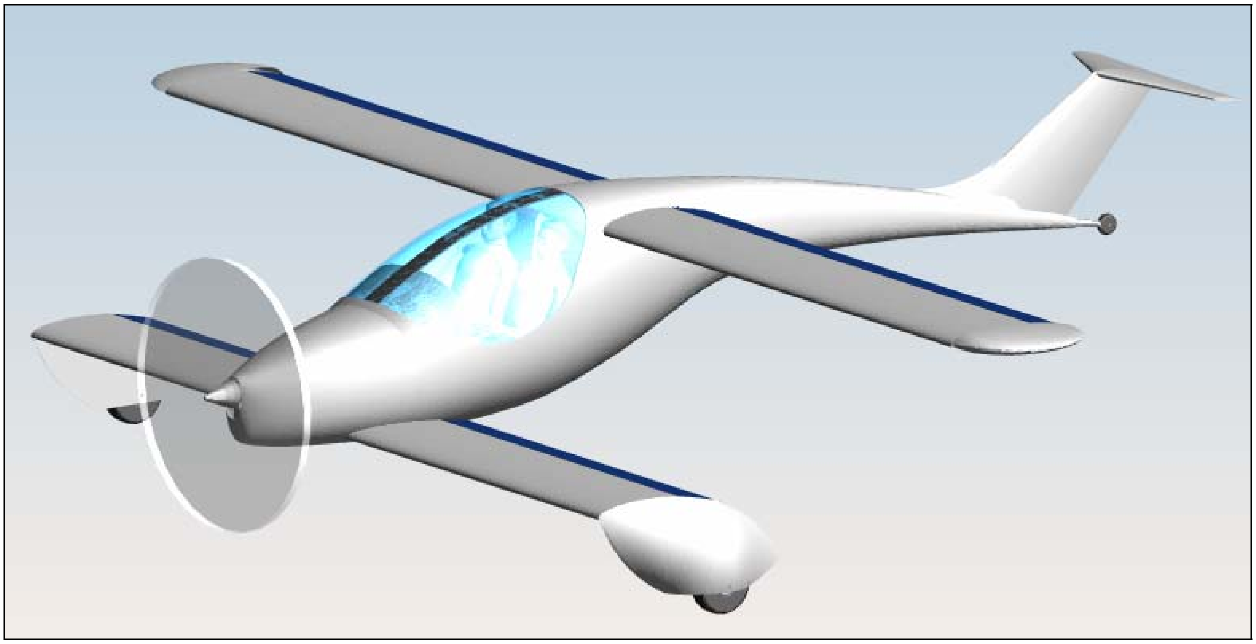
American Institute of Aeronautics and Astronautics
2006-2007 Undergraduate Individual Aircraft Design Competition
Design Proposal



REGULUS

Fixed-Wing Light Sport Aircraft

The University of Kansas
Department of Aerospace Engineering

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KU THE UNIVERSITY OF KANSAS

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Acknowledgements

Designing an aircraft at the undergraduate level involves a sequence of challenging tasks and decision makings. This design project could not have been accomplished without the contribution of many individuals who guided and encouraged me to explore the art and science of the aircraft design. Particular honor should be paid to Dr. Ron Barrett, the faculty advisor for this project. He donated great amount of time for this project to share his knowledge and experience about aircraft design with me. I thank for his help, patience, and encouragement for me to understand the subject and make this task enjoyable. Also, I would like to thank the other individuals for their contribution as consultants. It is critical that this project could receive their inputs, comments and suggestions based on the deep knowledge and experience of their profession.

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1. Introduction

1.1 Light Sport Aircraft - Background -

In 2004, the FAA has created new rules for a new aviation category, Light Sport Aircraft. The new category consists of a set of regulations for manufacturing, certification, operation, and maintenance, so that the new category will consequently increase the safety and affordability in the light aircraft market. Light-Sport Aircrafts are small, simple to operate, and relatively low performance aircrafts that weigh less than 1,320 pounds for aircraft not intended for operation on water. They are allowed to be heavier and faster than ultralight vehicles and include airplanes, gliders, balloons, powered parachutes, weight-shift-control aircraft, and gyroplanes. The certification requirements for a light sport aircraft is discussed further in the later section.

The direct intent of introducing the LSA category is to close the gaps in existing regulations and encourage the technology advancement in that category, and bring these light aircrafts under a new regulatory framework which allows individuals to experience sport and recreational aviation with enhanced safety and affordable cost.

The manufactures are now able to certify safe and economical aircrafts that exceed the limits currently allowed by ultralight regulation. Together with the lowered cost for the entry level sport pilot certificate, this will encourage more population into the aviation world, and allow them to operate these aircraft for sport and recreation, to carry a passenger, and to conduct flight training and towing in a safe manner.

For example, the typical private pilot's license costs approximately $9,000 and generally takes months to achieve. With the new sport pilot certificate, the estimated cost could be as low as $2,600 (Ref.1). Because the new rules will help keep recreational flying affordable, the FAA expects the return of thousands of pilots who left aviation because of high costs. The production of more planes will also bring down costs for everyone. This could be a new age of aviation with an affordable dream for everyone.

The future of the LSA market is projected to be in healthy growth. According to the GAMA 2006 General Aviation Statistical Databook (Ref.2), the total of 170 Light-Sport Aircraft (including fixed-wing and others) had been registered in the year 2005. The primary uses of the LSA are personal (115), Instructional (36), Business (5), and Others (14). This is only 0.08 % of all general aviation aircrafts. However, this number does not show that the LSA market share is small and negligible. The certification of LSA aircraft has just begun, and more registration is expected in coming years. According to the FAA Aerospace Forecasts Fiscal Years 2006-2017 (Ref.1), registration of 10,000 aircraft over a 6-year period beginning in 2005 is assumed. Also, this new aircraft category is projected to total roughly 14,000 in 2017. The expected increase rate in the total registered LSA is, 300 in 2006, 2295 in 2007, and 6275 in 2008. The implication of this forecast is that the large portion of the experimental/ ultralight category (5% of all 2005 GA aircrafts) aircrafts can be replaced by LSA.

As the potential customer for the LSA market, there are about 1000 sport pilots, 240 recreational pilots, and 85,000 student pilots in 2006. The expected growth rate in the total sport pilot certificate is very close to the one for the LSA aircraft registration.

It is true that the new manufacturer of Light-Sport Aircraft should estimate the target customer and the expected production rate based on these forecasts. Currently, about 100 manufacturers are producing certified or potentially certified fixed-wing LSA. Therefore, high production capability is one of the keys to be a successful a supplier in the market.

1.2 The Mission of Regulus and the Design Philosophy

This new Light-Sport Aircraft, the Regulus, is designed in response to the RFP issued by AIAA. The new aircraft are designed to serve the intended use and mission in the RFP. The mission specifications and requirements from the RFP are minimally specified as introduced in the later section. With some exception, the primal goal in this project is to design an affordable airplane which meets the LSA certification rules. As specified in the RFP the major use of this airplane is recreational use, and the emphasis is on the affordability. Inevitably, when the new airplane aims a successful debut in the light airplane market, the key for the new design is how to maximize the appeal of the new airplane while limiting the budget. To maximize the measure of appeal per cost, it has to select its character. Due to the limited weight, performance and cost requirements, the engine and airplane itself have to be small. The allowed design space for this category of airplane is very limited; therefore, the competition in this category is expected to be very close.

An example of this type of market is the Japanese K-car segment, which is a very small car segment with limitations on weight, size, and horsepower. In that market, there are two types of design, design for utility and specialty design. Ones designed for utility all have the similar configuration, performance, and look, while other specialty designs sell their unique characteristics as small-size sport car or off-road car with affordable price. Since this segment of cars is chosen mainly for daily use, the all-purpose, utility cars are the best-sellers way over the specialty K-cars. Identity, or uniqueness, is not the important factor for customers and manufacturers in that particular segment.

For the LSA market, the result of competition between utility and specialty can be different for several reasons. First, there are two different customer groups in LSA market, flight schools and individual pilots. While flight schools and certain groups of people prefer conventional, utility based airplanes for their ease of operation and familiar flight characteristics, still there are many individuals who demands more in aviation experience and appreciate the specialty. The customers choose an airplane over many luxury cars with competitive price. As noted in the previous section, the population in the LSA market is expected to increase very rapidly with new sport pilots. To support the market growth and lead the future of general aviation, the new design concept should not disappoint the pilots by just offering attractive price and average experience. The Regulus aims to establish its identity as a recreational airplane with full of excitement with safety and affordable price. It will maximize the experience that one can feel in a recreational flight in light sport airplane. And it will offer higher value to an ownership as one specialty LSA. With these mission statements of Regulus, the following items are considered important for the design.

- Meet the all requirements specified in the RFP with rules for certification
- High speed (target 120 knots CAS, the LSA limit)
- Design for Safety
- Design for Cost

Also, other design factors (e.g. Design for Utility, Design for Operation & Maintenance) are considered together to maximize the appeal of the final product.

1.3 Phasing of Tasks

This design project was divided into six major phases as shown in the following figure.

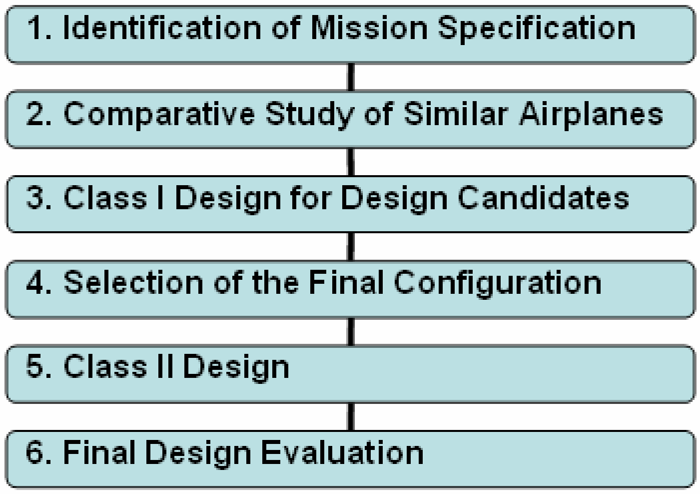


Figure 1. 1: Phasing of Tasks

1. Identification of Mission Specification

The mission specification is determined based on the RFP requirements and SLSA certification requirements. A general mission profile is also populated. A basic mission scale is determined with this step.

2. Comparative Study of Similar Airplanes

Aircrafts with similar mission task are compared with respect to their specifications and performance. This allows quantifying the competition in the market, and the performance goals can be depicted more accurately. Also, the possible configuration candidates are identified.

3. Class I Design for Design Candidates

Class I design sequence is performed on each configuration candidate.

4. Selection of the Final Configuration

The final configuration for the Class II design is selected by rating each configuration based on the Class I design results and discussion about other significant factors to accomplish the mission. The rating system is focused on maximizing the performance and value of the aircraft per its acquisition cost.

5. Class II Design

Class II design sequence is performed on the selected configuration.

6. Final Design Evaluation

The final design is evaluated whether it meets and clears all the requirements and concerns. And the final design specifications and performance are presented.

2. Mission Specification and Profile

In this section, the RFP and the SLSA regulation are reviewed, and the basic mission specification is clarified. Then, adding the design philosophy into the consideration, the final mission specification is determined.

2.1 Mission Specification

Summarizing from the RFP, the mission specification can be divided into two categories, LSA airplane certification requirements and mission specific requirements. First, the certification requirements for LSA airplanes can be summarized as follows.

- Fixed wing
- Maximum take-off weight less than 1320 lbs (as ground-based airplane)
- Maximum airspeed of less than 120 knots CAS at maximum continuous power under standard atmospheric conditions at sea level
- Maximum clean (no lift enhancing device) stall speed of less than 45 knots CAS at the aircraft's maximum take-off weight and the most critical center of gravity
- Maximum of 2 seats
- Single, reciprocating engine
- Fixed, or ground adjustable propeller
- Fixed landing gears
- Non-pressurized cabin
- Can be manufactured, ready to fly under the S-LSA aircraft certification without FAR 23 compliance
- Performance requirements from ASTM F-2245 – 04 section 4.4

Additionally, the mission specific requirements provided by AIAA are as follows.

- Engine is to be selected from the specified four Rotax series aircraft engines; Rotax 582, Rotax 912 UL, Rotax 912 ULS, and Rotax 914 UL.
- Maximum payload: Two 200 lbs people with 20 lbs baggage each. This statement says the airplane is to be 2-seat design.
- Take-off field length must be equal to the landing field length
- Light pilot (120 lbs) must be able to operate the airplane
- FAR 23 damping ratios and military requirements (MIL F8785C) must be met

There is no range requirement or minimum speed requirement specified in the RFP. These comparative performance figures must be determined by consulting to the mission statement and the design philosophy. The lower limit of the maximum level speed is set at 114 knots, which is 95% of the LSA limit, 120 knots. The reason why it's not strictly set at 120 knots is to expand the design space a little more toward the total balance of the airplane.   The range goal of the airplane is set at 250 nm with 25% reserve. This is based on the duration of a flight in a light airplane, which is typically less than 2 hours. The designer interviewed 10 pilots and student pilots, and the answers for the maximum tolerable flight duration in small airplanes (like the Cessna 152) were within the range of 2 - 3 hours. Over those hours, a flight in small airplane can be physically challenging because the comfort of cabin for this category of airplane is very limited due to the weight restriction. In fact, pilot fatigue can easily lead to accidents. The airplane can achieve the 250 nm range with 2.3 hours of flight and 110 knot cruise speed. In addition, for the required baggage size, the size of cargo compartments is designed to reasonably fit the two 20 lb bags and no further expansion is considered valuable. This is to select the speed and cost advantage over the cargo capacity. Also, the overall dimension of the airplane should be limited to fit in the standard size of T-hangars available in USA. Researching numbers of available T-hangar dimensions, the overall dimension to fit in a small T-hangar is determined. The following is the summary of the additional mission specifications.

