This design is used on many advanced cargo aircraft for these same characteristics, further solidifying our reasoning for investigating this design. The NASA SC(2)-714 is a supercritical airfoil that is a good starting point for further analysis.

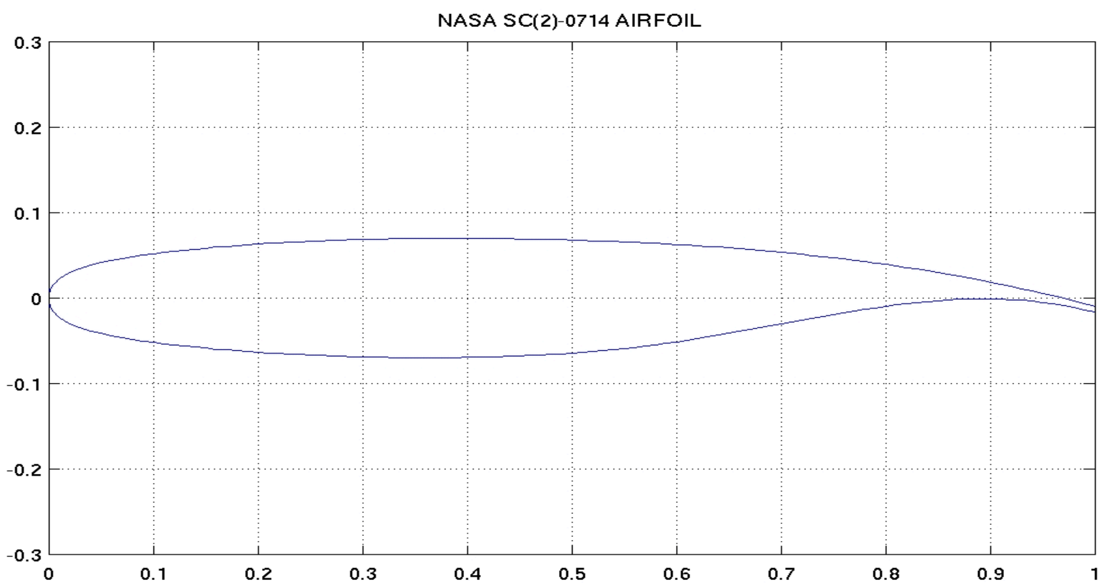


Figure 7: The NASA SC(2)-0714 Airfoil[10]

Drawings

Initial Design Sketch

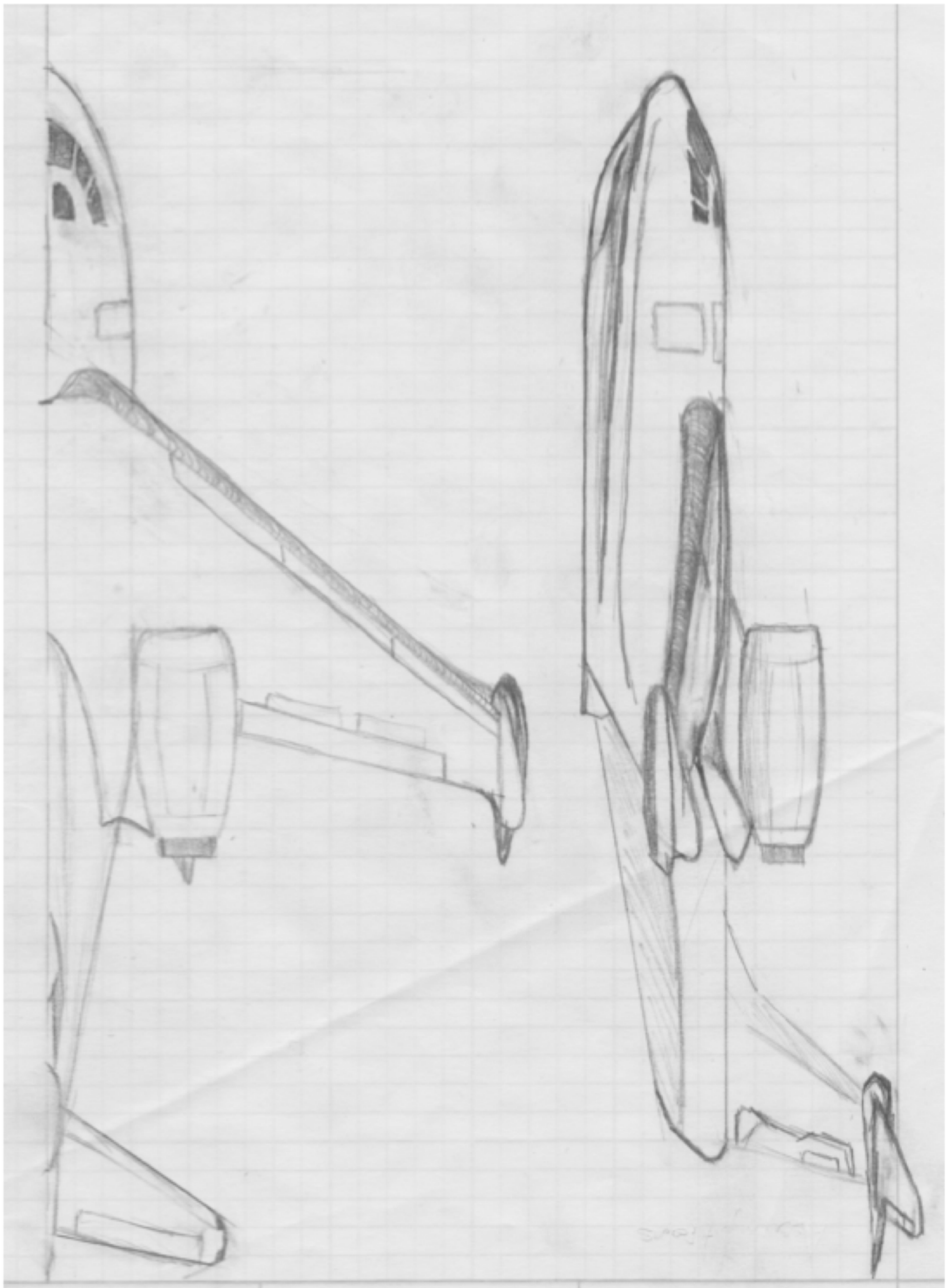


Figure 8: Initial Design Sketch

Dimensioned Drawing

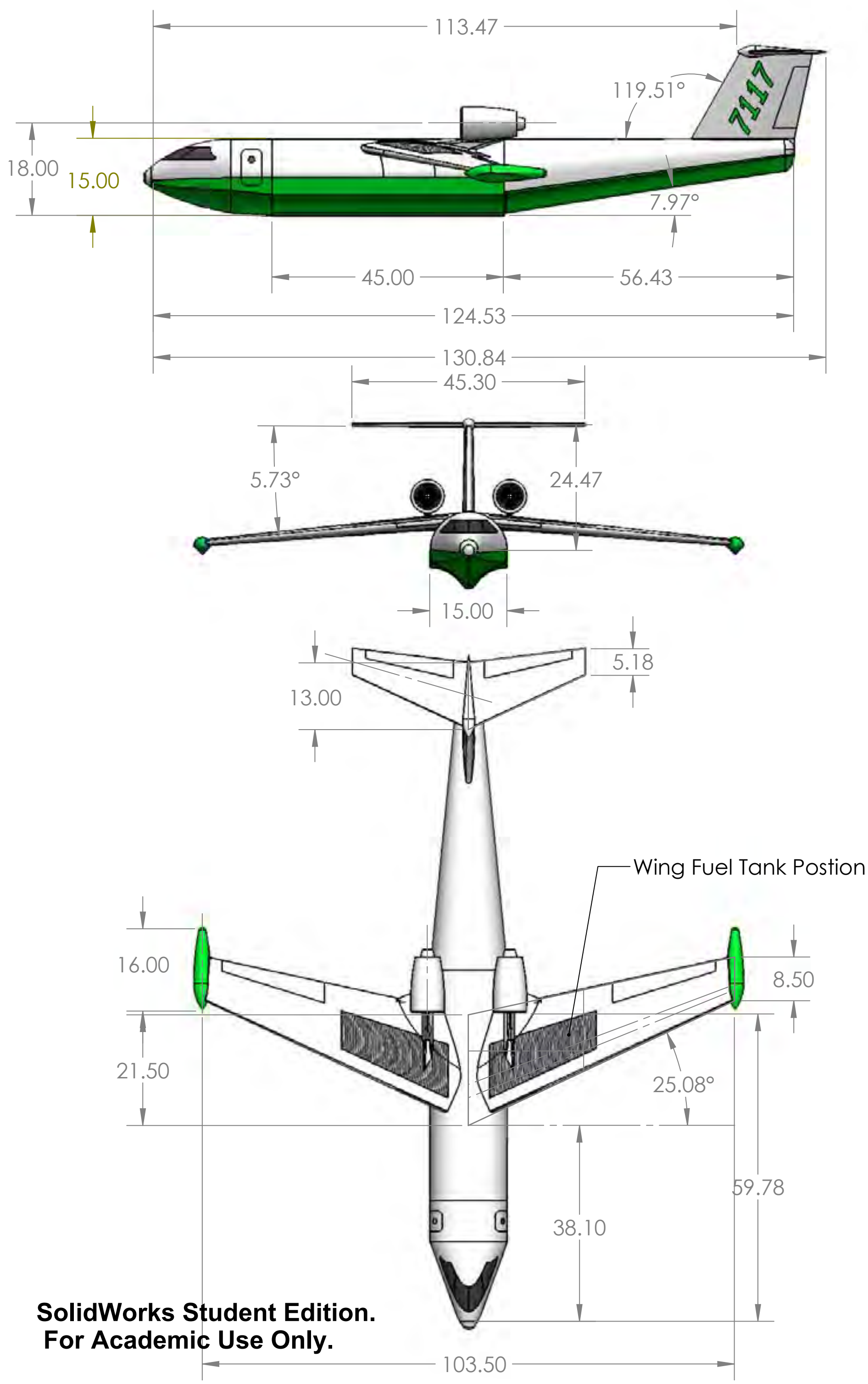


Figure 9: Dimensioned Drawing (3-Views)

Wing Geometry and Sizing

Using a historical data approach and the initial weight estimate, it was possible to determine initial wing geometry values. The calculations required were performed in Excel to allow parameters to be easily changed and to take advantage of the solver capabilities.