- Design lower limit of maximum airspeed, V_h, of 114 knots CAS
- Design minimum cruise range of 250 nm with 25% fuel reserve
- Maximum Overall Dimensions: Height (11 ft), Length (30 ft), Span (39 ft)

Range as the Design Driver

At designing a LSA airplane, the design range is one of the most significant design drivers. It directly and indirectly affects numbers of design parameters. For example;

- Fuel volume and weight to be carried
- Airplane gross weight
- Wing area to meet the stall speed requirement
- Airplane drag
- Required engine horsepower
- Cost

As explained earlier, the design cruise range is selected by targeting the ideal flight hours for pilots. The selected design range, 250 nm with 25% reserve, provides an enjoyable recreational flight suited for fun ride, sightseeing, and short trip to next airport. However, the results of market study shows that the average range of similar airplanes is 470 nm (max. 1030 nm, min. 174 nm). There is another reason for purposely selecting shorter cruise range than the competitors. The reason is cost.

Among the suggested four Rotax engines, the smallest one, 65-hp Rotax 582, has a significant advantage in its acquisition cost (see figure 2.1). Its price is less than a half of the next cheapest engine, 80-hp Rotax 912 UL. Comparing to the most expensive selection, 115-hp Rotax 914 UL, the difference in cost reaches up to $20,000. Knowing the fact that the average price of ready-to-fly LSA is about $80,000, it is evident that the engine selection has a significant impact on the acquisition cost of the airplane. In this design project where cost saving is the special interest, the selection of the 65-hp engine is very appealing solution for reducing the total cost of the airplane.

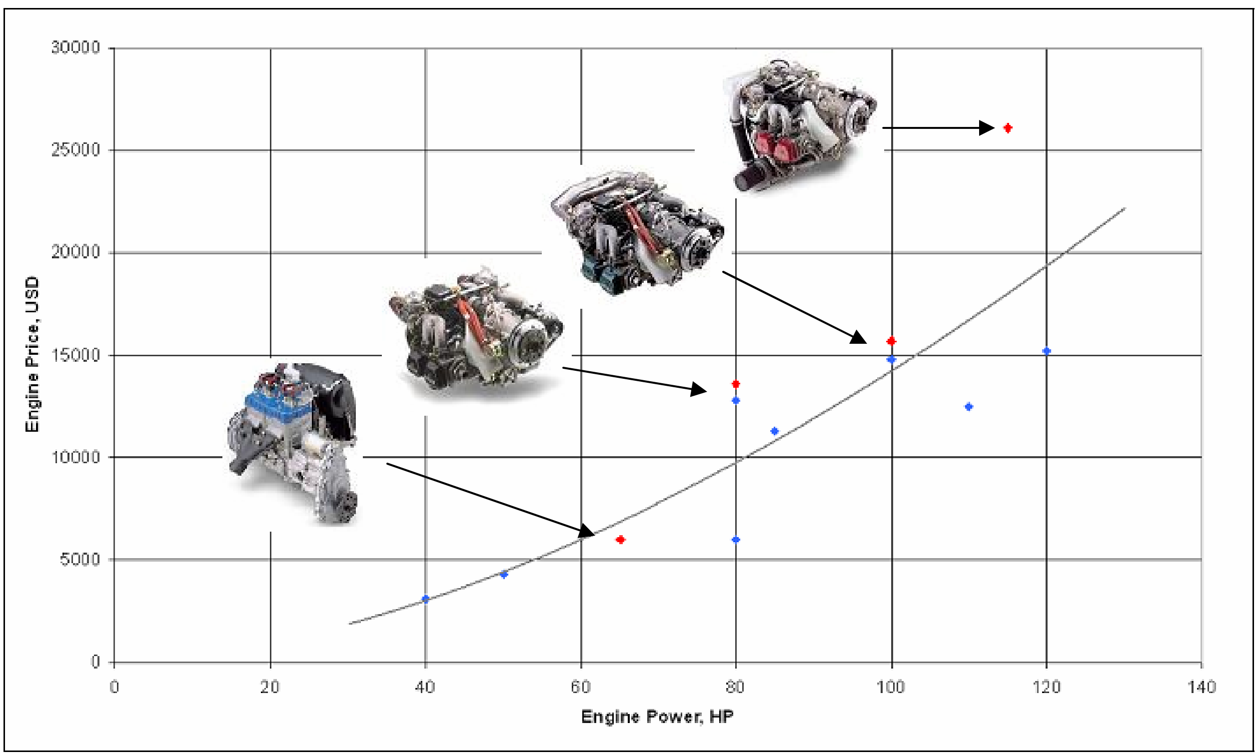


Figure 2. 1: Variation of Engine Price with Horsepower

However, one problem of choosing the 65-hp engine is its fuel consumption. The 2-stroke, water-cooled Rotax 582 engine consumes twice as much fuel than the other 4-stroke engines in average (in [lb/hp/hr]). If the 65-hp engine is selected, the airplane must carry more fuel than average. Therefore, given the limited gross weight of the airplane, the achievable range can be limited. This means setting a long design range can exclude this great cost advantage from the selection. This selection of the design range is the first trade study to be considered.

Design for Cost is one of the most important design philosophies in this project. Therefore, the short design range of 250 nm is selected purposely not to exclude the small engine from the selection. As a result, the first design challenge becomes how to design a light, low-drag airplane to meet the speed requirement with the small engine.

2.2 Mission Profile

Based on the determined mission specifications, the mission profile of Regulus is as follows. The design cruise range is 250 nm, with standard cruise altitude of 7000 ft above sea-level.

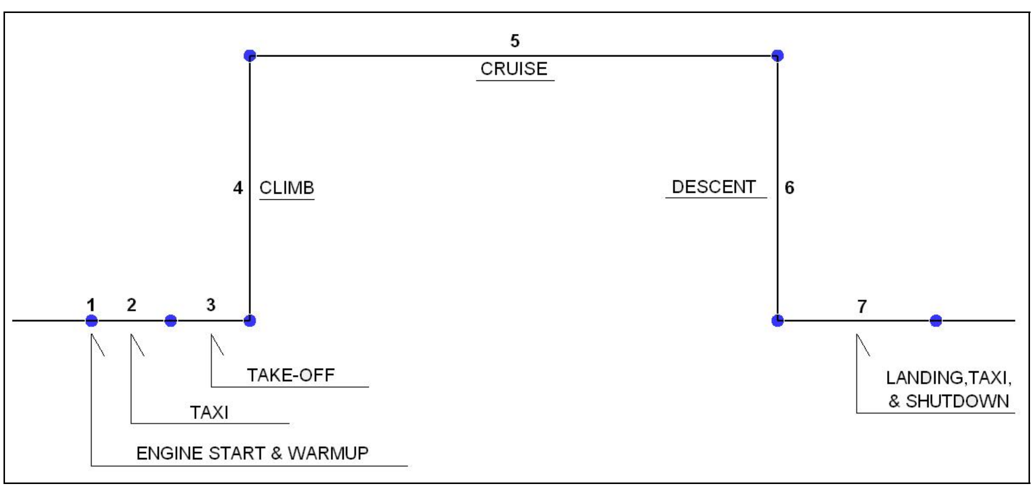


Figure 2. 2: Mission Profile

3. Description of Similar Airplanes

For better understanding about the competition in the light airplane market, more than 100 similar size airplanes are researched by the designer. The database includes ranges of data including their specifications, performances, costs, configuration, and construction. The database includes airplanes with different constructions (composite, metal, fabric & tubing, and hybrid [combination of composite and metal]) and different configurations (conventional, canard, and tandem-wing). In the database, there are 48 composite airplanes, 36 metal airplanes, 17 fabric & tubing airplanes and 9 hybrid airplanes including several off-category airplanes for configuration study. A database was created to study trends in the market from many aspects. In this section, some of the representative types of airplanes are introduced, and their performance figures are tabulated with other similar airplanes. Each airplane is built with different configuration and construction. Also they are equipped with different engines. This study of similar airplanes revealed several important trends in the competition as explained in later in this section.

3.1 Description of Similar LSA's

Aircraft Manufacturing & Development
CH601XL

Gross Weight:	1320 lbs.
Empty Weight:	770 lbs.
Cruise Speed:	113 knots
Clean Stall Speed:	44 knots
Range:	621 nm
Rate of Climb:	1000 ft/min
Wing Area:	132 ft^2
Powerplant:	100-hp Continental 0-200
Major Construction:	Aluminum
Estimated fly-away price:	US$ 79,900

CH601 is an example of a conventional tail-aft LSA with tricycle landing gears. Its low-wing has constant chord through the span. Its weight is at the LSA-limit with aluminum structure and the 100-hp engine. This airplane is currently available in the market.

Jabiru USA Sport Aircraft
J170-SP

Gross Weight:	1200 lbs.
Empty Weight:	638 lbs.
Cruise Speed:	100 knots
Clean Stall Speed:	45 knots
Range:	900 nm
Rate of Climb:	700 ft/min
Wing Area:	100 ft^2
Powerplant:	85-hp Jabiru 2200
Major Construction:	Composites
Announced fly-away price:	US$ 79,900

J-170-SP is also an example of LSA with conventional configuration with tricycle landing gears, and a constant-chord high wing. The composite structure supports its 1200 lbs gross weight including the 85-hp Jabiru engine. This airplane is currently available in the market.

RANS
S-7LS

Gross Weight:	1232 lbs.
Empty Weight:	750 lbs.
Cruise Speed:	96 knots
Clean Stall Speed:	43 knots
Range:	296 nm
Rate of Climb:	850 ft/min
Wing Area:	147.1 ft^2
Powerplant:	100-hp ROTAX 912 ULS
Major Construction:	Fabric & Tubing
Announced fly-away price:	US$ 80,000

RANS S-7LS is another example of LSA with conventional configuration. The difference is that this airplane is constructed with welded-tubing and fabric skin. This airplane is currently available in the market.

3.2 Description of Similar Non-LSA's

Quickie Aircraft Corporation
Quickie Q2

Gross Weight:	1000 lbs.
Empty Weight:	475 lbs.
Max Level Speed:	156 knots
Clean Stall Speed:	56 knots
Range:	592 nm
Rate of Climb:	800 ft/min
Wing Area:	134 ft^2 (combined)
Powerplant:	64-hp Revmaster 2100DQ
Major Construction:	Composites
Estimated fly-away price:	N/A

The Quickie is a light homebuilt aircraft designed in late 1970's by Burt Rutan, Tom Jewett, and Gene Sheehan. It has the unique tandem wing design and slender fuselage. The efficient design achieves a high speed with small horsepower. The original single seat version achieved 109 knot level speed with only 18-hp engine. Thousands of kits were sold before the production ended. It utilizes the moldless composite construction technique.

Dart Industries
Dragonfly

Gross Weight:	1075 lbs.
Empty Weight:	605 lbs.
Max Level Speed:	146 knots
Clean Stall Speed:	39 knots
Range:	434 nm
Rate of Climb:	1050 ft/min
Wing Area:	97 ft2 (combined)
Powerplant:	56-hp HAPI modified Volkswagen engine
Major Construction:	Composites
Estimated fly-away price:	N/A

The Dragonfly is a similar homebuilt aircraft to the Quickie with slightly bigger body. Its production started in early 1980's. As for Quickie, its main construction material is glass fiber and foam core. The kit is still sold today.

Rutan Aircraft Factory
VariEze

Gross Weight:	1050 lbs.
Empty Weight:	560 lbs.
Cruise Speed:	170 knots
Clean Stall Speed:	
Range:	
Rate of Climb:	
Wing Area:	54 ft^2
Powerplant:	100-hp
Major Construction:	Composite
Estimated fly-away price:	N/A

The VariEze is a high performance, pusher propeller, canard configuration homebuilt aircraft designed in 1970's. It is a 2-seat airplane with tandem seat layout. The vertical tails are located at the tips of swept wing. Its nose gear is retractable to lower the nose on the ground to help passengers get onboard.

3.3 Tabulated Information of Similar Airplanes

Based on the research on over 100 aircrafts in similar category, several useful trends were observed. Some of these results are presented in this section. For each plots, data points are colored differently depending on the interested trends to be presented. Also, in these charts, amphibians and non-fixed wing aircrafts are excluded. Single-seat airplanes are also excluded, except for special cases with specific purpose. The Figure 3.1 is showing the weight trend among LSA-class airplanes. It shows their weight ranging from around 1000 lbs up to the LSA limit 1320 lbs. It is clearly shown that many airplanes are targeting the LSA-limit, 1320 lbs. In the figure, points are colored based on their major construction types; Composite, Metal, Fabric & (steel) Tubing, and Hybrid. Here, the "hybrid" means its construction uses significant amount of both composite and metal structure. There is no clear weight advantage in composite airplanes comparing to other constructions.