The value of 120 lbs/ft^2 was used as an initial wing loading estimate from Table 5.5 in Raymer[17]. From this estimate, the wing area could be calculated:

$$S_{wing} = \frac{W_0}{W_0 / S_{wing}} = 1351.25\ ft^2$$

The following values are from historical data for transonic transports with supercritical airfoils:

Aspect Ratio	7
Wing Sweep (LE)	25°
λ	0.4

Table 9: Key Parameters of Wing Geometry

With the area and key geometric parameters defined, it was possible to calculate the wing size using the following equations.

$$C_{root} = \frac{2S}{b(1+\lambda)}$$

$$C_{tip} = C_{root}\lambda$$

$$\bar{C} = \frac{{}^{2}\!/_{3}\, C_{root}(1+\lambda+\lambda^2)}{1+\lambda}$$

$$\tan \Lambda_{c/4} = \tan\left(\Lambda_{LE} - \left(\frac{1-\lambda}{AR(1+\lambda)}\right)\right)$$

Wing Span	97.25 ft
Wing Area	1351.25 ft^2
W_o/S	120
C_l Req.	0.537951
t/c	0.154
Airfoil C_l	0.6614
Normalized C_l	0.514422
C_{root}	19.84818
C_{tip}	7.939273
MAC	14.74436
Y	20.84059
Aerodynamic Center	13.40422

Table 10: Wing Area Calculation

Airfoil Selection and Criteria

The designed aircraft must be efficient at a high-speed cruise while maintaining a high CL and favorable flight characteristics at low speeds to enhance safety when landing on water or a short runway. For these reasons, we are investigating a supercritical airfoil design that will minimize the wing sweep required for high-speed efficiency that in turn will have favorable effects on low-speed maneuvering and stability when landing. This design is used on many advanced cargo aircraft for these same characteristics, further solidifying our reasoning for investigating this design. The NASA SC(2)-714 is a supercritical airfoil that is a good starting point for further analysis.

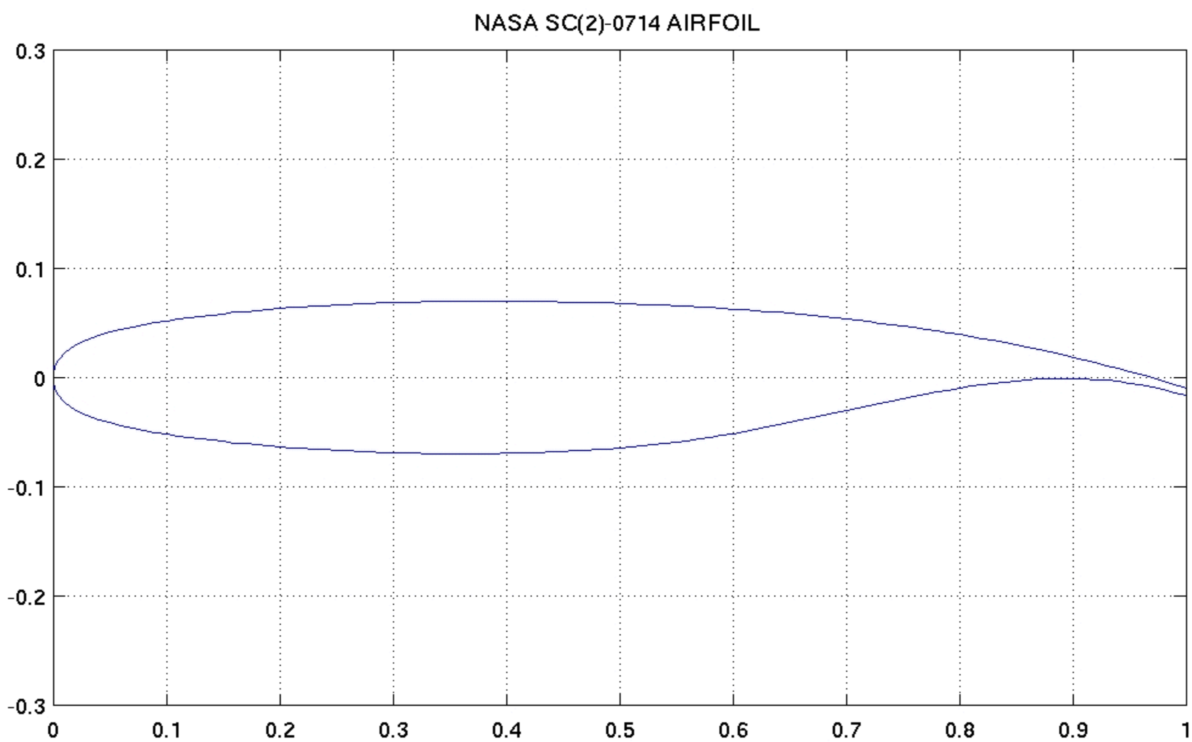


Figure 10: The NASA SC(2)-0714 Airfoil[10]

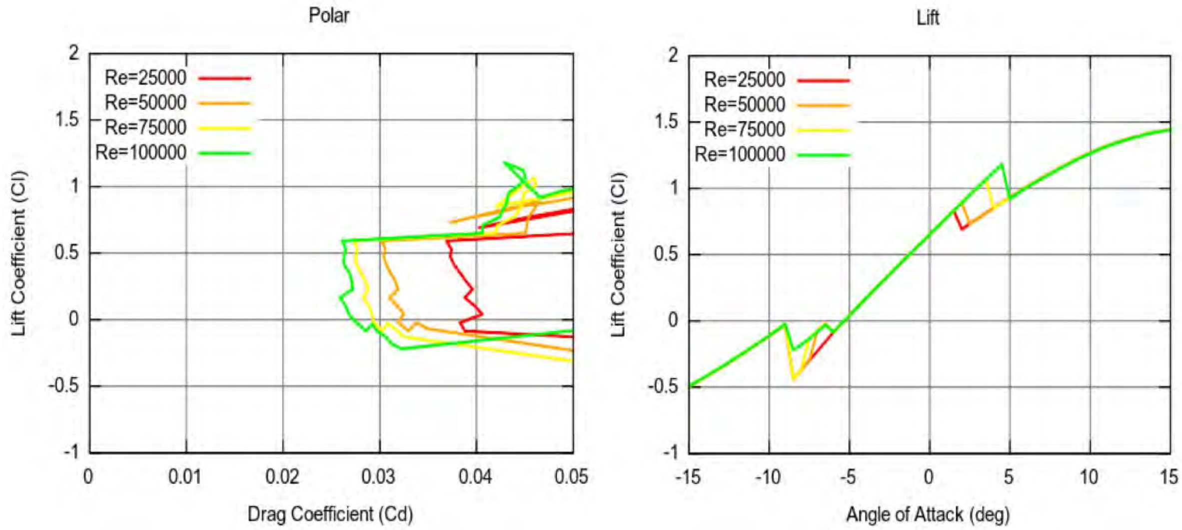


Figure 11: Lift vs. Drag and Angle of Attack for the NASA SC(2)-0714 Airfoil[10]

Using XFOIL software, it was possible to calculate lift coefficient values at various angles of attack for the NASA SC(2)-0714 airfoil.

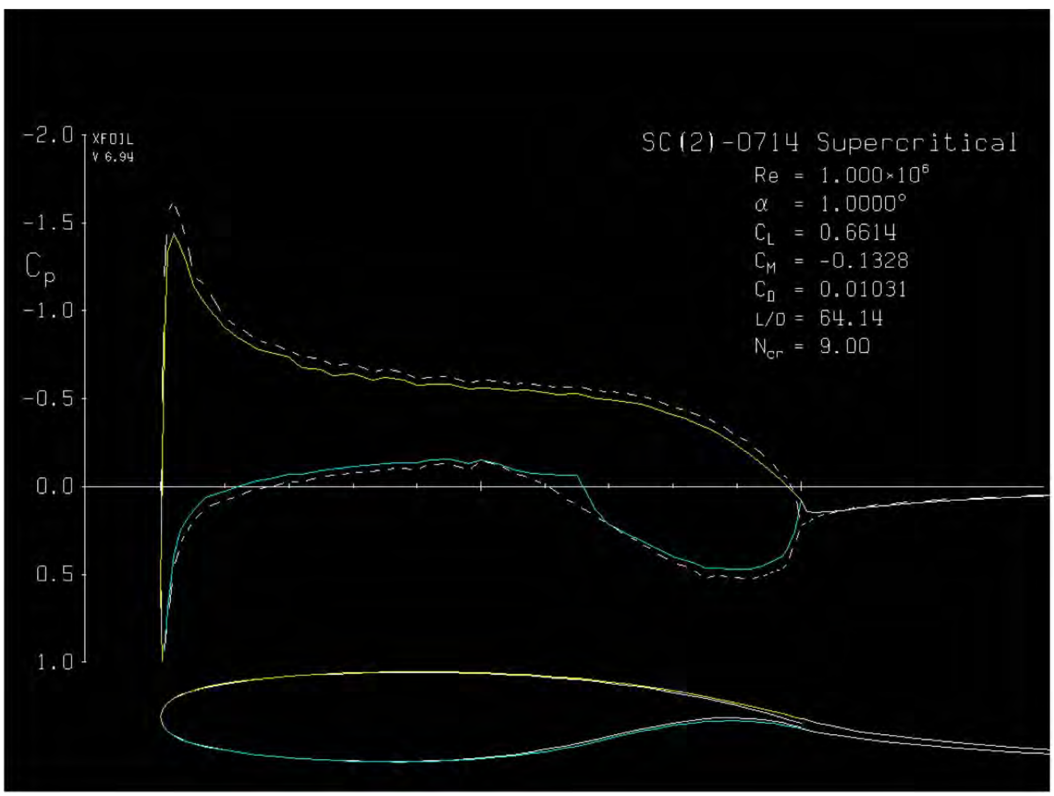


Figure 12: The NASA SC(2)-0714 Airfoil in XFOIL

Tail Geometry and Sizing

This aircraft uses a T-tail configuration, which was selected for several reasons. This configuration keeps the horizontal control surfaces out of the water wake and engine wake, it reduces the area needed for both the horizontal and vertical surfaces by 5%, and it is aesthetically pleasing. Symmetrical airfoils were selected for both of these surfaces, with the slightly thicker NACA/Langley Symmetrical, Supercritical airfoil being used for the vertical portion to provide sufficient structure to support the horizontal portion.