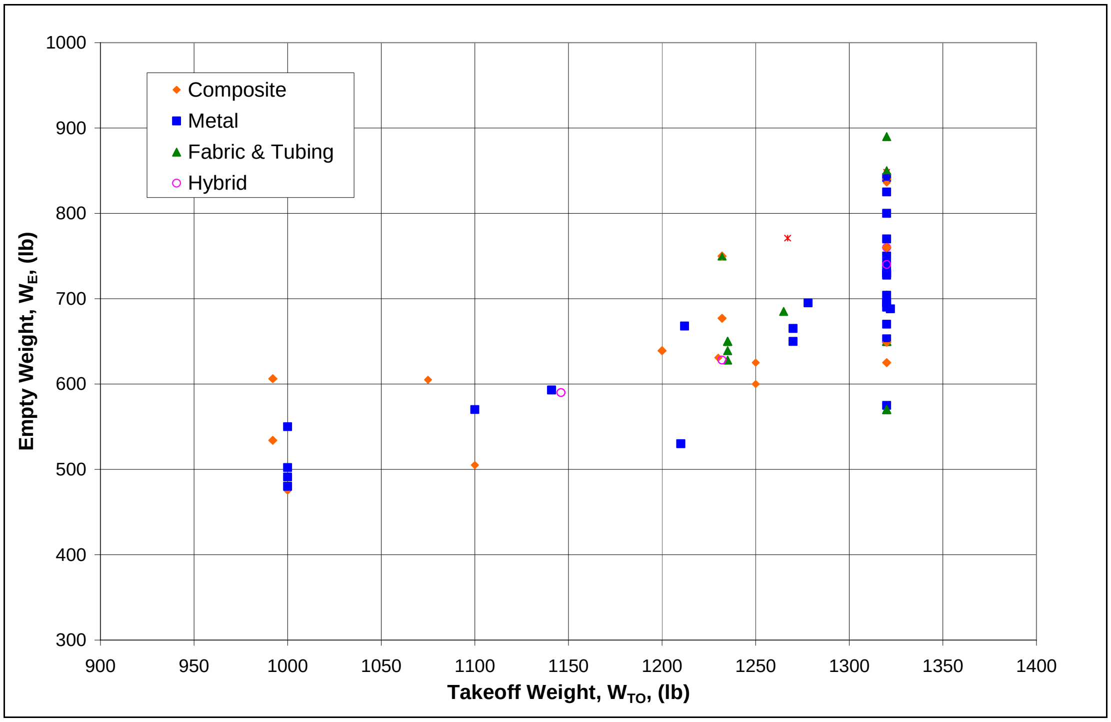


Figure 3. 1: Relationship between Takeoff Weight and Empty Weight, Classified by Construction Type

Figure 3.2 shows the design space for light airplanes in terms of wing-loading and power-loading. For certified LSA, there is a trend for the power loading because many of them have 1320 lb gross weight and 100-hp engine. The average take-off weight among the certified LSA is 1258 lb, and the average engine horsepower among them is 96 hp.

For the revealed weight range of 1000 - 1320 lbs, the engine power selections typically range from 65-hp to 120-hp. Majority of the LSA type airplanes use either 80-hp or 100-hp engines. The shown range of wing loading is determined by the combination of airplane weight, airfoil performance, and target stall speed. While most of these airplanes aim the 45-knot maximum allowed clean stall speed, some models declare lower stall speed for shorter take-off field length.

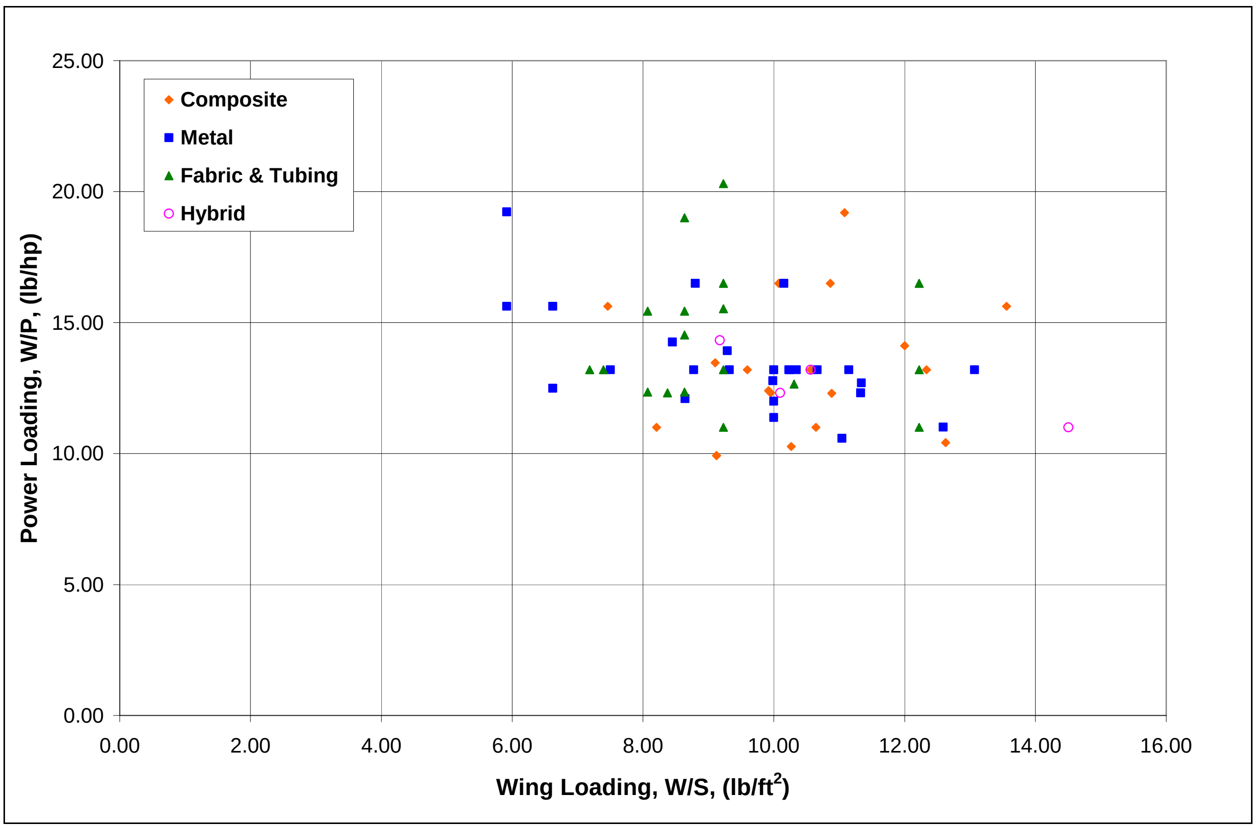


Figure 3. 2: Sizing Chart Showing Wing Loading and Power Loading, Classified by Construction Type

Figure 3.3 shows the average price of ready-to-fly airplane for different construction type. The engine price is separated from the total acquisition cost. The price information for each airplane was obtained from manufacturer/ distributor websites and book resource “Jane’s All the World Aircrafts”. Many of these airplanes are sold as ready-to-fly, while some other non-LSAs are sold in kit form. From airplanes sold in both flyaway and kit form, the price fraction is obtained, and used to estimate the unknown fly-away price of some kit-only airplanes. The compared engineless prices are obtained by subtracting the estimated price for each installed engine from the total airplane price. Considering the difference in size, equipped options, and other factors among the researched airplanes, there can be several thousand dollars variation for each column in the figure below. For better comparison between the construction types, another chart is prepared as shown in the next page.

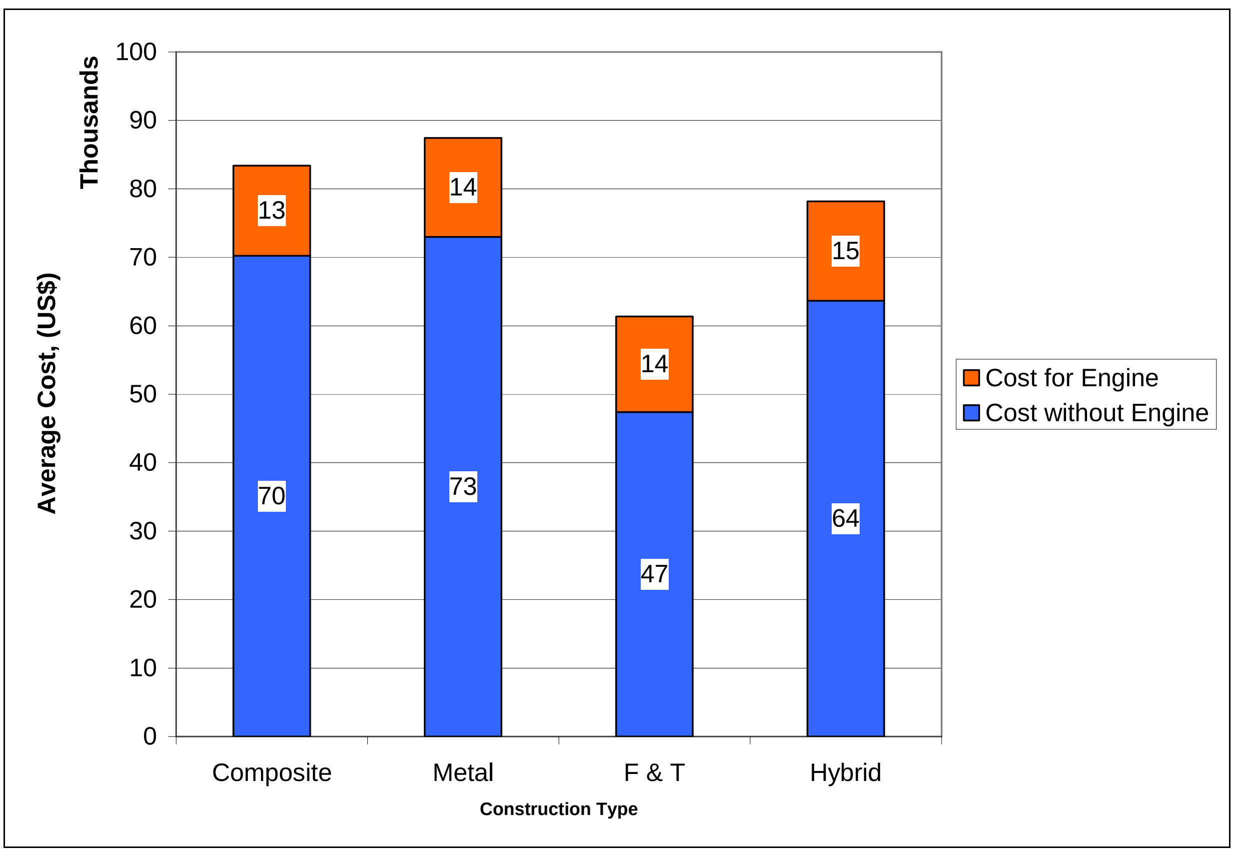


Figure 3. 3: Average Airplane Cost for Different Construction Type

Figure 3.4 shows the comparison of researched airplanes based on their cost-per-weight value. The total acquisition costs of airplanes are divided by their empty weight, and compared in terms of their major construction types. It is true that even this comparison involves variations in the result due to many other differences among the researched airplanes including the difference in their equipments. Interpretations of the figures need to account for that. Still, these price-per-pound values give more meaningful comparison between the construction types for their production cost. As shown, there is no significant cost advantage by selecting either composite structure or metal structure. One clearly evident fact is that the fabric & tubing structure has significant advantage in cost saving. The apparent low cost for hybrid construction is most likely because there were not many data available for that construction type.

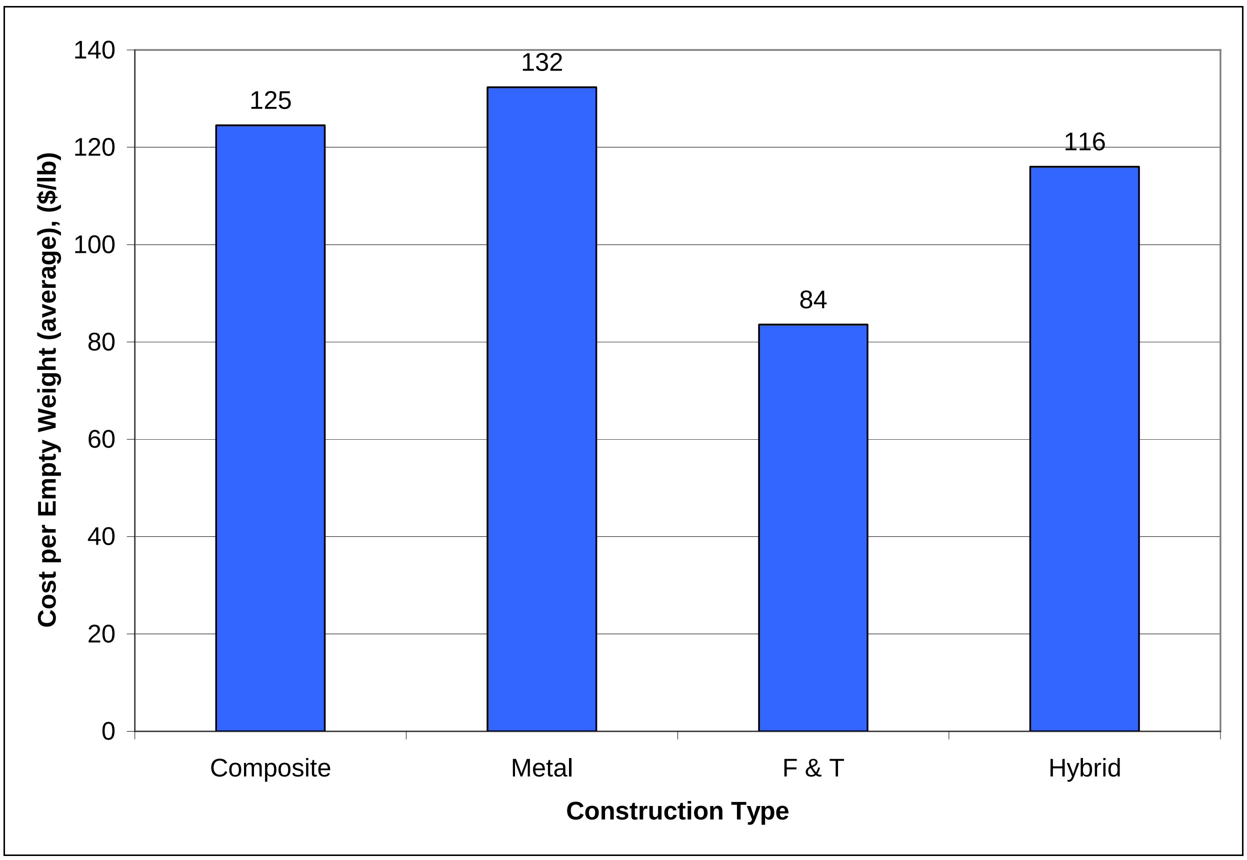


Figure 3. 4: Average Airplane Cost for Different Construction Type

With Figure 3.1 and 3.2, the weight trends for LSA type airplanes are observed. Then, with Figure 3.3 and 3.4, the relationship between cost and construction types is identified. The next two figures show another observation by comparing the airplane performance to the selection of configurations and construction types.