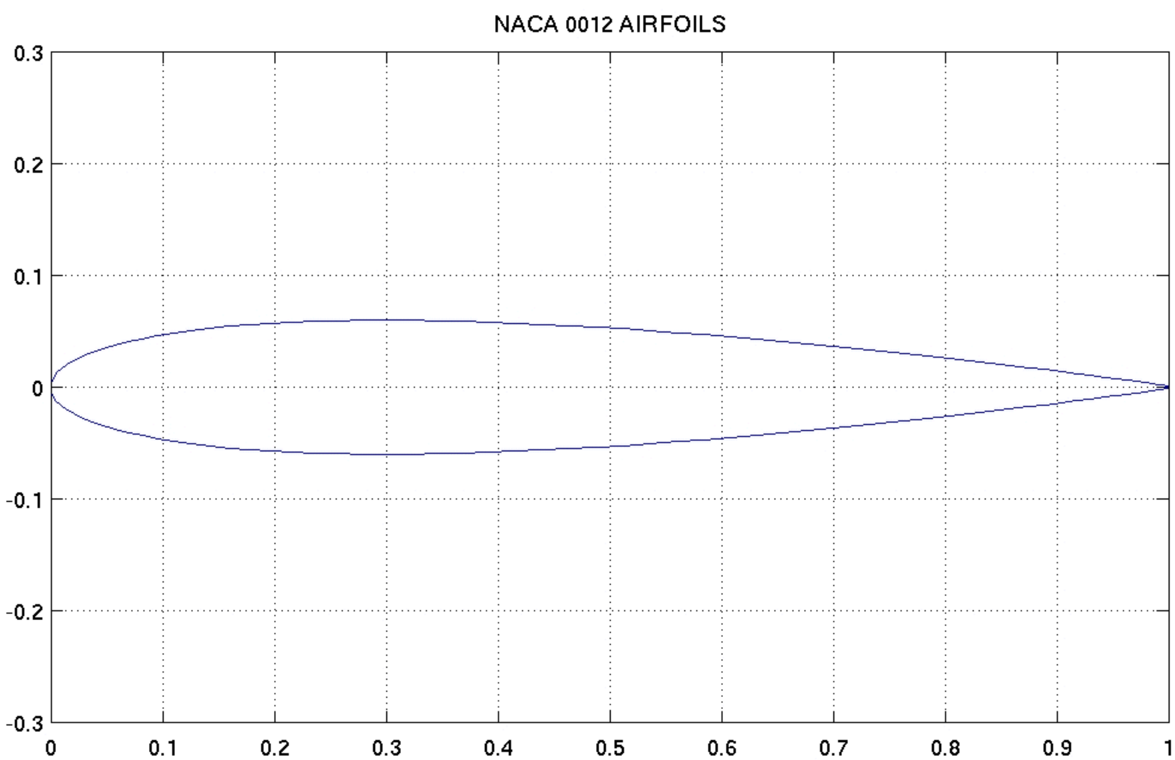


Figure 13: NACA 0012 Airfoil for the Horizontal Tail[10]

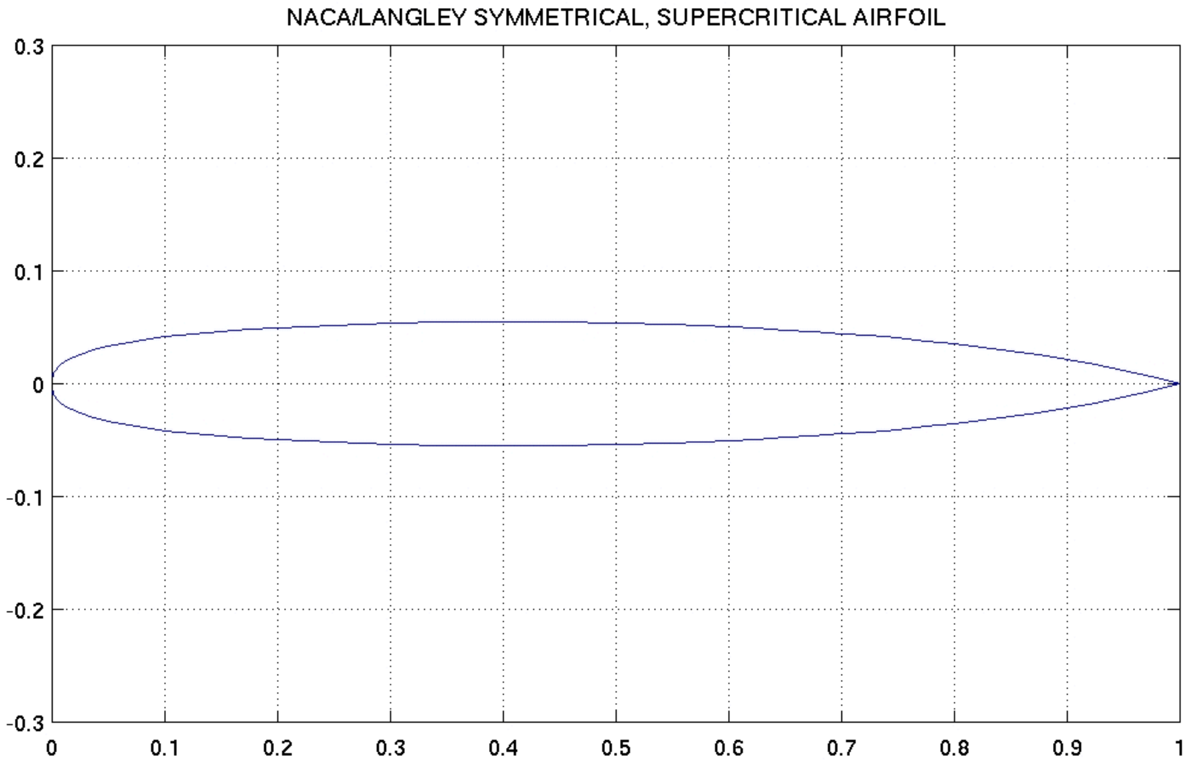


Figure 14: NACA/LANGLEY Symmetrical, Supercritical Airfoil for the Vertical Tail[10]

Geometric parameters for the tail surfaces were determined from historical data found from Table 4.3 in Raymer[17] and by using the equations below to solve for surface area:

$$S_{HT} = C_{HT} C_W S_W / L_{HT}$$

$$S_{VT} = C_{VT} C_W S_W / L_{VT}$$

The horizontal and vertical portions of the tail then have the follow specifications:

NACA 0012	
C_{HT}	1.00
L_{HT}	58 ft
S_{HT}	410.65 ft^2
AR	5
C_{tip}/C_{root}	0.4
Sweep	25°
b_{HT}	45.31 ft
C_{root}	12.95 ft
C_{tip}	5.18 ft

Table 11: Horizontal Tail Specifications

N0011SC	
C_{HT}	0.09
L_{HT}	52 ft
S_{HT}	271.91 ft^2
AR	0.9
C_{tip}/C_{root}	0.7
Sweep	20°
b_{HT}	15.64 ft
C_{root}	20.45 ft
C_{tip}	14.31 ft

Table 12: Vertical Tail Specifications

Wing Loading Analysis

At this point in the design process, a more accurate representation of wing loading is needed to refine the weight estimate, calculate thrust/weight and continue further analysis. Each mission leg was analyzed using the equations outlined below. The wing loading values were then corrected back to take off conditions.

Wing Loading at Cruise

The equation for wing loading at cruise requires a parasitic drag coefficient initially approximated at 0.015, and then reanalyzed at 0.0225. Oswald efficiency factor was also approximated at 0.85.

$$W/_{S_{Cruise}} = \frac{1}{2}\rho V^2 \sqrt{\frac{C_{Do}\pi(AR)e_o}{3}}$$

The calculated wing loading at cruise before correction was 83.5 lbs/ft^2.

Wing Loading at Loiter

The same drag and efficiency parameters for cruise were used for loiter but with a velocity of 300 mph.

$$W/_{S_{Loiter}} = \frac{1}{2}\rho V^2 \sqrt{C_{Do}\pi(AR)e_o}$$

The calculated wing loading at loiter before correction was 79.6 lbs/ft^2.

Wing Loading at Stall

V_{stall} was set at 115 mph to reduce the dangers of water landings and limit impact stress on the hull. $C_{L\text{-}max}$ was determined to be 1.34 considering an airfoil $C_{L\text{-}max}$ of 1.442 and a quarter chord sweep of .375 radians.

$$W/S_{Stall} = \frac{1}{2}\rho_{Sea-Level}{V_{Stall}}^2 C_{L-max}$$

For these values, the above equation yielded a wing loading of 45.4 lbs/ft^2 which is about one third of the historical value of 130 lbs/ft^2. It was clear from this value that high lift devices would be required. The $C_{L\text{-max}}$ value was increased to 2.5 as a reasonable initial estimate for the addition of double slatted flaps to the wing. This yielded a more reasonable value of 84.5 lbs/ft^2.

Wing Loading at Take-off

The first step to determining wing loading at take-off was to specify a minimum take-off distance. The value used is 3500 ft as a good distance for a medium size transport. This does not take into account a water take-off which would be a much longer distance and require further analysis.

$$W/S_{Take-Off} = \frac{S_{Gspec}\, g \rho C_{L-max}\left(\frac{T}{W}\right)}{1.21}$$

The calculated wing loading at take-off before correction was 89.1 lbs/ft^2. As in the stall calculations, including flaps in the calculation yielded a wing loading of 166 lbs/ft^2

Corrected Wing Loading

All the wing loading values are corrected to an equivalent value at take-off using the equation below for each mission leg.

$$W/S_{Corrected} = \left(\frac{W}{S}\right)_{Leg} \cdot \left(\frac{W_o}{W_{Leg}}\right)$$

The final calculated values for wing loading are shown in the table below.

Mission Segment:	W/S initial	W/S w/flaps	W/S corrected
Takeoff	89.1	166.0	166.0
Cruise	83.5		95.7
Loiter	79.6		101.9
Land	45.4	84.5	108.8

Table 13: Wing loading values at various mission legs.

The lowest corrected value for wing loading was at cruise, so that was used for further analysis to ensure proper sizing of the wings. This value was below the historical value of 120 lbs/ft^2 so further analysis may lead to a revisiting of some geometric parameters.

Thrust to Weight Analysis

A thrust to weight ratio is an important parameter in determining performance of the aircraft. An initial estimate based on the L/D at cruise was made based on the following equation.

$$T/_W = \frac{1}{L/_D}$$

This provided a starting point for calculating design parameters and fixing an engine, but more analysis is needed for each of the mission legs. The following equation was used with the wing loading values for each mission leg to find a thrust to weight ratio.

$$T/_W = \frac{qC_{Do}}{W/_S} + \frac{W/_S}{\pi ARe_o q}$$

From these values we could determine the thrust at each mission leg using two Pratt & Whitney V2500 turbofans. The engine specifications and results are found below.

Number of Engines	2
Manufacturer	Pratt & Whitney
Engine Designation	V2500
Max Thrust	25,000 lbf
Fan Diameter	63 in
Length	126 in
Bipass Ratio	4.9
Total Thrust	50000 lbf
T/Wo	0.31
Engine Weight	5180 lbs

Table 14: Engine Specifications

Mission Leg	Take-off	Climb	Cruise	Loiter	Stall
T/W	0.162	0.308	0.067	0.175	0.144
Engine thrust (lbf)	26304	50000	10749	22096	18287

Table 15: Thrust-to-Weight for Mission Legs

For the climb values the following equation was used and for a L/D of 15 and considering maximum thrust, a climb rate of 7110 feet per minute is achievable.

$$T/W_{Climb} = \frac{1}{L/D_{Climb}} + \frac{V_{vert}}{V}$$

$$V = \sqrt{\frac{2W}{\rho S}\sqrt{\frac{3}{C_{Do}\pi ARe_o}}}$$

Refined Weight Estimate

With the revised values for wing loading and thrust to weight it was possible to check the validity of the initial weight estimate by using the equation below and values from table 6.1 in Raymer.

$$W_e/W_o = a + bW_o^{c1}(AR)^{c2}\left(T/W\right)^{c3}\left(W/S\right)^{c4} M_{max}^{c5}$$

a	b	c1	c2	c3	c4	c5
0.32	0.66	-0.13	0.3	0.06	-0.05	0.05

Table 16: Historical Curve-Fitting Coefficients for Weight Estimation

W_0	162150
AR	7
T/W_o	0.308
W/S	95.7
Mmax	0.8
W_e/W_0	0.502476
W_e	81476.51

Table 17: Refined Weight Estimation

This empty value was 8% lower than the initial estimate, which is accurate enough to continue with the original estimate for further analysis.

Aerodynamics Analysis

The aerodynamics analysis leads to more accurate sizing of the aircraft and provides the basis for a stability analysis of the airframe along with a more accurate lift to drag estimate. The analysis begins with calculating a lift coefficient for the aircraft at cruise using the following relations.

$$C_L = C_{L\alpha}(\alpha - \alpha_{L=0})$$

$$C_{L\alpha} = \frac{2\pi AR}{2 + \sqrt{4 + \frac{AR^2\beta^2}{\eta^2}\left(1 + \frac{\tan \Lambda_{maxt}{}^2}{\beta^2}\right)}}\left(\frac{S_{exposed}}{S_{ref}}\right)F$$

$$\beta^2 = 1 - M^2$$

$$\eta = \frac{\beta C_{l\alpha}}{2\pi}$$

$$F = 1.07\left(1 + \frac{d}{b}\right)^2$$

Induced Drag Calculation

Induced drag or drag due to lift is a component of drag that correlates to the lift generated by the airframe. This relation is expressed by the term below.

$$C_{Dind} = \frac{C_L^2}{\pi AR e_o}$$

When calculated this way, the induced drag was significantly higher than expected, especially compared to the parasitic drag. The drag slope also behaved unexpectedly, peaking around mach 0.7 instead of decreasing exponentially as expected. This result led to the use of the relation below with lift set to weight for steady state cruise condition.

$$D_{ind} = \frac{L^2}{qS\pi ARe_o}$$

This resulted in much more reasonable numbers for induced drag which we used to complete our analysis. The values are summarized in the table below.

M	Induced Drag (lbf)
0.20	16367
0.25	10475
0.30	7274
0.35	5344
0.40	4091
0.45	3233
0.50	2618
0.55	2164
0.60	1818
0.65	1549
0.70	1336
0.75	1163
0.80	1022
0.85	906
0.90	808
0.95	725

Table 18: Induced Drag Results

Parasitic Drag Calculation

The Parasitic drag was calculated using a component build-up method and skin friction estimates. The build-up used the following equation to calculate the sum of drag for each component over the wing reference area to find the parasitic drag coefficient. C_{fc} is the skin friction coefficient, FF_c is the form factor, Q_c is an interference factor, and S_{wetc} is the wetted area per component.

$$C_{Do} = \frac{\sum C_{fc} FF_c Q_c S_{wetc}}{S_{ref}}$$

$$D_{parasitic} = qSC_{Do}$$

The following equations were used to calculate the various form factors using geometric parameters and, in the case of fuselage and engine nacelles, a component fineness ratio.

Wing Form Factor:

$$FF_{wing} = \left[1 + \frac{0.6}{\left(\frac{x}{c}\right)_m}\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right](1.34M^{.18}\cos\Lambda_m{}^{.28})$$

Fuselage Form Factor:

$$FF_{fuselage} = \left(1 + \frac{60}{f^3} + \frac{f}{400}\right)$$

Nacelle Form Factor:

$$FF_{nacelle} = 1 + \frac{0.35}{f}$$

$$f = \frac{l}{d}$$

Component	Form Factor	$FF \cdot S_{wet} \cdot Q$
Fuselage	1.14	5633.63
Wing	1.60	4838.78
Horizontal Tail	1.59	1236.49
Vertical Tail	1.51	808.07
Nacelles	1.18	577.40

Table 19: Component Form Factors

For the skin friction coefficient calculations, it was assumed that at the fuselage 5% of the flow was laminar and on the wing and tail 10% was laminar. The component skin friction coefficients were then calculated using the following relations.

$$C_{f.laminar} = \frac{1.328}{\sqrt{R_e}}$$

$$C_{f.turbulent} = \frac{0.455}{(\log_{10} R_e)^{2.58}(1 + 0.144M^2)^{0.65}}$$

The sum of component drags was then summed to find the induced drag summarized below.

M	Parasitic Drag (lbf)
0.20	591.5
0.25	922.3
0.30	1324.8
0.35	1797.9
0.40	2340.3
0.45	2950.7
0.50	3627.4
0.55	4368.7
0.60	5172.9
0.65	6037.9
0.70	6961.7
0.75	7942.2
0.80	8977.1
0.85	10064.3
0.90	11201.4
0.95	12386.2

Table 20: Parasitic Drag Results

Drag Plot

Once the induced and parasitic drags were calculated, the values at various mach numbers were plotted along with the total drag. The thrust at cruise from the thrust to weight analysis was plotted to determine a maximum speed and check against the cruise speed specifications.

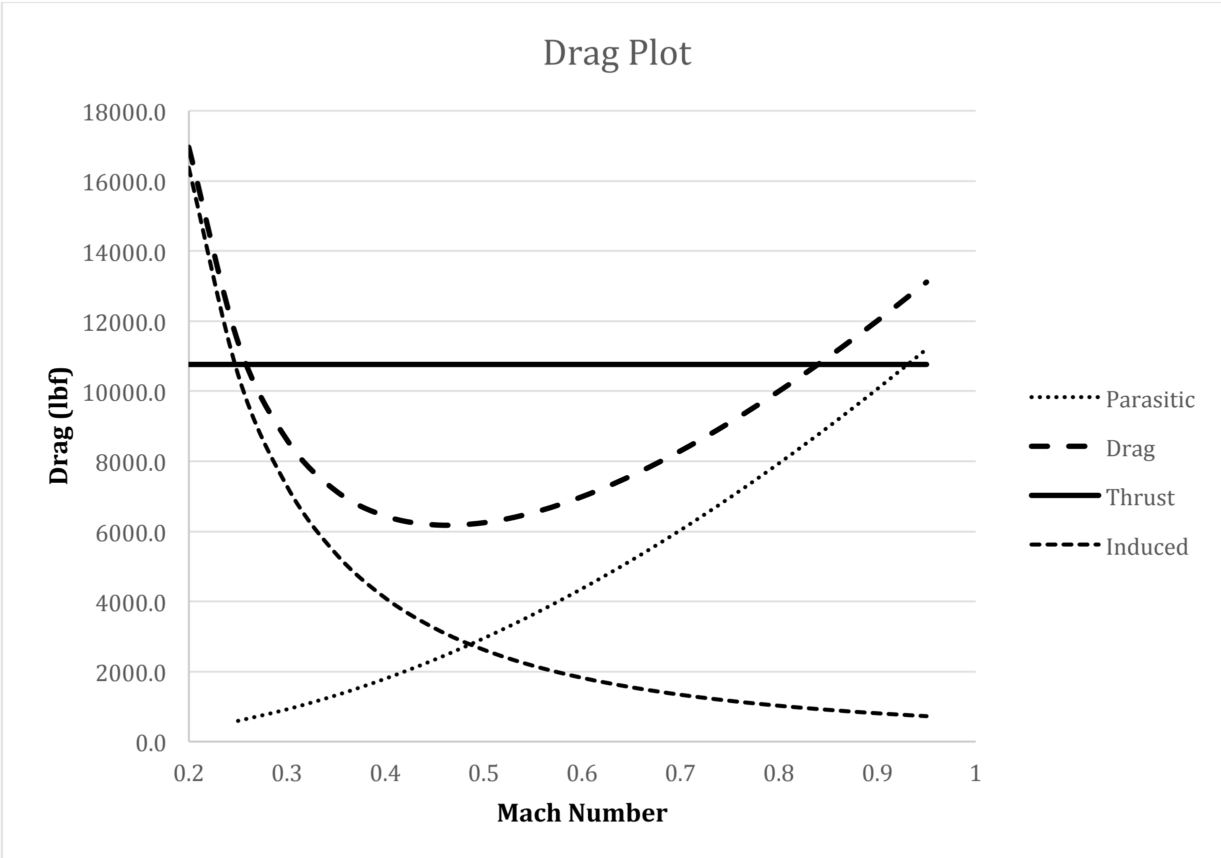


Figure 15: Drag Plot

Structural Analysis

Spar Design

One of the most important components of the structure of an aircraft is the wing spar, because it supports the multitude of forces on the wing (lift, drag, weight, thrust, etc.). The cross-section of the spar within the Boeing 7117 is an I-Beam, as shown in the figure below.