Figure 3.5 and 3.6 show the relationship between airplanes' power loadings and their announced maximum level speed. The data points in the first figure are colored based on their construction types, and the points in the second figure are colored based on their configurations. The purpose of these plots is to study if configuration and construction types affect the airplane's speed performance at all. Since there is only little number of airplanes with canard or tandem configurations, several single-seat airplanes and some off-category, heavier than LSA airplanes are added to the chart to compare between configurations. This includes the single-seat Quickies and several homebuilt canard airplanes like Berkut. The airplanes with canard or tandem configuration in Figure 3.6 are non-LSA.

From Figure 3.5, it can be seen that composite airplanes are scattered in higher speed range while fabric & tubing airplane are in lower speed range. The average cruise speed for each construction (excluding models with over 120 knot cruise speed, for fair comparison) is: 106 knots for composite, 99 knots for metal, and 86 knots for fabric & tubing construction.

Also, from Figure 3.6, it can be observed that airplanes with canard and tandem configurations exhibit higher speed comparing to the conventional configurations. However, since not enough data points are available for those unique configurations, it is premature to claim the absolute speed advantage in those configurations. Theoretically, the induced drag penalty is same for conventional configuration and tandem wing design with equivalent wing area.

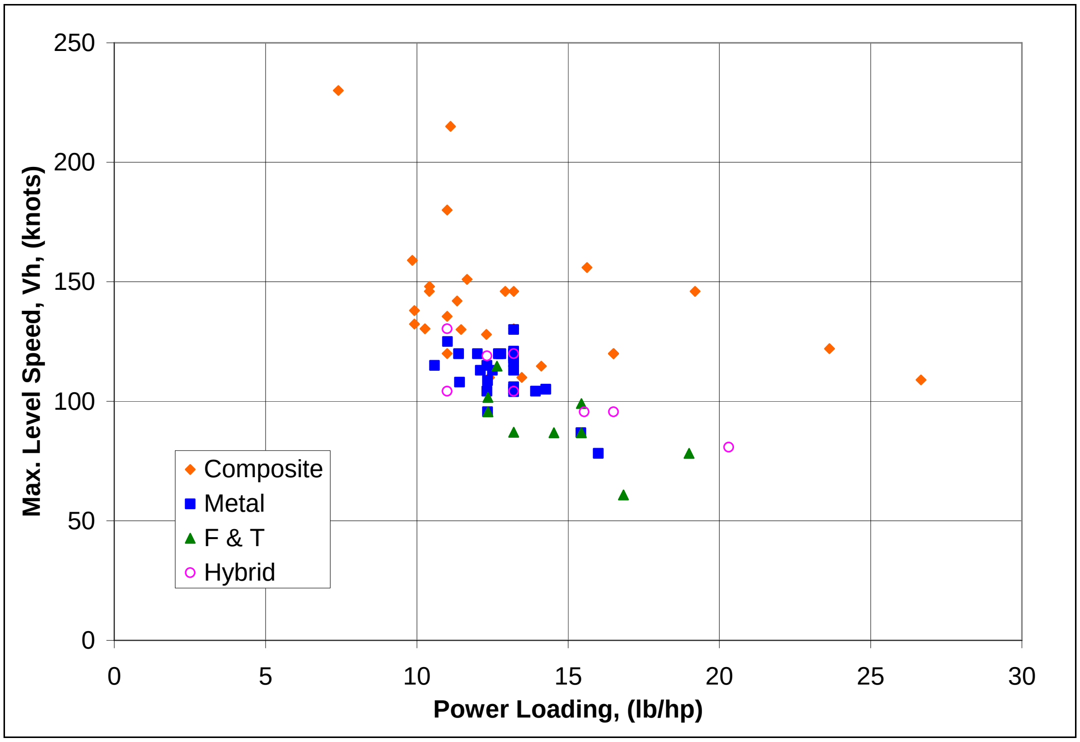


Figure 3. 5: Effect of Power Loading to Top Speed, Classified by Construction Type

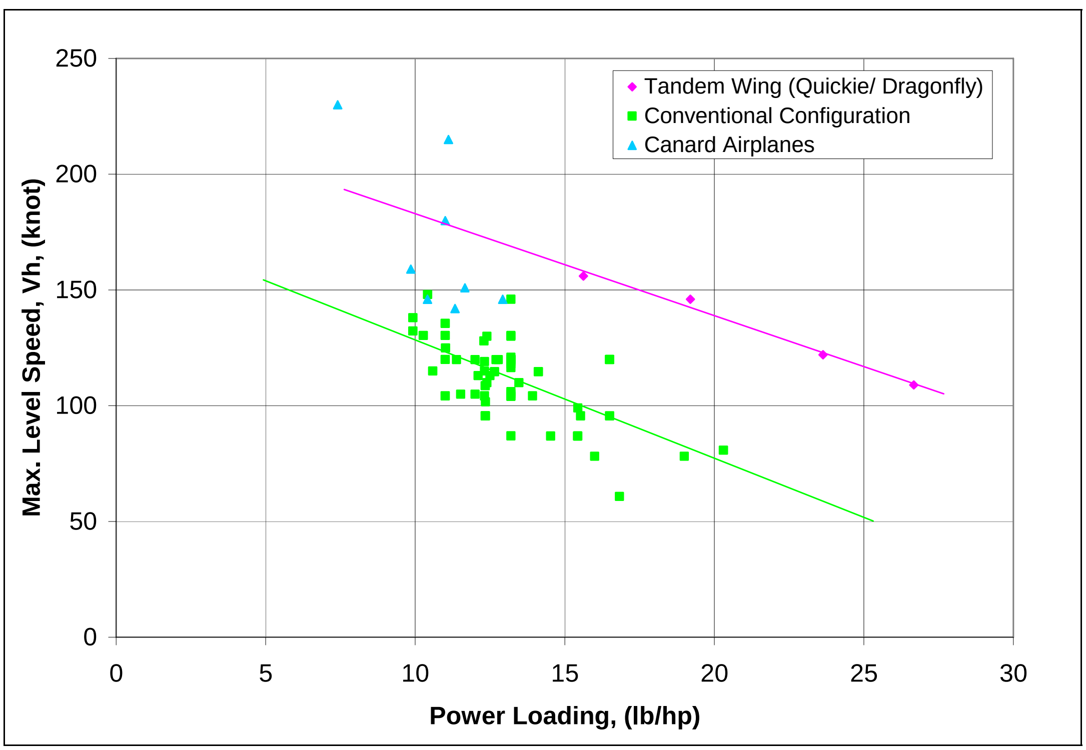


Figure 3. 6: Effect of Power Loading to Top Speed, Classified by Configuration Type

Overall, the findings and observations from these six figures are summarized as follows.

- The composite airplanes do not exhibit significant advantage in weight reduction in this light airplane category. One probable reason for this is, for small airplanes like a LSA, the weight advantage in composite material can conflict with the minimum-gage requirements of its structure.
- There is no significant difference in manufacturing cost between composite airplanes and metal (aluminum) airplanes. This is because the total production cost including material cost, cost for tools, and labor cost reach up to the same level for either construction types. On the other hand, the fabric and tubing construction has significant advantage in cost saving, however with penalty in airplane performance.
- Airplanes with fabric & tubing construction exhibit lower speed than other construction types. It is not suited for higher speed cruise for its difficulty to form efficient aerodynamic shapes.
- Airplanes with composite construction exhibit higher speed than other construction types. Composite material is preferred for its advantage to form complex aerodynamic shape easier.
- Those canard airplanes and tandem-wing airplanes are designed for higher speed for their engine power. Consequently, these specific designs (together with their use of composite constructions) prove their advantage for achieving higher speed for given engine power.

3.4 Comparative Performance

To design the new airplane right for the market, the performance competition in the market is also analyzed from the database. Among the LSA size airplanes, the seven common performances are selected for comparison; Cruise speed, Stall speed, Range, Rate of climb, Take-off/ Landing field length, and the Price (as ready-to-fly). Cruise speed is chosen for this comparison because there were more data available for cruise speed comparing to maximum level speed data. The following is the statistic results among 2-seat, ground-based airplanes.

- Cruise Speed
  - Maximum: 143 knots (Wing loading: 11.1 [lb/ft^2], Power loading: 19.2 [lb/hp], tandem-wing configuration, composite construction, non-LSA)
  - Minimum: 59 knots (Wing loading: 8.64 [lb/ft^2], Power loading: 19.0 [lb/hp], conventional configuration, fabric & tubing construction, LSA)
  - Average: 100 knots

- Stall Speed (clean)
  - Maximum: 56 knots (Wing loading: 7.46 [lb/ft^2], Power loading: 15.6 [lb/hp], tandem-wing configuration, composite construction, non-LSA)
  - Minimum: 29.5 knots (Wing loading: 7.39 [lb/ft^2], Power loading: 13.2 [lb/hp], conventional configuration, fabric & tubing construction, LSA)
  - Average: 40.9 knots

- Range
  - Maximum: 1030 nm (Wing loading: 12.0 [lb/ft^2], Power loading: 14.1 [lb/hp], conventional configuration, composite construction, LSA)
  - Minimum: 174 nm (Wing loading: 8.64 [lb/ft^2], Power loading: 19.0 [lb/hp], conventional configuration, fabric & tubing construction, LSA)
  - Average: 470 nm
- Rate of Climb
  - Maximum: 1800 ft/min (Wing loading: 12.2 [lb/ft^2], Power loading: 11.0 [lb/hp], conventional configuration, composite construction, non-LSA)
  - Minimum: 500 ft/min (Wing loading: 7.39 [lb/ft^2], Power loading: 13.2 [lb/hp], conventional configuration, fabric & tubing construction, LSA) and (Wing loading: 9.23 [lb/ft^2], Power loading: 20.3 [lb/hp], conventional configuration, hybrid construction, non-LSA)
  - Average: 1038 ft/min
- Take-Off Field Length
  - Maximum: 820 ft (Wing loading: 8.72 [lb/ft^2], Power loading: 11.5 [lb/hp], conventional configuration, fabric & tubing construction, non-LSA)
  - Minimum: 160 ft (Wing loading: 9.95 [lb/ft^2], Power loading: 12.3 [lb/hp], conventional configuration, fabric & tubing construction, LSA)
  - Average: 449 ft

- Landing Field Length
    - Maximum: 950 ft (Wing loading: 8.21 [lb/ft^2], Power loading: 11.0 [lb/hp], tandem-wing configuration, composite construction, non-LSA)
    - Minimum: 200 ft (Wing loading: 5.92 [lb/ft^2], Power loading: 19.2 [lb/hp], conventional configuration, metal construction, non-LSA) and (Wing loading: 9.29 [lb/ft^2], Power loading: 13.9 [lb/hp], conventional configuration, metal construction, non-LSA)
    - Average: 466 ft
- Price (including engine)
    - Maximum: $116,300 ($W_{TO}$: 1320 lbs, W_E: 836 lbs, Engine Power: 100 hp, conventional configuration, composite construction, non-LSA)
    - Minimum: $39,900 ($W_{TO}$: 1320 lbs, W_E: 695 lbs, Engine Power: 80 hp, conventional configuration, fabric & tubing construction, LSA)
    - Average: $81,800

4. Class I Design Procedures

The Class I design is the first preliminary design sequence to size the airplane for the given mission requirements. In this project, several possible configuration concepts were investigated through this Class I design sequence to weed out any designs that are not suitable for the mission. This design procedure is based on the set of empirical methods introduced in the series of writings “Airplane Design” composed by Dr. Jan Roskam (Ref.3). The software “Advanced Aircraft Analysis” developed by DAR Corporation is used to follow the method quickly.

4.1 Mission Weight Estimates

In this section, the following three basic weights are estimated for the airplane.

- Take-off gross weight, W_{TO}
- Empty weight, W_E
- Mission fuel weight, W_F

The take-off weight can be written as;

$W_{TO} = W_E + W_{tfo} + W_{crew} + W_F + W_{PL}$

From the mission specification, it is known that;

W_{crew} = 200 lb

W_{PL} = 240 lb (the weight for the passenger and baggage)

Also, the weight for trapped fuel and oil, W_{tfo}, is assumed to be 0.5% of the take-off weight. To estimate the mission fuel weight, W_F, the fuel-fraction method is used. The fuel consumption as a fraction of the take-off weight is estimated for each mission leg shown in

Figure 2.2. Except for the cruise leg, the each fraction is assumed to be the suggested values for homebuilt airplanes (Ref.1). To estimate the fuel-fraction for the cruise leg, several mission parameters must be identified, such as; design cruise range, specific fuel consumption (SFC), propeller efficiency (η_p), and lift-to-drag ratio (L/D). For the design cruise range, the following parameters are assumed.