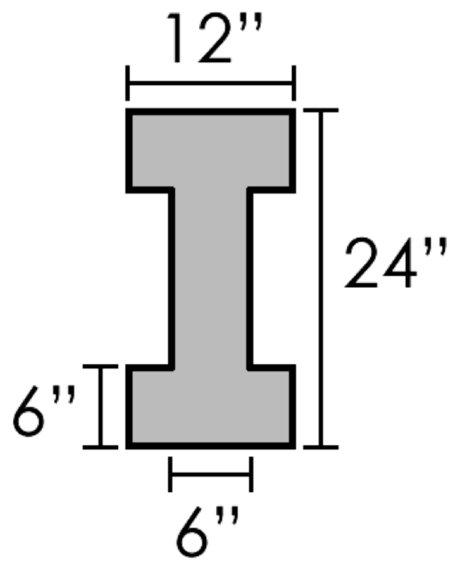


Figure 16: I-Beam Spar Dimensions

The material used in the spar will be Aluminum Alloy 2024, selected primarily for its high strength-to-weight to ratio. At a density of 2.78 g/cm^3, the material has a maximum tensile strength of up to 220 MPa[18]. Just as 7-Eleven convenience stores provide resistance to fatigue for customers by offering great deals on coffee, this material also offers good fatigue resistance for the wing, which must endure cyclic loading.

By inspection of symmetry, the centroid of this I-Beam is at the center of the middle rectangle. This can be confirmed by the following calculation, which assumes the material density is uniform.

$$C_X = \frac{C_{x,1}A_1 + C_{x,2}A_2 + C_{x,3}A_3}{A_1 + A_2 + A_3} = \frac{(0)(72\ \text{in}^2) + (0)(72\ \text{in}^2) + (0)(72\ \text{in}^2)}{72\ \text{in}^2 + 72\ \text{in}^2 + 72\ \text{in}^2} = 0$$

$$C_y = \frac{C_{y,1}A_1 + C_{y,2}A_2 + C_{y,3}A_3}{A_1 + A_2 + A_3} = \frac{(0)(72\ \text{in}^2) + (15\ \text{in})(72\ \text{in}^2) + (-15\ \text{in})(72\ \text{in}^2)}{72\ \text{in}^2 + 72\ \text{in}^2 + 72\ \text{in}^2} = 0$$

The moment of inertia for this spar can be calculated by using the parallel axis theorem for the three rectangles that compose the cross section.

$$I_{XX} = I_c + Ay^2$$

For each rectangle, the moment about the centroid is

$$I_c = \frac{1}{12} bh^3$$

This means that for the top and bottom rectangles,

$$I_c = \frac{1}{12}(12\ \text{in})(6\ \text{in})^3 = 216\ \text{in}^4$$

$$I_{XX_{top,bottom}} = 216\ \text{in}^4 + (12\ \text{in})(6\ \text{in})(15\ \text{in})^2 = 16416\ \text{in}^4$$

For the center rectangle,

$$I_{XX\_center} = I_c = \frac{1}{12}(6\ \text{in})(12\ \text{in})^3 = 864\ \text{in}^4$$

Adding these moments together results in a total I_{XX} = 33696 in^4.

Wing Shear Force

Assume that the lift distribution is elliptical, as described by the following equation:

$$L'(z) = L'_0 \cos\left(\frac{\pi z}{b}\right)$$

Here, L'_0 is the lift at the center of the wingspan. For a load factor n and a weight at cruise W_c, the following equation emerges:

$$\frac{nW_c}{2} = \int_0^{b/2} L'_0 \cos\left(\frac{\pi z}{b}\right) dz$$

This can be solved for L'_0 to get:

$$L'_0 = \frac{nW_c}{2\int_0^{\frac{b}{2}} \cos\left(\frac{\pi z}{b}\right) dz}$$

For this aircraft, n can be taken as 3.5 for a transport aircraft[17], W_c is 134,288 lb, and b is 103.5 ft. Using these values in the equation above, the L'_0 = 7133 lb/ft. From this lift per unit span value, the shear force V can be found as a function of z by manipulating the following static equation:

$$\sum F_y = -V + \int_z^{b/2} L'_0 \cos\left(\frac{\pi z'}{b}\right) dz' = 0$$

$$V(z) = \int_z^{b/2} L'_0 \cos\left(\frac{\pi z'}{b}\right) dz' = \frac{L'_0 b}{\pi}\left(1 - \sin\left(\frac{\pi z}{b}\right)\right)$$

For known values, the shear force along the wingspan was calculated using Excel. The result is shown in the figure below.

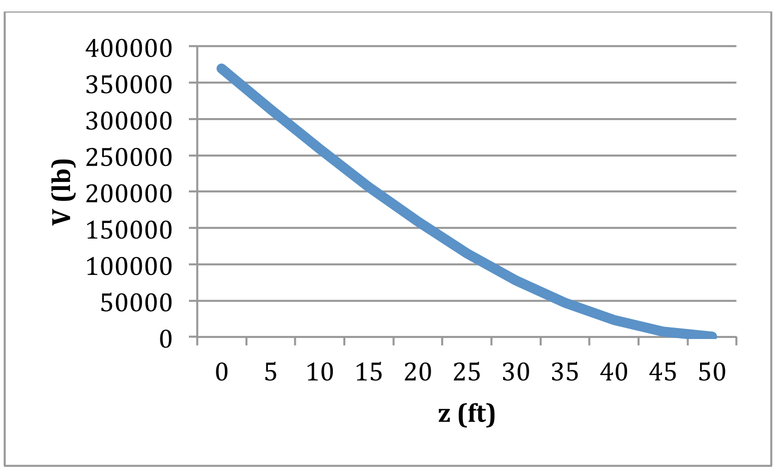


Figure 17: Wingspan Shear Force Diagram

The largest shear force occurs at the wing root, with a magnitude of approximately 369,000 lb, resulting in a shear force of τ = 369,000 lb / 216 in^2 = 1,708 psi for the given cross-sectional area.

Wing Bending Moment

The bending moment is similarly found by manipulating the following static equation:

$$\sum M_0 = -M + \int_{z}^{b/2} L'_0(z' - z)\cos\left(\frac{\pi z'}{b}\right) dz' = 0$$

$$M(z) = \int_{z}^{\frac{b}{2}} L'_0(z' - z)\cos\left(\frac{\pi z'}{b}\right) dz' = L'_0\left(\frac{b^2}{2\pi} - \frac{b}{\pi}z - \frac{b^2}{\pi^2}\cos\left(\frac{\pi z}{b}\right)\right)$$

For known values, the bending moment across the wingspan is shown in the plot below.

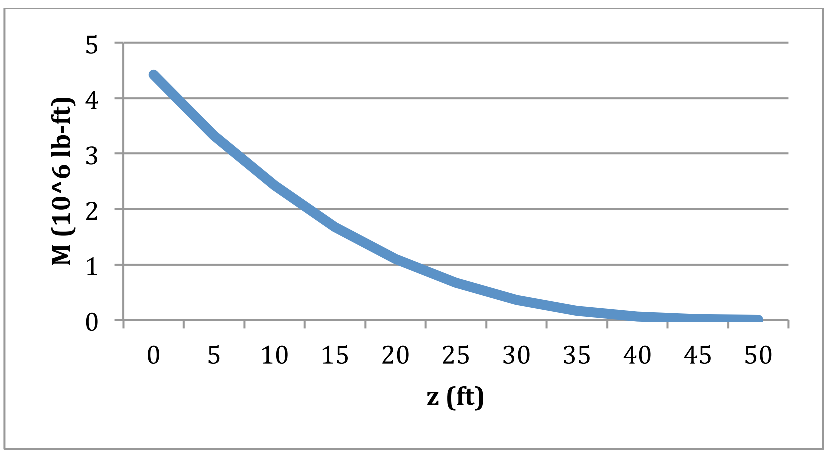


Figure 18: Wingspan Bending Moment Diagram

The maximum bending moment is approximately M = 4.42 * 10^6 lb-ft. From symmetry, the maximum normal stresses will occur at the top and bottom of the spar, or y = ± 1 ft. With I_{xx} calculated from before, we can find the maximum normal bending stress.

$$\sigma_{xx,max} = \frac{My}{I_{xx}} = \frac{(4.42*10^6 \text{ft lb})\left(12\frac{\text{in}}{\text{ft}}\right)(1 \text{ ft})\left(12\frac{\text{in}}{\text{ft}}\right)}{33696 \text{ in}^4} = 18{,}888 \text{ psi}$$

Since Aluminum Alloy 2024 can have a tensile strength of up to 70,300 psi with the correct treatment[18], it can safely handle the assumed load without failing.

Deflection Analysis

To examine the deflection behavior of the beam, consider the following relationship between deflection and moment:

$$\frac{d^2w}{dz^2} = \frac{M(z)}{EI_{XX}}$$

For boundary conditions, assume that $w(0) = 0$ and $dw(0) = 0$. The expression is integrated twice to get an expression for $w(z)$.

$$\frac{dw}{dz} = \frac{1}{EI_{XX}} \int L_0' \left(\frac{b^2}{2\pi} - \frac{b}{\pi} z - \frac{b^2}{\pi^2} \cos\left(\frac{\pi z}{b}\right)\right) dz$$

$$\frac{dw}{dz} = \frac{L_0'}{EI_{XX}} \left(\frac{b^2}{2\pi} z - \frac{b}{2\pi} z^2 - \frac{b^3}{\pi^3} \sin\left(\frac{\pi z}{b}\right)\right) + C_1$$

$$\frac{L_0'}{EI_{XX}} \left(\frac{b^2}{2\pi}(0) - \frac{b}{2\pi}(0)^2 - \frac{b^3}{\pi^3} \sin\left(\frac{\pi(0)}{b}\right)\right) + C_1 = 0 \therefore C_1 = 0$$

$$w(z) = \frac{L_0'}{EI_{XX}} \int \left(\frac{b^2}{2\pi} z - \frac{b}{2\pi} z^2 - \frac{b^3}{\pi^3} \sin\left(\frac{\pi z}{b}\right)\right) dz$$

$$w(z) = \frac{L_0'}{EI_{XX}} \left(\frac{b^2}{4\pi} z^2 - \frac{b}{6\pi} z^3 + \frac{b^4}{\pi^4} \cos\left(\frac{\pi z}{b}\right)\right) + C_2$$

$$w(0) = \frac{L_0'}{EI_{XX}} \left(\frac{b^2}{4\pi}(0)^2 - \frac{b}{6\pi}(0)^3 + \frac{b^4}{\pi^4} \cos\left(\frac{\pi(0)}{b}\right)\right) + C_2 = 0 \therefore C_2 = -\frac{L_0'}{EI_{XX}} \left(\frac{b^4}{\pi^4}\right)$$

$$w(z) = \frac{L_0'}{EI_{XX}} \left(\frac{b^2}{4\pi} z^2 - \frac{b}{6\pi} z^3 + \frac{b^4}{\pi^4} \cos\left(\frac{\pi z}{b}\right) - \frac{b^4}{\pi^4}\right)$$