- Range: 250 nm
- SFC: 0.63 lb/hr/hp
- $\eta_p = 0.85$
- L/D = 10

The design range is 250 nm as decided in Chapter 2. Also, for the cost advantage discussed in the Chapter 2, the 65-hp Rotax 582 is selected as the first engine candidate. Therefore, the corresponding cruise SFC of 0.63 lb/hr/hp is obtained from the engine performance curves provided by the manufacturer (Ref.5). The cruise power is assumed to be 75 % of the maximum power. Also, the propeller efficiency for the cruise is assumed to be 0.85, which is the ideal efficiency for cruise based on the propeller performance curves provided by AIAA. For the lift-to-drag ratio, the typical value for small airplane is assumed as above.

Using these numbers, the fuel fraction for the cruise leg is calculated using Breguet Range Equation. The obtained fuel-fractions for the mission of Regulus are as follows. The subscript numbers indicate the mission leg corresponding to the Figure 2.2.

$W_1/W_{TO} = 0.9980$

$W_2/W_1 = 0.9980$

$W_3/W_2 = 0.9980$

$W_4/W_3 = 0.9950$

$W_5/W_4 = 0.9447$

$W_6/W_5 = 0.9950$

$W_7/W_6 = 0.9950$

$$M_{ff} = \frac{W_1}{W_{TO}} \frac{W_2}{W_1} \frac{W_3}{W_2} \frac{W_4}{W_3} \frac{W_5}{W_4} \frac{W_6}{W_5} \frac{W_7}{W_6} = 0.9251$$

Using this mission fuel fraction, the mission fuel weight can be calculated as follows.

$$W_F = \left(1 - M_{ff}\right) W_{TO} + W_{F(res)}$$

where the fuel reserve is 25% of the mission fuel weight used in the mission.

Now, the mission fuel weight can be calculated by selecting a value for the W_{TO}, take-off weight. Hence, the airplane empty weight can be obtained using the rest of weight values obtained. Here, iteration has to be performed to achieve the proper relationship between W_{TO} and W_E. The suggested proper ratio of those weights can be obtained from the regression in the weight data among the similar light airplanes (Figure 4.1).

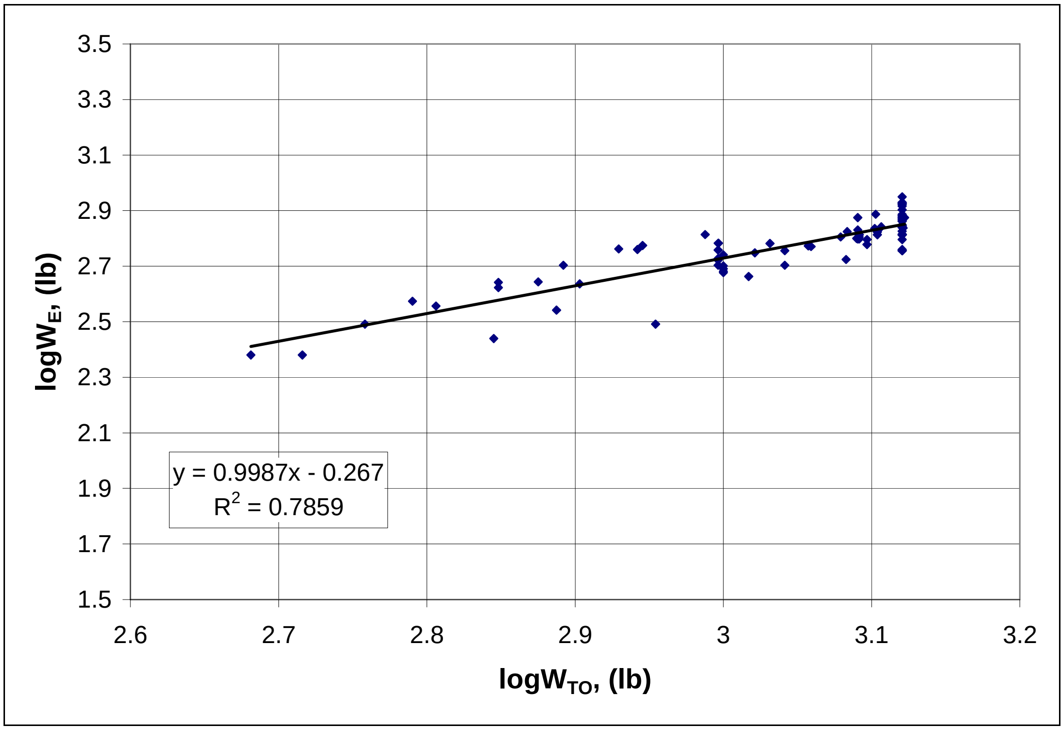


Figure 4. 1: Weight Regression for Light Airplanes

The weight equation with the regression constants is obtained as follows.

$$\log_{10} W_{TO} = (0.2673) + (1.0013)\log_{10} W_E$$

As a result, the Class I weight estimation resulted as follows.

- $W_{F(used)}$ = 90.2 lbs
- $W_{F(res)}$ = 22.6 lbs
- W_F = 112.8 lbs
- W_{crew} = 200 lbs
- W_{PL} = 240 lbs
- W_E = 645.1 lbs
- W_{TO} = 1203.9 lbs

4.2 Performance Constraint Analysis

To select a proper number of wing loading and power loading for this mission, it is necessary to identify the critical performance constraints for the mission. From the mission specifications (see Chapter 2), those can be summarized as follows.

- Clean stall speed: 45 knots (or less)
- Maximum level speed: 114 knots (up to 120 knots)
- Take-off field length is equal to the landing field length

The aircraft's weight, wing area, and engine power are sized for the above performance constraints. However, since no specific take-off/ landing distance is required, the airplane sizing for those field lengths is verified in the later sections.

4.2.1 Sizing to Stall Speed Requirement

The airplane wing loading (W/S) necessary to meet the stall speed requirement can be calculated by estimating the airplane's maximum lift coefficient, $C_{L,\max}$.

$$V_s = \sqrt{\frac{2(W/S)}{\rho \cdot C_{L,\max}}} \text{ [ft/s]} \qquad \text{therefore,} \qquad (W/S) = \frac{1}{2}\rho V_s^2 C_{L,\max} \text{ [lb/ft}^2\text{]}$$

The 45-knot stall speed must be achieved with a clean configuration. A reasonable value must be selected for the airplane clean maximum lift coefficient to be targeted. The typical value of clean $C_{L,\max}$ for homebuilt airplanes is within 1.2 to 1.8. For this LSA design, use of high-lift, low-speed airfoils is expected to achieve the stall-speed requirement. However, the performance of airfoils must be adjusted to the very low Reynolds number condition due to relatively low speed range of LSA airplanes. The NASA GA series airfoil is a great example of the low-speed general aviation airfoils.

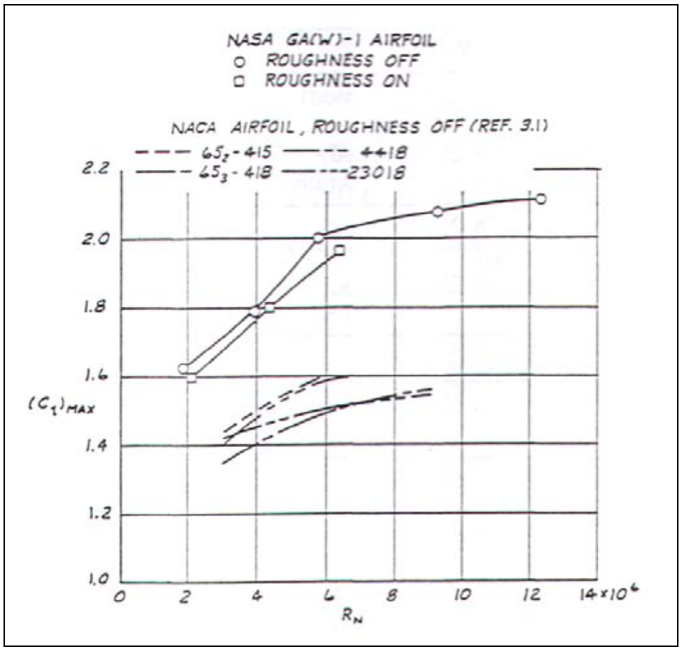


Figure 4. 2 Variation of Section Maximum Lift Coefficient with Reynolds Number (Ref.6)

As shown in the above figure, the section maximum lift coefficient drops rapidly in low Reynolds number range. At the required LSA stall speed, assuming the standard sea-level atmosphere, the Reynolds number can be as low as 2×10^6 or even less depending on the reference length. Considering the fact the lift coefficient can be even lower for 3-D wing, achieving a high maximum lift coefficient at stall is challenging. Therefore, as the initial choice, the $C_{L,\max}$ value of 1.5 is selected. The corresponding value for the wing-loading is 10.28. This gives the estimated wing area of 117 ft^2 (total area of the major lifting surfaces).

4.2.2 Sizing to Maximum Speed Requirement

For this airplane, the lower limit of the maximum level speed is set at 114 knots (192.4 ft/s). The power-loading should be selected to meet the speed requirement. However, the engine selection is limited to the four suggested Rotax engines (65-hp, 80-hp, 100-hp, and 115-hp). For cost saving purpose, the first candidate for the engine selection is the 65-hp Rotax 582. Therefore, assuming the obtained Class I take-off weight, the corresponding airplane power-loading is 18.52. For this design, the parameter to be sized is the airplane total drag coefficient, which achieves the required maximum speed with given engine horsepower. The airplane drag polars are verified in later sections.

4.3 Summary of All Class I Design Candidates and Down Selection

The Class I Design was performed for the following three configurations.

- Conventional
- Canard
- Tandem-wing (with horizontal tail)

Here, a modification is done for the tandem-wing configuration used in Quickies and Dragonflies. The tandem-wing configuration used in those airplanes does not have horizontal tail. By researching the past incidents and owners' voices, several problems were found for that configuration. For tandem-wing airplanes without horizontal tail,

- It can enter a deep stall if aft-plane is stalled before the foreplane. This must be prevented by design.

- Because both surfaces are heavily loaded, even a stall from the foreplane can exhibit violent characteristics.
- Its steerable tail landing gear does not get enough traction on the ground because it lacks down-force at the tail end.

To solve these problems, a horizontal tail is added to the Quickie type configuration.

By following the Class I design procedure, the pros and cons for each configuration are identified. The inside of the Class I procedure is explained in the later section for the winning design. Before entering the Class I design, a few restrictions are made on design choices.

- Seating is side-by-side, which is widely preferred by customers.
- To save the manufacturing cost, wing must be straight, no-taper, no-twist, no-dihedral, and no-sweep. This does not apply for empennages to keep the minimum margin for the design for good-looking.

Airfoil Selection

For all Class I designs, the NASA LS (1)-0413 airfoil (known as GA (W)-2) is selected as the wing airfoil because it gives a superior maximum lift coefficient among all low-speed, manufacturable airfoils. A high maximum lift coefficient is required to meet both the stall speed requirement and high speed. The figure below is the lift curve of the LS (1)-0413.

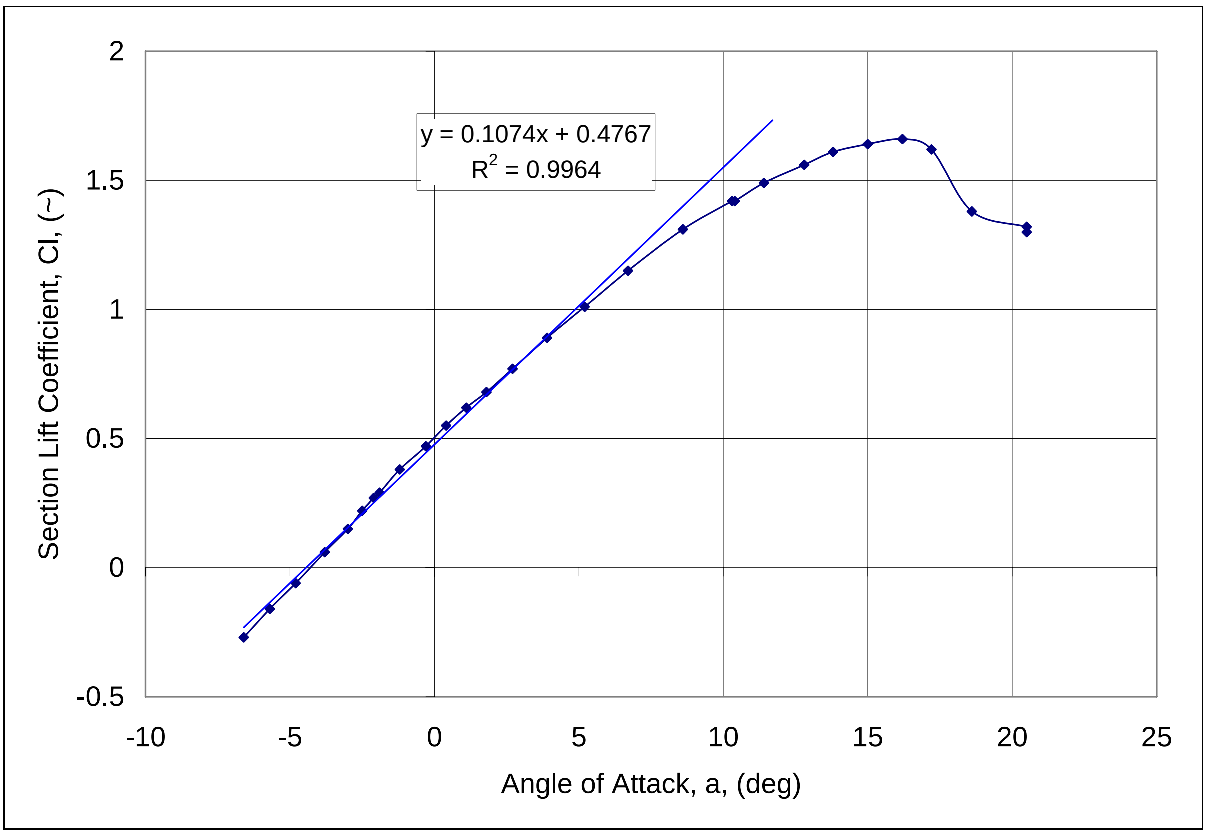


Figure 4. 3: Lift Curve Slope of NASA LS (1)-0413 (smooth, Re = 1.5E6)

The following Class I designs are made to meet the design requirements for Weight & Balance, Stability & Control, Ground clearance, and other issues to be considered.

Conventional Configuration:

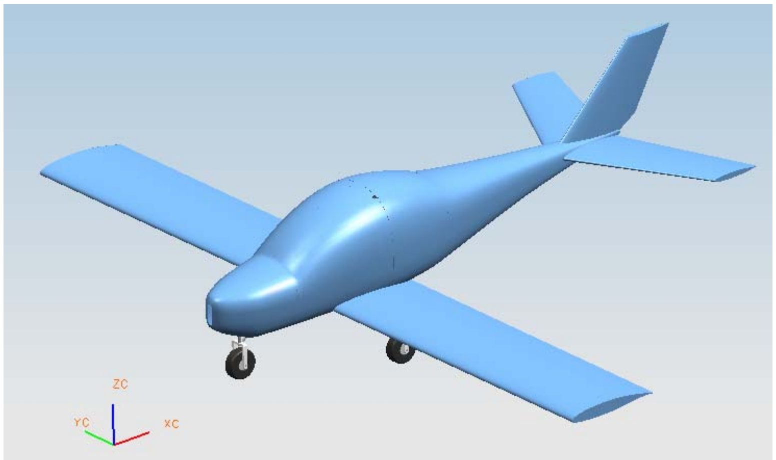


Figure 4. 4: Class I Design for Conventional Configuration

This conventional configuration is designed with tractor propeller at nose, low-wing, tricycle gears, and side-by-side seats. The low-wing configuration is selected to tune the aircraft to sportier side. Mid-wing is not a viable option since it conflicts with the cabin room. Also the tricycle landing gear is selected because of strong market preference, and there is no significant advantage by having tail-wheel gears.

Pros	Cons
• Well-known design. • There is no interference to the wing aerodynamics, except the prop-wash. • Very conventional, easy to handle.	• Wing main structure passes underneath the pilot seats. • The frontal area is large. • No particular advantage to reduce drag. • Lacks uniqueness significantly in the market.

Canard Configuration:

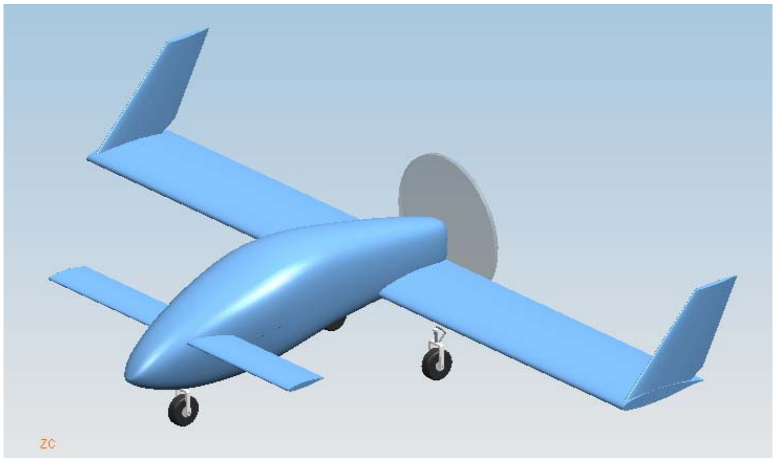


Figure 4. 5: Class I Design for Canard Configuration

This is the canard configuration designed with pusher propeller, tricycle landing gear, and side-by-side seating. The pusher engine configuration and the main wing section provide very efficient structural synergism. Tricycle gears should be selected to prevent the propeller to hit the ground at ground rotations. The vertical tails are placed at the tips of the main wing, swept back to achieve longer moment arm from the center of gravity.

Pros	Cons
• Prop-wash does not interfere with any surface. • Efficient structural layout. • Aerodynamically efficient design, which can provide low-drag.	• Because of the unswept wing, the vertical tail area is large due to the short moment arm from C.G. • There is a difficulty for passengers to get on board. Usually, a mechanism to lower the cabin to the ground is necessary. • C.G. travel is large between the different fuel weights and crew weights.

Tandem-Wing Configuration:

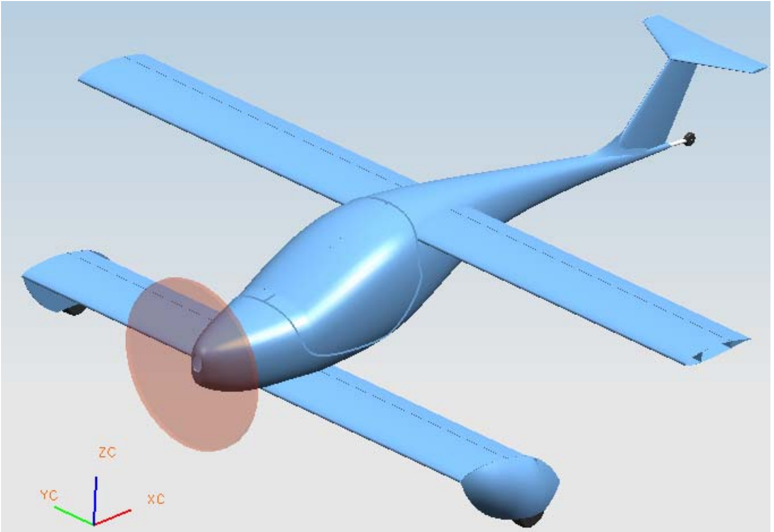


Figure 4. 6: Class I Design for Tandem-Wing Configuration

This is the tandem-wing configuration with the horizontal tail added. The horizontal tail is placed on top of the vertical tail to prevent it from scratching the ground, and add the end-plate effect to the vertical tail. It has the tractor propeller and the tail-wheel landing gear. The main gears are placed at the tips of foreplane to minimize the drag. The main gears have enough height to prevent the propeller to hit the ground. The hatches are gull-wing type for convenient access to the cockpit.

Pros	Cons
• Very aerodynamically efficient design. • Efficient structural layout. • Easy access to the cockpit. • Stands out in the market.	• Complexity in aerodynamic design. • Tricycle gear is more preferred. • Downward visibility is not good. • Reynolds number is low for the shorter chord length. • Long T.O. and Landing field lengths

Down-Selection

Since all the three configurations are inherited from proved concepts, they all meet the basic requirements for weight & balance, stability & control, and ground clearance. Also, since their sizes are very similar, the Class I drag estimation and corresponding performance are also very similar. The characteristics of each configuration found during the Class I design are shown as pros and cons in the previous section. Comparing the advantages and disadvantages of each configuration, the tandem-wing design was selected as the final configuration. This configuration has a potential to achieve very efficient aerodynamic design with very unique packaging appeal. As shown in Figure 3.6, the tandem-wing configuration exhibits the proven potential to achieve a low-drag design. The speed performance it pulls out from the small horsepower engine is a very strong statement. Designing a unique airplane is a challenge, but this configuration will be able to convey the design philosophy with its styling and performance.

To improve the safety and performance for take-off and landing scene, flaps system is added to the design. This does not improve the clean stall speed, but it will significantly improve the actual stall speed in operations. Considering the relatively high approach speed and poor downward visibility, addition of flap system will greatly improve the safety, and also the performance.

Next sections show the Class I design results for the final configuration.

4.4 Class I Weight & Balance

To perform the Class I weight & balance analysis the airplane component weights are estimated by the weight fraction method (Ref.4). A weight fraction data is a set of component weights as fraction of the airplane's gross weight. The airplane's center of gravity location is calculated by mapping the obtained component weights. For this very light airplane category, the only weight fraction data available at the time was the one for Bede BD5B homebuilt airplane. The set of weight fraction data includes the weight fractions for the following components and component groups. Because the Bede BD5B airplane has the conventional configuration, its weight fraction value has to be modified. A part of its wing group weight is redistributed to the empennage group weight so that the foreplane can be treated as a part of empennage. The weight for each surface is considered proportional to the each area. This modified weight fractions and component weights are as follows.

	Fraction	Weight (lb)
• Structure Weight	0.214	269.1
• Powerplant Weight	0.180	226.3
• Fixed Equipment Weight	0.119	149.6
• Empty Weight	0.513	645.1
• Wing Group Weight	0.050	62.9
• Empennage Group Weight	0.049	61.6
• Fuselage Group Weight	0.085	106.9
• Landing Gear Group Weight	0.030	37.7

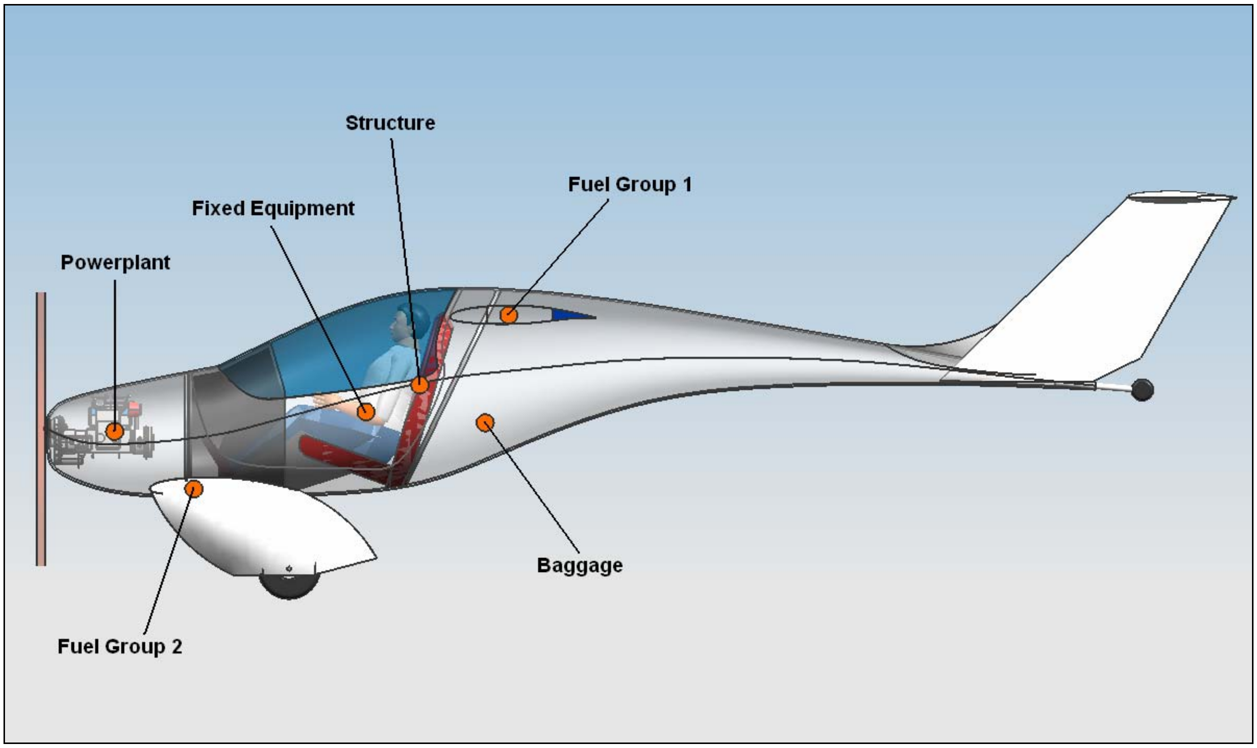


Figure 4. 7: Class I Side View with Component Weight Distribution

The figure above is showing several component C.G locations from the airplane side view. The detailed component weight distribution with respect to a reference point is shown in the following figures. These figures are the screen shot from the AAA program.

Empty Weight Table

Component	Weight lb	X_{cg} ft	Y_{cg} ft	Z_{cg} ft
Fuselage Group	106.9	10.83	0.00	4.58
Wing Group	62.9	12.95	0.00	6.29
Empennage Group	61.6	10.52	0.00	4.17
Landing Gear Group	37.7	10.30	0.00	2.88
Nacelle Group	0.0	0.00	0.00	0.00
Powerplant Group	226.3	6.42	0.00	4.05
Fixed Equipment Group	149.6	10.24	0.00	4.50

Output Parameters

$W_{structure}$	269.1	lb	$X_{cg_{structure}}$	11.18	ft	$Y_{cg_{structure}}$	0.00	ft	$Z_{cg_{structure}}$	4.65	ft
W_E	645.1	lb	X_{cg_E}	9.29	ft	Y_{cg_E}	0	ft	Z_{cg_E}	4.40	ft

Figure 4. 8: Class I Component Weight Distribution for Empty Weight C.G.