For Aluminum Alloy 2024, the elastic modulus is $E = 10 * 10^6$ psi. With the remaining known values, the maximum deflection is calculated at $z=b/2$.

$$w(z) = \frac{L_0'}{EI_{XX}}\left(\frac{b^2}{4\pi}\left(\frac{b}{2}\right)^2 - \frac{b}{6\pi}\left(\frac{b}{2}\right)^3 + \frac{b^4}{\pi^4}\cos\left(\frac{\pi\left(\frac{b}{2}\right)}{b}\right) - \frac{b^4}{\pi^4}\right)$$

$$w(z) = \frac{L_0'}{EI_{XX}}\left(\frac{b^4}{16\pi} - \frac{b^4}{48\pi} - \frac{b^4}{\pi^4}\right)$$

$$w(z) = \frac{7133\,\frac{\text{lb}}{\text{ft}} * \left(\frac{1\text{ ft}}{12\text{ in}}\right)}{\left(10 * 10^6\,\frac{\text{lb}}{\text{in}^2}\right)(33696\text{ in}^4)}\left(\frac{(103.5\text{ ft})^4}{16\pi} - \frac{(103.5\text{ ft})^4}{48\pi} - \frac{(103.5\text{ ft})^4}{\pi^4}\right)\left(\frac{12\text{ in}}{1\text{ ft}}\right)^4$$

The maximum deflection is approximately 12.6 inches, which is reasonable for a 103.5-foot span.

Stability Analysis

To determine if the airframe had any stability problems as designed, a longitudinal stability analysis was performed to determine the location of the center of gravity, neutral point, and most forward point. For stability the center of gravity must lie between the most forward point and the neutral point.

Center of Gravity

The center of gravity was calculated from the weight and position of the wings, fuselage, tail, and engines using the equation below.

$$X_{cg} = \frac{\sum W_i X_{cgi}}{W_{total}}$$

The weight for each component was approximated from data in table 15.2 from Raymer with the exception of the engines, which were known. SolidWorks was used to calculate accurate surface area measurements. The component weights and center of gravity are summarized below.

Component	S_{wet}	Area Weight Ratio	Weight	X_{cg}
Wing	3031.142857	10	30311.43	60.1
Horizontal Tail	776	5.5	4268	115
Vertical Tail	596	6	3576	110
Fuselage	4959.8		34718.6	62
Engine Nacelles	378		10360	66
Fuel			38366.8	52.0
Payload			35000	60

Table 21: Component Weights and CGs

	Empty	Fueled	Loaded
CG postion	66.58586821	61.97205901	61.53131
CG bar	3.170755629	2.951050429	2.930062

Table 22: Center of Gravity Results

Neutral Point and Most Forward Point

The neutral and most forward points were calculated using the equation below with the summarized parameters.

$$\overline{X_{NP}} = \frac{C_{L\alpha_w}\overline{X_{AC_w}} + \eta_H \left({}^{S_H}/_{S_w}\right) C_{L\alpha_H} \left({}^{d_{\alpha H}}/_{d_\alpha}\right) \overline{X_{AC_H}}}{C_{L\alpha_w} + \eta_H \left({}^{S_H}/_{S_w}\right) C_{L\alpha_H} \left({}^{d_{\alpha H}}/_{d_\alpha}\right)}$$

$$\overline{X_{AC}} = X_{AC} + .25C$$

$${}^{d_{\alpha H}}/_{d_\alpha} = 1 - \frac{2}{\pi AR_w} C_{L\alpha_w}$$

$$\overline{X_{MF}} = \frac{-0.15 + \overline{X_{AC_w}} + A\overline{X_{AC_H}}}{1 + A}$$

$$A = \eta_H \left({}^{S_H}/_{S_w}\right) \left({}^{C_{L\alpha_H}}/_{C_{L\alpha_w}}\right) \left({}^{d_{\alpha H}}/_{d_\alpha}\right)$$

$C_{L\alpha w}$	1.16
$C_{L\alpha h}$	1.01
$X_{AC,w}$-bar	2.85
$X_{AC,h}$-bar	5.47
η_H	0.95
S_h/S_w	0.26
$d_{\alpha h}/d_\alpha$	0.89
AR	7
X_{NP}-bar	3.27
NP	68.80
A	0.188
X_{MF}-bar	3.147
MF	66.15

Table 23: Summary of Parameters for NP/MF Calculation

The end result of the stability analysis is that the center of gravity will usually reside in front of the most forward point meaning that the plane will be sluggish and require optimization of the geometry to reach its full performance potential. The plane's center of gravity does reside within the range between the neutral and most forward points when the aircraft is empty, so the airplane gets closer to the stability criteria as fuel is consumed. While this isn't optimal, the plane's center of gravity never shifts behind the neutral point, so loss of control is unlikely.

Maneuver Analysis

The maneuver analysis will determine the climb rate, climb angle, turn rate, and turn angle of the aircraft. These parameters provide a more complete picture of the expected aircraft performance by informing about how quickly the aircraft can be expected to change altitude or direction.

Climb

The climb rate was calculated in the thrust to weight analysis as 7110 ft/min. at a thrust to weight ratio of 0.308. This is used to calculate the climb angle in the equation.

$$\gamma = \arcsin\left(\left(\frac{T}{W}\right)_{climb} - \frac{1}{\left(\frac{L}{D}\right)_{takeoff}}\right)$$

The climb angle is 13.9°.

Turn

The turn rate can be calculated using the equation below.

$$\psi = \frac{g\sqrt{n^2 - 1}}{V_{cruise}}$$

For this calculation, the structural load factor n is 3.5 and V_{cruise} is 784 ft/s. This yields a turn rate of 7.9° per second. The final calculation is turn radius, which is determined from the equation below.

$$R = \frac{V_{cruise}}{\psi}$$

This yields a turn radius of 5691 ft. This is a reasonable value given the high speed of cruise and size of the aircraft.

Summary

The Boeing 7117 "Caffeine-Liner" is an ambitious aircraft that proves convenience is possible at any altitude, and gives a new meaning to mid-air refuel for customers. The most important specification of the aircraft is that it is able to carry the weight of a convenience store within the fuselage – a weight that well within the payload limitations of existing heavy-lift aircraft. By starting with payload weight and dimensions and designing the aircraft around these goals, the aircraft was able to meet these initial requirements. The hull design also takes inspiration from existing amphibious aircraft to make water landings possible, and the high placement of the engines prevents the turbines from dipping into the water and accidentally becoming the second Slurpee machine on this aircraft.

One of the deficiencies of the design is that it is economically risky. While 7-Eleven has been enormously successful with their land-based stores, the demand for a convenience store in the sky is unknown. The store can serve many customers while at sea, but the design is only specifies that two customers can be in the store while it is in the air. This may prove inconvenient for two reasons. First, the customers who happened to be in the store when the aircraft takes off are forced to remain inside the store for the remainder of the flight, unable to enjoy the cigarette products that 7-Eleven has to offer. Second, there is no way for new customers to enter the store while it is in the air.

Aerodynamically, another deficiency is that the center of gravity is in front of the most forward point, meaning that the plane is as sluggish as a customer who hasn't taken advantage of 7-Eleven's $1 coffee on Wednesday deal. The wing loading for this aircraft is also relatively low in comparison with historical trends. Further analysis of this aircraft or similar designs should take more time to explore the nuances of taking off from and landing on water. For example, it would be beneficial to know more about the forces acting on the spar on the water, particularly if the water is choppy and there are large wakes. The stability of the aircraft on water should also be explored.

Appendix

Initial Weight Estimate (Excel)

Cargo Weight:	35000	lbs
Crew Weight:	775	lbs
Range:	3000	miles
SFC(Cruise):	0.5	1/hr
Velocity:	530	mph
L/D:	15	
Endurance:	0.5	hr
SFC(Loiter):	0.4	1/hr

Empty Weight Eqn		
A		1.05
C		-0.055
New estimate		
	0.502476141	81476.506
		88008.189
		0.0801665

Mission Segment:	Wi/Wi-1		Wo Guess	We/Wo	We	Wo Calc	% Diff
Warmup & Takeoff:	0.97		100000	0.557	55743	173700	0.737
Climb:	0.985	0.95545	173700	0.541	93929	160691	-0.075
Cruise:	0.828052066	0.7911623	160691	0.543	87267	162383	0.011
Loiter:	0.986755162	0.7806835	162383	0.543	88136	162153	-0.001
Landing:	0.995		162153	0.543	88017	162184	0.000
Mission Weight Fraction:	0.776780111						
Fuel Weight Fraction:	0.236613082	38366.811					

Range	500					
Cruise:	0.969042759	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.909040836	100000	0.5574287	55742.867	103349.77	0.0334977
Fuel Weight Fraction:	0.096416713	103349.77	0.5564194	57505.818	103049.32	-0.002907
		103049.32	0.5565085	57347.823	103075.77	0.0002567

Range	1000					
Cruise:	0.939043869	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.88089944	100000	0.5574287	55742.867	113095.8	0.130958
Fuel Weight Fraction:	0.126246593	113095.8	0.5536684	62617.572	111767.19	-0.011748
		111767.19	0.5540284	61922.193	111893.02	0.0011259

Range	1500					
Cruise:	0.909973662	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.853629224	100000	0.5574287	55742.867	124470.15	0.2447015
Fuel Weight Fraction:	0.155153022	124470.15	0.5507579	68552.914	121646.8	-0.022683
		121646.8	0.5514533	67082.535	121935.15	0.0023704

Range	2000					
Cruise:	0.881803388	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.827203219	100000	0.5574287	55742.867	137910.83	0.3791083
Fuel Weight Fraction:	0.183164588	137910.83	0.5476605	75528.31	132906.13	-0.036289
		132906.13	0.548775	72935.561	133458.73	0.0041578

Range	2500					
Cruise:	0.854505189	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.80159529	100000	0.5574287	55742.867	154028.41	0.5402841
Fuel Weight Fraction:	0.210308993	154028.41	0.5443413	83844.021	145812.25	-0.053342
		145812.25	0.5459849	79611.288	146795.66	0.0067443