Input Parameters

W_E	645.1	lb	X_{cg_E}	9.29	ft	Y_{cg_E}	0	ft	Z_{cg_E}	4.40	ft

Loading Table

Component	Weight lb	X_{cg} ft	Y_{cg} ft	Z_{cg} ft
Crew	200.0	10.33	-0.92	4.17
Trapped Fuel and Oil	6.0	6.59	0.00	2.88
Mission Fuel Group 1	56.4	12.67	2.60	6.29
Mission Fuel Group 2	56.4	6.59	-2.60	2.88
Passenger Group 1	200.0	10.33	0.92	4.17
Passenger Group 2	0.0	0.00	0.00	0.00
Passenger Group 3	0.0	0.00	0.00	0.00
Passenger Group 4	0.0	0.00	0.00	0.00
Baggage	40.0	12.50	0.00	4.75
Cargo	0.0	0.00	0.00	0.00
Military Load Group 1	0.0	0.00	0.00	0.00
Military Load Group 2	0.0	0.00	0.00	0.00

Output Parameters

$W_{current}$	1203.9	lb	X_{cg}	9.76	ft	Y_{cg}	0.00	ft	Z_{cg}	4.35	ft

Figure 4. 9: Class I Component Weight Distribution for Total C.G.

Based on these results of weight distribution, the following loading scenario is considered. The loading/ unloading order is indicated by the numbers from 1 thorough 13.

C.G. Excursion Table

Component	Weight lb	X_{cg} ft	Load (1-13)	Unload (1-13)
Empty Weight	645.1	9.29	1	13
Crew	200.0	10.33	7	12
Trapped Fuel and Oil	6.0	6.59	2	7
Mission Fuel Group 1	56.4	12.67	4	9
Mission Fuel Group 2	56.4	6.59	3	8
Passenger Group 1	200.0	10.33	6	11
Passenger Group 2	0.0	0.00		
Passenger Group 3	0.0	0.00		
Passenger Group 4	0.0	0.00		
Baggage	40.0	12.50	5	10
Cargo	0.0	0.00		
Military Load Group 1	0.0	0.00		
Military Load Group 2	0.0	0.00		

Figure 4. 10: Loading Scenario

The amount of C.G. shift expected in operations is shown in the following Class I C.G. Excursion diagram. The red line indicates the X-location of the main landing gear, and the blue line indicates the location of the wing. For this excursion diagram for the maximum take-off weight, the C.G. shift during flight due to the fuel consumption is only 0.02 ft (0.24 in). The fuel in the two fuel tanks is used at the same time, at the same rate. This small shift in C.G. maintains the control feel during a flight. The most aft C.G. occurs at the end of flight from maximum take-off weight.

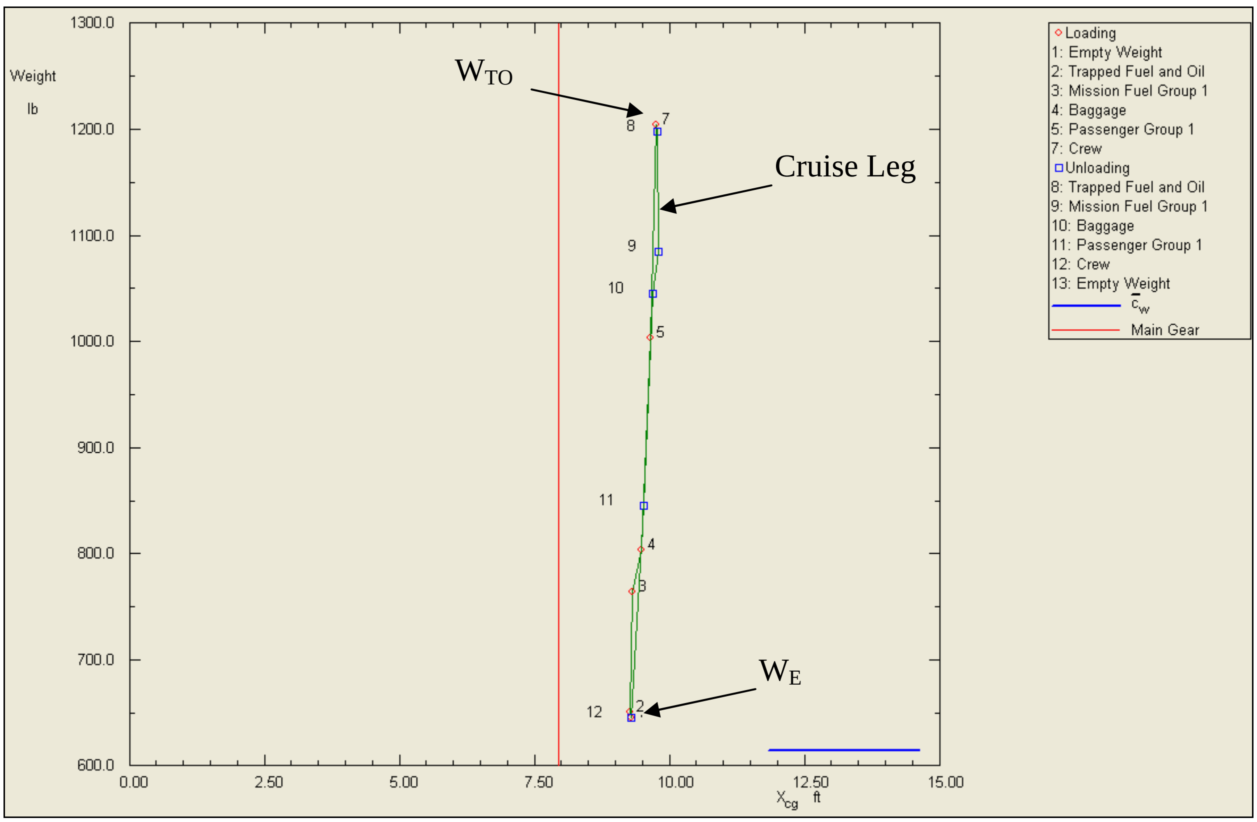


Figure 4. 11: Class I C.G. Excursion Diagram

4.5 Class I Stability & Control

4.5.1 Static Longitudinal Stability

This airplane is designed to be an inherently stable airplane. Use of a feedback augmentation system gives more freedom to the design, but it is not an affordable choice. Therefore, the 10 % of airplane static margin should be targeted.

Regulus is now a three-surface airplane with tandem-wing configuration as a base design. The foreplane still is the major authority for the pitch control. The area of the horizontal tail relative to the foreplane area is decided to be less than 15 %. There are three reasons for this decision. First reason is to prevent the design to diverge from the tandem-wing heritage. Second reason is to keep the horizontal tail small enough to fit it on top of the vertical tail. The last reason is for styling purpose. By keeping the area ratio, the Class I empennage size to satisfy the ideal static margin is calculated using AAA program. Result shows the 5.74 ft^2 horizontal tail area and 45.91 ft^2 foreplane area. The final Class I horizontal tail area ratio, S_h/S_c, is 13 %.

Input Parameters

S_w	70.27	ft^2	$C_{L_{\alpha_{wf}}}$	4.9297	rad^{-1}	$(d\varepsilon_h/d\alpha)_{p.off}$	0.2076		X_{cg_0}	10.02	ft
AR_w	8.96		$X_{ac_{wf}}$	12.25	ft	dX_{cg}/dS_c	-0.0030	ft^{-1}	S_h/S_c	0.13	
λ_w	1.00		dX_{cg}/dS_h	0.0277	ft^{-1}	$C_{L_{c_\alpha}}$	5.0219	rad^{-1}	SM	10.00	%
$\Lambda_{c/4_w}$	0.0	deg	$C_{L_{h_\alpha}}$	3.3828	rad^{-1}	X_{ac_c}	6.81	ft			
X_{apex_w}	11.83	ft	X_{ac_h}	25.23	ft	$d\varepsilon_c/d\alpha$	0.1075				

Output Parameters

C_{L_α}	8.7824	rad^{-1}	$\bar{x}_{ac_{wf}}$	0.1479		$\bar{x}_{ac_h}$	4.7864	
X_{cg}	10.04	ft	$\bar{x}_{ac}$	-0.5395		S_c	45.91	ft^2
$\bar{x}_{cg}$	-0.6395		S_h	5.74	ft^2	$\bar{x}_{ac_c}$	1.7929	

Figure 4. 12: Class I Longitudinal Stability Calculation by AAA

4.5.2 Static Directional Stability

Again, this airplane is designed to be an inherently stable airplane. Therefore, it is assumed the overall level of directional stability (C_{n_β}) must be 0.0010 deg^{-1} (0.0573 rad^{-1}). As shown below, the calculated result by AAA program shows the Class I vertical tail size for the stability criteria is 6.16 ft^2.

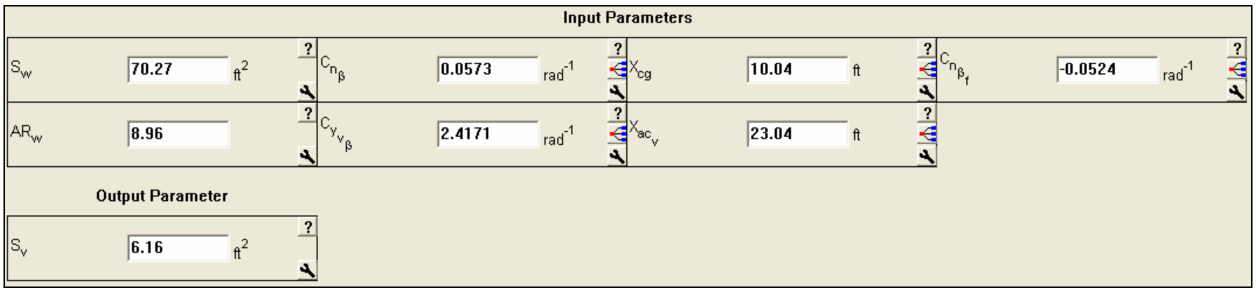


Figure 4. 13: Class I Vertical Tail Area Calculation for Directional Stability

4.6 Class I Drag Polars

Before entering the Class I drag estimation for the airplane, the drag coefficients of the similar airplanes are calculated to improve the accuracy of the Class I drag estimation. For the following tandem-wing and canard airplanes, the following data is known. The canard airplane, VariEze is studied together for later comparison purpose.

Table 4. 1: Specifications and Performances for the Similar Type Airplanes

Airplane	Gross Weight (lb)	Engine HP (hp)	Wing Area (ft^2)	AR (~)	Max. Level Speed (ft/s)
Quickie A	480	18	27	10.26	184
Quickie B	520	22	27	10.26	206
Quickie Q2	1000	64	67	4.15	263
Dragonfly A	1075	56	49	9.98	246
Dragonfly B	N/A	45	49	9.98	231
VariEze	1050	100	54	9.20	N/A

* The wing area does not include the foreplane area.

Using these known parameters, the zero-lift drag coefficients, (C_{D_o}), the equivalent parasite area, (f), and the wetted area, (S_{wet}), of these similar airplanes are calculated. For the calculations in the next page, several assumptions are made for several unknown conditions such as their Oswald's efficiency factor (e) and propeller efficiency (η_p). For convenience, typical values are assumed for those; e = 0.80 and η_p = 0.80. In addition, it is assumed that all the engine power is used for propulsion. Also, their equivalent skin friction coefficient, (C_f), is assumed to be the same as the well-known homebuilt airplanes, VariEze and KR-1. Standard sea-level atmosphere is also assumed.

The drag equation can be written as;

$$C_D = C_{D_o} + \frac{C_L^2}{\pi Ae} \qquad \text{this yields;} \qquad C_{D_o} = C_D - \frac{C_L^2}{\pi Ae}$$

At the maximum level speed; $D = T = \frac{P}{V} = \frac{550 \cdot SHP \cdot \eta_p}{V}$

The drag can be written as;

$$D = \frac{1}{2}\rho V^2 C_D S \qquad \text{this yields;} \qquad C_D = \frac{2D}{\rho V^2 S}$$

At level flight;

$$W = L = \frac{1}{2}\rho V^2 C_L S \qquad \text{this yields;} \qquad C_L = \frac{2W}{\rho V^2 S}$$

Combining the above all, the zero-lift drag coefficient can be written as;

$$C_{D_o} = \frac{2 \cdot 550 \cdot SHP \cdot \eta_p}{\rho S V^3} - \frac{1}{\pi Ae}\left(\frac{2W}{\rho S V^2}\right)^2$$

Also, the equivalent parasite area can be expressed as; $f = S \cdot C_{D_o}$

Using the known parameters shown in Table 4.1, with aid of Figure 4.15, the following results can be obtained.

Table 4. 2: Calculated Drag Parameters for the Similar Type Airplanes

Airplane	Zero-lift drag coefficient, C_{D_o}	Equivalent parasite area, f (ft^2)	Wetted Area, S_{wet} (ft^2)
Quickie A	0.03199	0.8663	189.9
Quickie B	0.02882	0.7804	171.1
Quickie Q2	0.01622	1.0871	238.3
Dragonfly A	0.02481	1.2031	263.8
Dragonfly B	0.02778	1.3475	295.4
VariEze	N/A	N/A	285.0

Now, the Class I drag is estimated by the empirical method introduced by Roskam (Ref.4). The method can be summarized as follows.