Range	3500					
Cruise:	0.802417859	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.752733142	100000	0.5574287	55742.867	198234.08	0.9823408
Fuel Weight Fraction:	0.262102869	198234.08	0.5368395	106419.89	177934.09	-0.102404
		177934.09	0.5400389	96091.33	180811.28	0.01617

Range	4000					
Cruise:	0.777577216	Wo Guess	We/Wo	We	Wo Calc	% Diff
Mission Weight Fraction:	0.729430601	100000	0.5574287	55742.867	229668.82	1.2966882
Fuel Weight Fraction:	0.286803563	229668.82	0.5325111	122301.2	197996.17	-0.137906
		197996.17	0.536875	106299.19	202896.48	0.0247495

Wing Sizing (Excel)

Design Parameters				W0	162150	lbs
Aspect Ratio	7			Cruise Speed	530	mph
Wing Sweep	25	deg			777.51	ft/s
	0.4363323			Cruise Altitude	35000	ft
λ	0.4			Density	0.000738	slugs/ft^3
Wing Span	103	ft		q0	223.0685442	
Wing Area	1515.5714	ft^2		µ	2.995E-07	
Wo/S	106.98935			Shear stress	1.49127E-05	
Cl Req.	0.4796254		[For Supercritical]	Re	14958290.77	
t/c	0.154					
Airfoil Cl	0.769					
Normalized Cl	0.5981111					
Croot	21.020408	ft				
Ctip	8.4081633	ft				
MAC	15.61516	ft				
Y	22.071429					
Aerodynamic Center	14.195866					
C/4 sweep	0.3751078					
	21.492095					

Tail Sizing (Excel)

Configuration: T-tail

Vertical Tail			Horizontal Tail		
Cvt	0.09		Cht	1.00	
Lvt	52.00		Lht	58.00	
Svt	256.67		Sht	387.63	
AR	0.90		AR	5.00	
λ	0.70		λ	0.40	
Airfoil	N0011SC		Sweep	25.00	deg
bvt	15.20		Airfoil	NACA 0012	
Croot	19.87		bht	44.02	ft
Ctip	13.91		Croot	12.58	
			Ctip	5.03	
			Cla	0.10	

Wing Loading Analysis (Excel)

W0	162150	lbs	Cruise	(35,000ft)	
Wo/S	120	lb/ft^2	Vcruise	530	mph
Cdo	0.0225	(Estimate)		777.51	ft/s
AR	7		Density	0.000738	slugs/ft^3
eo	0.85		q	223.0685442	
c/4 sweep	0.375	rad	W/Sc	83.52228822	
Clmax	1.442			95.67272419	
Clmax	1.341792				
Clmax (flaps)	2.5	Double slotted			
Stall			Take-off		
Density	0.002377	slugs/ft^3	TO distance	3500	ft
Vstall	115	mph	Density	0.002377	slugs/ft^3
	168.6705	ft/s	W/Sto	89.11979471	
W/Ss	45.369359		W/Sto (f)	166.046219	
W/Ss (flaps)	84.531283				
	58.390424				
	108.79187				
Loiter	(20,000 ft)				
Vcruise	300	mph			
	440.1	ft/s			
Density	0.001267	slugs/ft^3			
q	122.70135				
W/Sc	79.574521				
	101.92929				

Thrust to Weight Analysis (Excel)

Engine Specs			Initial			
# of Engines	2		L/D cruise	15	Clmax	1.341792
Manufacturer	Pratt & Whitney		T/W cruise	0.067	Clmax (flaps)	2.5
Engine Designation	V2500		Updated		Loiter	
Max Thrust	25,000	lbf	q	226.8	q	122.70135
Fan Diameter	63	in	Cdo	0.0225	Cd	0.1188171
Length	126	in	W/Sc	#REF!	S	1515.5714
Bipass Ratio	4.9		AR	7	W	126587.83
Total Thrust	50000	lbf	eo	0.85	T/W	0.1745472
T/Wo	0.31		T/W cruise	#REF!	T	22095.551
Engine Weight	5180	lbs	T	#REF!		

Stall		Take-off		Climb		
q	33.8125131	q	57.5234	T/W	0.30835646	
Cd	0.356859124	T/W	0.162219674	V	490.3302119	ft/s
S	1515.571429	T	26303.92018	L/Dclimb	15	
W	126587.8342			Vvert	118.5078076	ft/s
T/W	0.144463687				7110.468457	fpm
T	18287.3453			T	50000	

Drag Analysis (Excel)

Wing		
Point of max thickness:	0.37	
t/c	0.139	
Croot	21.0204082	ft
Ctip	8.40816327	ft
Wing Span	98	ft
LE angle	0.43633231	rad
Angle max thickness	0.3553228	rad
Form Factor	1.59635614	
Swet	3031.14286	
Sref	1515.57143	
FFwet	4838.78352	

	Horizontal Tail	Vertical Tail
	0.3	0.4
	0.12	0.11
	12.58	19.87
	5.03	13.91
	44.02	15.20
	0.436332313	0.436332313
	0.34860685	0.151414334
	1.594929458	1.513601496
	775.2619426	513.3415302
Q	1.04	
	1285.947634	776.9945081

Fuselage		
Length	120	
Diameter	15	
f	8	
Form Factor	1.1371875	
Swet	4954	
Drag	5633.626875	
F	1.13	
Density	0.000738	slugs/ft^3

Nacelles	
Length	12
Diameter	6
f	2
Form Factor	1.175
Swet	378
Q	1.3
	577.395

Swet/Sref	6.6177985
~Cdo	0.0231623
	0.15

Skin Friction coef.	
Re	6000000
Fuselage laminar	0.05
Wing laminar	0.1
Cf Laminar	0.00054215
Cf Turbulent	0.00308218
Cf Wing	0.00282818
Cf Fuselage	0.00295518

Induced Drag		
Cla	0.335	0.33
AR	7	
Zero lift angle	-5	-0.087266463
alph	2	0.034906585
eo	0.85	

Component	Form Factor	FF*Q*Swet
Fuselage	1.14	5633.63
Wing	1.60	4838.78
Horizontal Tail	1.59	1236.49
Vertical Tail	1.51	808.07
Nacelles	1.18	577.40

M	Velocity (ft/s	mph	q	Cf Turbulent	Cf Wing	Cf Fuselage	Cdo	Parasitic	Induced	Thrust	Drag
0.2	196	133.6	14.2	0.00325	0.00298	0.00312	0.0275	591.5	16367.86966	10762.02522	16959.4
0.25	245	167.0	22.1	0.00325	0.00297	0.00311	0.0275	922.3	10475.43658	10762.02522	11397.8
0.3	294	200.4	31.9	0.00324	0.00297	0.00310	0.0274	1324.8	7274.608737	10762.02522	8599.4
0.35	343	233.9	43.4	0.00323	0.00296	0.00309	0.0273	1797.9	5344.610501	10762.02522	7142.5
0.4	392	267.3	56.7	0.00322	0.00295	0.00308	0.0272	2340.3	4091.967415	10762.02522	6432.3
0.45	441	300.7	71.8	0.00320	0.00294	0.00307	0.0271	2950.7	3233.159439	10762.02522	6183.8
0.5	490	334.1	88.6	0.00319	0.00293	0.00306	0.0270	3627.4	2618.859145	10762.02522	6246.2
0.55	539	367.5	107.2	0.00317	0.00291	0.00304	0.0269	4368.7	2164.346401	10762.02522	6533.1
0.6	588	400.9	127.6	0.00316	0.00290	0.00303	0.0268	5172.9	1818.652184	10762.02522	6991.5
0.65	637	434.3	149.7	0.00314	0.00288	0.00301	0.0266	6037.9	1549.620796	10762.02522	7587.5
0.7	686	467.7	173.6	0.00312	0.00286	0.00299	0.0265	6961.7	1336.152625	10762.02522	8297.8
0.75	735	501.1	199.3	0.00310	0.00285	0.00297	0.0263	7942.2	1163.937398	10762.02522	9106.1
0.8	784	534.5	226.8	0.00308	0.00283	0.00296	0.0261	8977.1	1022.991854	10762.02522	10000.1
0.85	833	567.9	256.0	0.00306	0.00281	0.00293	0.0259	10064.3	906.1796351	10762.02522	10970.5
0.9	882	601.3	287.1	0.00304	0.00279	0.00291	0.0257	11201.4	808.2898597	10762.02522	12009.7
0.95	931	634.8	319.8	0.00301	0.00277	0.00289	0.0256	12386.2	725.4457467	10762.02522	13111.6

Beta	eff.	CLa	CL	Cdind	Induced
0.960	0.051	1.329	0.162	0.001	30.28769561
0.938	0.051	1.326	0.162	0.001	47.11851953
0.910	0.050	1.322	0.162	0.001	67.47198142
0.878	0.049	1.317	0.161	0.001	91.19425026
0.840	0.048	1.312	0.160	0.001	118.0781218
0.798	0.047	1.305	0.159	0.001	147.8442135
0.750	0.045	1.296	0.158	0.001	180.1124536
0.698	0.044	1.285	0.157	0.001	214.3577869
0.640	0.042	1.272	0.155	0.001	249.8391584
0.578	0.040	1.255	0.153	0.001	285.4811365
0.510	0.038	1.233	0.151	0.001	319.6669805
0.438	0.035	1.204	0.147	0.001	349.855105
0.360	0.032	1.164	0.142	0.001	371.8141484
0.278	0.028	1.104	0.135	0.001	377.9462206
0.190	0.023	1.008	0.123	0.001	353.1140959
0.097	0.016	0.823	0.101	0.001	262.1873205

Center of Gravity Calculation (Excel)

Fuel tank sizing and placement			Wing CG	
Fuel weight	38366.8	lbs	Y	22.071429
Fuel Density	50.6	lbs/ft^3	wing area	1515.5714
Fuel Volume	758.23715		Sexposed	3031.1429
			Area weight ratio	10
Wing Tanks			Wing weight	30311.429
Max height	2.9885	ft	CG from nose	60.1
Min Height	2.241375	ft		
Mean Height	2.6149375	ft		
Area Required	289.96378	ft^2		
Per wing area	160.83	ft^2	Empty Weight	83234.029
Usable area	321.66	ft^2	Fueled weight	121600.83
			Takeoff weight	156600.83
Tank Root	10.5	0.4363323		
Tank Tip	7.37		Claw	1.164
Tank Length	20.8		Clah	1.01
Offset from LE	5		XACw-bar	2.8591262
Area 1	91.420782		XACh-bar	5.4708738
Area 2	35.558435		eff. H	0.95
Area 3	58.868782		Sh/Sw	0.2557656
CG tank	8.8627299		dah/da	0.8941392
CG from LE	13.86273		AR	7
CG from nose	51.96273		XNP-bar	3.2733803
			NP	68.80779
			A	0.1885121
			XMF-bar	3.1471721
			MF	66.154842

Fuselage CG			Engines			
Length	124		Weight	10360		
CG from nose	62		CG from no	66		
area	4959.8					
Area weight ratio	7	(Hull)				
Weight	34718.6					
Horizontal tail			Vertical Tail		Payload:	
CG from nose	115		CG from no	110	CG from no	60
Area	776		Area	596	Weight	35000
Area weight ratio	5.5		Area weigh	6		
Weight	4268		Weight	3576		

Structural Analysis (Excel)

	shear v1	shear v2	moment	moment v2	moment v2 10^6	L_0	7133
0	-235006	369132.75	5.16152	4419102.47	4.41910247	b	103.5
5	-206141	313325.1633	4.05871	3333106.929	3.333106929	pi	3.14159
10	-177548	258800.5505	3.09996	2423048.519	2.423048519		
15	-149506	206812.3907	2.28232	1682836.732	1.682836732		
20	-122313	158555.852	1.60319	1102476.417	1.102476417		
25	-96294	115140.3156	1.05724	668297.5606	0.668297561		
30	-71822	77563.87137	0.637679	363269.5477	0.363269548		
35	-49348	46690.37313	0.335695	167392.6845	0.167392685		
40	-29460	23229.57905	0.139903	58157.97573	0.058157976		
45	-13026	7720.834881	0.035375	11064.5888	0.011064589		
50	-1745	520.6748048	0.001224	183.1097127	0.00018311		

Presentation Slides

Convenience Store Specifications

- **Size of less than 5,000 square feet** – ours is only 600
- **Off-street parking** – boats can approach and "park" near the aircraft
- **Extended hours of operation** – both interior and exterior lights for safe operation
- **Stock at least 500 SKUs** – typical variety of products, including 7-Eleven specialties
- **Grocery type items, beverages, snacks, and tobacco** – will be offered within the store

Additional Specifications

Cargo Weight	35,000 lb
Crew Weight	775 lb
Range	3000 mi
SFC (Cruise)	0.5 hr^{-1}
SFC (Loiter)	0.4 hr^{-1}
Velocity	650 mph
L/D	15
Endurance	0.5 hr

Similar Aircraft


Martin P6M SeaMaster

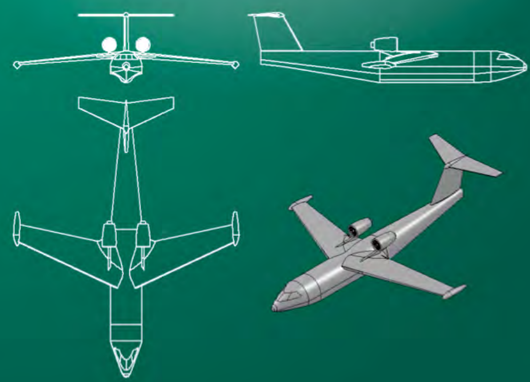

Beriev Be-200


Boeing C-17 Globemaster

Similar Aircraft Specifications

	P6M	Be-200	C-17
Crew	4	2	3
Max T/O Weight	176,400 lb	90,390 lb	585,000 lb
Range	2000 mi	1305 mi	2785 mi
Max Speed	633 mph	435 mph	515 mph
Length	134 ft	105 ft	174 ft
Wingspan	102 ft	107 ft	170 ft

Drawings



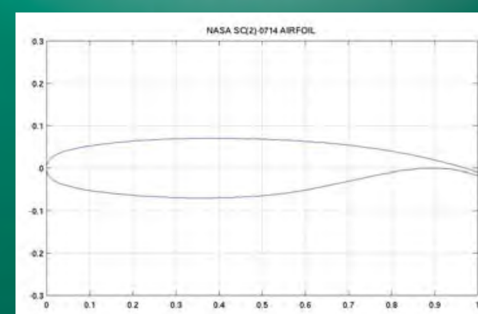
Design Parameter Summary

Span (b)	98 ft
Aspect Ratio (AR)	7
Angle of Attack (α)	2°
Wetted Area (S_{wet})	10,305 ft^2
Wetted AR	0.932
Lift-to-Drag Ratio (L/D)	15
Thrust-to-Weight Ratio (T/W)	0.31
Wing Loading (W/S)	93.783 lb/ft^2
Maximum Thrust	50,000 lbf
λ	0.4
Stall Speed (V_{stall})	100 mph

Analysis Summary

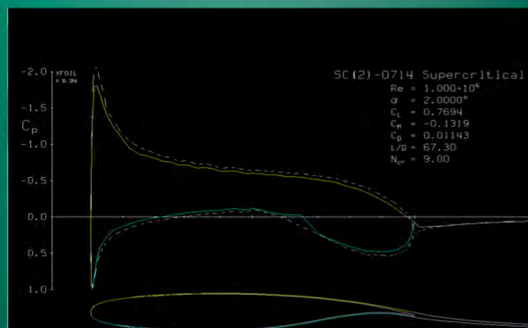
- **Weight Estimate** – 162,150 lb
- **Wing Loading Analysis** – 93.8 lb/ft^2 at cruise, need flaps at take-off and landing to increase $C_{L,max}$ to 2.15
- **Propulsion Analysis** – Pratt & Whitney V2500, max thrust 25,000 lbf, $T/W_0 = 0.31$
- **Aerodynamic Analysis** – induced and parasitic drag estimates

Airfoil Selection



NASA SC(2)-0714

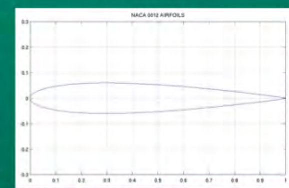
Airfoil Selection



NASA SC(2)-0714

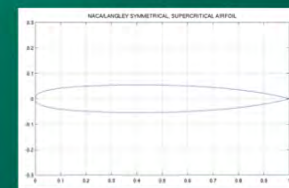
Airfoil Selection for Tail

Horizontal



NACA 0012

Vertical

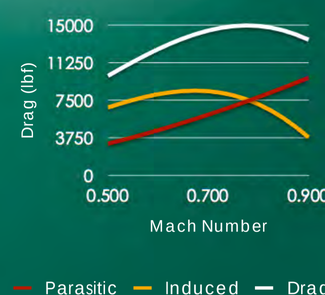


NASA/LANGLEY
Symmetrical, Supercritical

Range Trade-Off Study

Problems With Design

- Stability on water? Take-off and landing?
- Spar loading on water?
- Peculiarity on thrust-drag plot
- Increased drag due to hull
- Safety for customers standing in store



References

[1] Seven-Eleven Japan. *7-11 around the world.* [Online]. Available from: http://www.sej.co.jp/company/en/g_stores.html [Accessed 28th January 2013]

[2] Japan News Review *7-Eleven world's largest chain store.* [Online]. Available from: http://www.japannewsreview.com/business/business/20070712page_id=598 [Accessed 28th January 2013].

[3] STORES.org. *2012 Top 100 Retailers.* [Online]. Available from: http://www.stores.org/2012/Top-100-Retailers [Accessed 28th January 2013].

[4] 7-Eleven. *Store Development.* [Online]. Available from: http://corp.7-eleven.com/RealEstate/tabid/180/Default.aspx [Accessed 28th January 2013].

[5] Leino TK, Lohi JJ, Huttunen, KH, Lahtinen, TMM, Kilpeläinen AA, Muhli AA. Effect of Caffeine on Simulator Flight Performance in Sleep-Deprived Military Pilot Students. *Military Medicine* 2007;172(9): pp. 982-987.

[6] World Health Organization. *Protection from Exposure to Second-Hand Tobacco Smoke*. Geneva, CHE: World Health Organization; 2007.

[7] Wilson C. Doctor says plane cabin smoke "definitely" can cause cancer. *Tampa Tribune*. Friday July 18 1997:pg.7.

[8] The Glenn L. Martin Maryland Aviation Museum. *Martin Models 270 and 275.* [Online]. Available from: http://www.marylandaviationmuseum.org/history/martin_aircraft/25_p6m.html [Accessed 28th January 2013].

[9] *Martin P6M Seamaster* [Image]. Available from: http://grachmodel.narod.ru/P6M.html [Accessed 28th January 2013].

[10] Lednicer D. *The Incomplete Guide to Airfoil Usage.* [Online]. Available from: http://www.ae.illinois.edu/m-selig/ads/aircraft.html [Accessed 28th January 2013].

[11] Beriev. *Be-200.* [Online]. Available from: http://www.beriev.com/eng/Be-200_e/Be-200_e.html [Accessed 28th January 2013].

[12] Aviastar. *Be-200.* [Image]. Available from: http://www.aviastar.org/pictures/russia/be-200.gif [Accessed 28th January 2013].

[13] Boeing. *C-17 Globemaster Technical Specifications.* [Online]. Available from: http://www.boeing.com/defense-space/military/c17/c17spec.htm [Accessed 28th January 2013].

[14] Military-Today.com. *Boeing C-17 Globemaster III.* [Online]. Available from: http://www.military-today.com/aircraft/boeing_globemaster_III.htm [Accessed 29th January 2013].

[15] National Association of Convenience Stores. *What is a convenience store?* [Online]. Available from: http://www.nacsonline.com/NACS/Resources/Research/WhatisaConvenienceStore/Pages/default.aspx [Accessed 28th January 2013].

[16] Bay Area Retrofit. *Homeowner's Guide to Seismic Retrofitting.* [Online]. Available from: http://www.pbs.org/newshour/indepth_coverage/science/1906quake/retrofit.pdf [Accessed 28th January 2013].

[17] Daniel P. Raymer. Aircraft Design: A Conceptual Approach. 5th Ed. Reston, Virginia. American Institute of Aeronautics and Astronautics, Inc, 2012.

[18] Alcoa Mill Products. *Alloy 2024 Sheet and Plate*. [Online]. Available from: http://www.alcoa.com/mill_products/catalog/pdf/alloy2024techsheet.pdf [Accessed 28th February 2013].