First, the airplane's wetted area, S_{wet}, is estimated using a statistical data. The figure below shows the regression lines exist in the chart relating wetted area and maximum take-off weight for historical homebuilt airplanes. The colored points are the previously obtained data for the tandem-wing and canard configurations, which is more aerodynamically efficient than average airplanes. Since the configuration is known to be very similar to these airplanes, the regression line is shifted down to match the trend as shown in the figure. The equation for the regression line is; $\log_{10} S_{wet} = c + d \log_{10} W_{TO}$, where <u>c = 1.0972</u> and <u>d = 0.4319</u>.

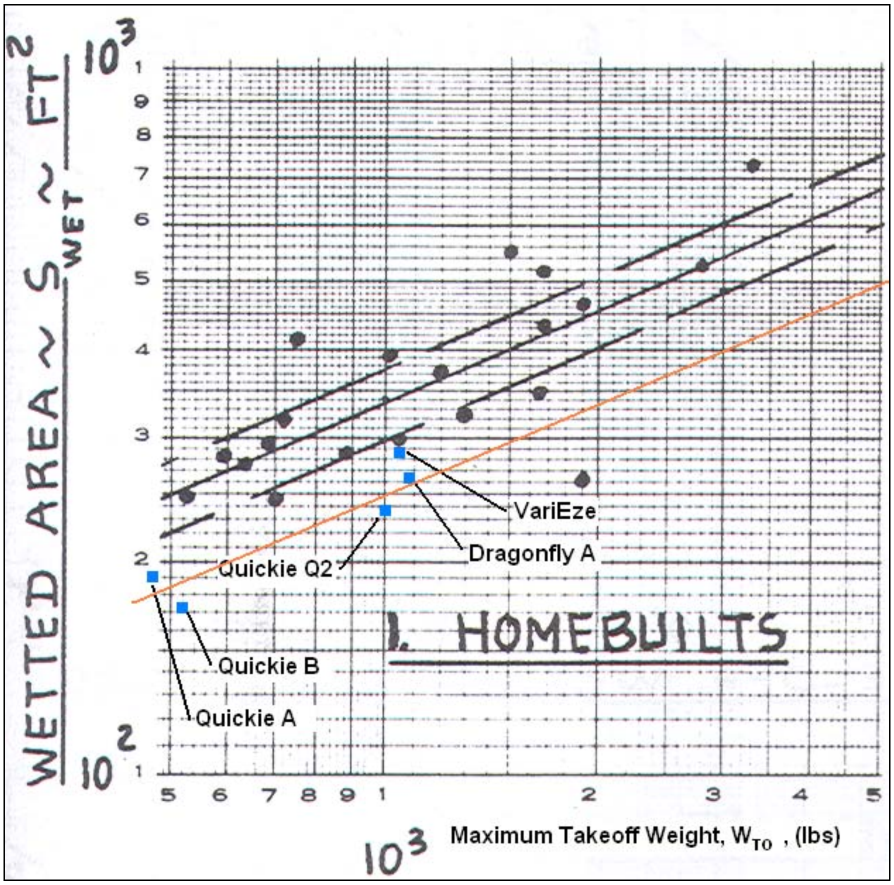


Figure 4. 14: Correlation between Wetted Area and Take-off Weight for Homebuilt Airplanes (copied form Ref.4)

Next, the airplane's equivalent parasite area, f, is estimated from another chart as shown in Figure 4.15. In this chart, the correlation coefficients are a function of the equivalent skin friction coefficient, C_f, of an airplane. As shown, those tandem-wing airplanes assume the same skin friction coefficient as the famous homebuilt airplanes, VariEze and KR-1 (the corresponding C_f value is about 0.0045). The equation to be used to estimate the new airplane's equivalent parasite area is; $\log_{10} f = a + b \log_{10} S_{wet}$, where <u>a = -2.3409</u> and <u>b = 1</u>.

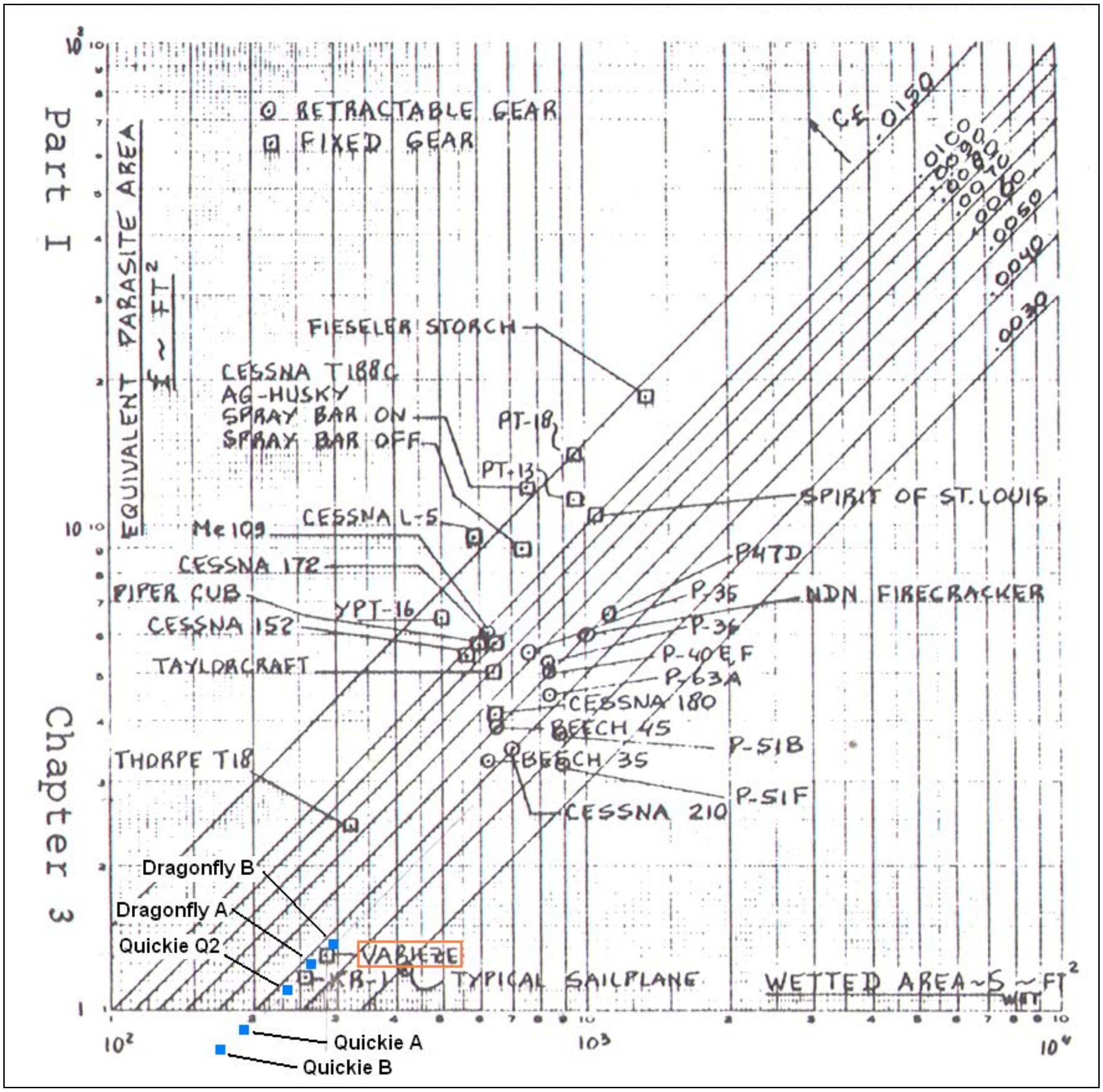


Figure 4. 15: Effect of Equivalent Skin Friction and Wetted Area on Equivalent Parasite Area for Single Engine Propeller Driven Airplanes (copied from Ref.4)

With the previous two charts, the equivalent parasite area can be estimated from the airplane's maximum take-off weight. Then, the airplane's zero-lift drag coefficient, C_{D_o}, can be expressed as;

$C_{D_o} = \frac{f}{S}$ where the f is the equivalent parasite area, and the S is the reference wing area, which is currently 70.27 ft^2.

Now, in addition to the clean zero-lift drag coefficient, there is the increment zero-lift drag coefficient, ΔC_{D_o}, depending on the selection of flaps and landing gears. The table below is the typical drag increment and Oswald's efficiency factor due to those items. The increments are additive.

Table 4. 3: First Estimates for Increment zero-lift drag and 'e' with Flaps and Gear Down

Configuration	ΔC_{D_o}	e
Clean	0	0.80 - 0.85
Take-off Flaps	0.010 - 0.020	0.75 - 0.80
Landing Flaps	0.055 - 0.075	0.70 - 0.75
Landing Gear	0.015 - 0.025	No effect

- For the clean configuration, e = 0.80 is selected for this Class I estimates.
- For the take-off configuration, a moderate increment in drag coefficient is assumed, with ΔC_{D_o} = 0.015 and e = 0.80
- For the landing configuration, a moderate increment in drag coefficient is assumed, with ΔC_{D_o} = 0.065 and e = 0.75
- The fixed landing gears have the tailwheel configuration with short main gears covered by fairings. Therefore, a small increment in drag coefficient is assumed, with ΔC_{D_o} = 0.015

Now, the Class I drag polar equations can be computed with the known take-off weight of 1203.9 lbs and the current wing aspect ratio, A = 8.96. In terms of the drag polar equation ($C_D = C_{D_o} + \frac{C_L^2}{\pi A e}$), the Class I low-speed drag polars can be expressed as follows.

- Clean (gears are fixed down): $C_D = 0.0324 + 0.0444 C_L^2$
- Take-off configuration: $C_D = 0.0474 + 0.0444 C_L^2$
- Landing configuration: $C_D = 0.0974 + 0.0474 C_L^2$

With this drag polar for the clean configuration, the reverse calculation gives that the required power to maintain 114-knot speed is 49.8 hp. Since this is smaller than the available engine horsepower, the current Class I design satisfies the maximum speed requirement.

The figure below is the drag polars plotted by AAA program.

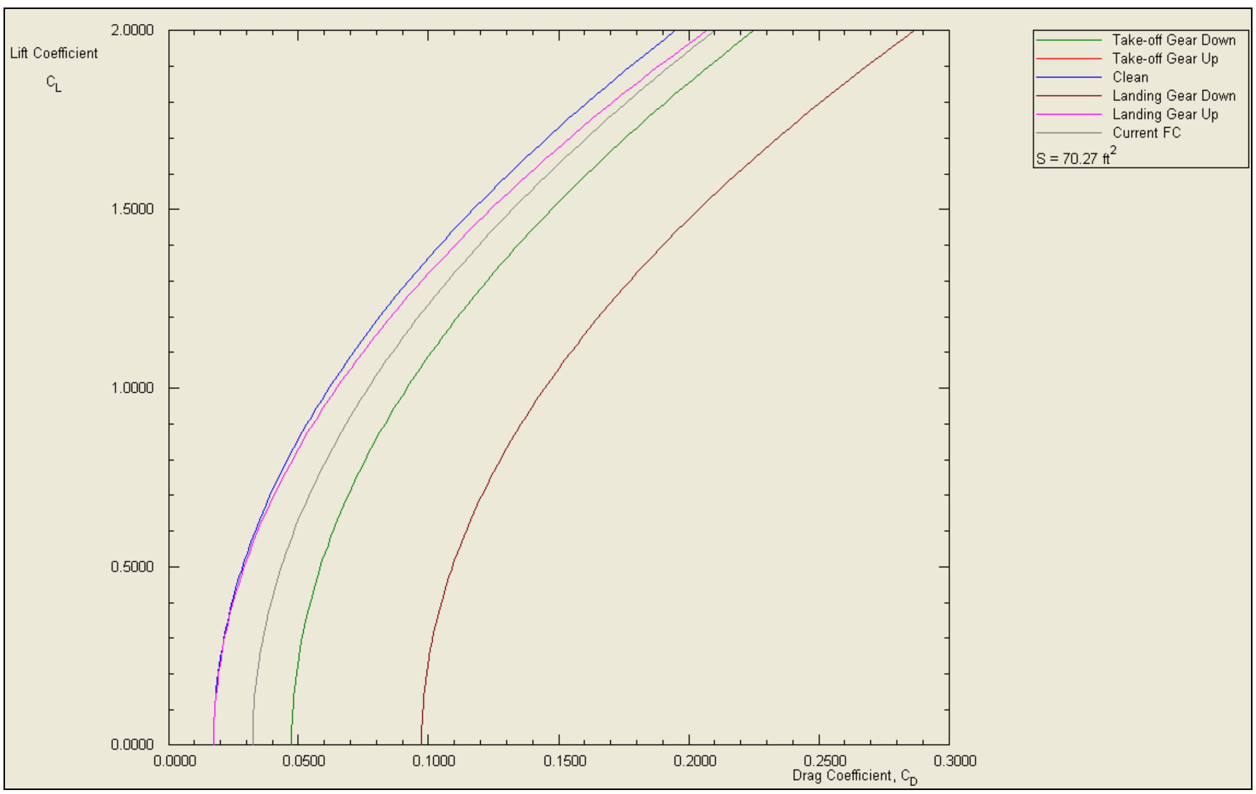


Figure 4. 16: Class I Drag Polar

4.7 Class I Landing Gear Design

This airplane is designed with the fixed landing gears with tailwheel configuration. In this section, the disposition of the landing gears is reviewed.

4.7.1 Longitudinal Tip-over Criterion

The C.G. is well behind the main gear, so that longitudinal tip-over does not occur. The rotation angle is 27 degree, which is larger than usual rotation angle. This size of rotation angle is accepted for this configuration because the horizontal tail and the wing with flaps can produce enough rotational moment at take-off.

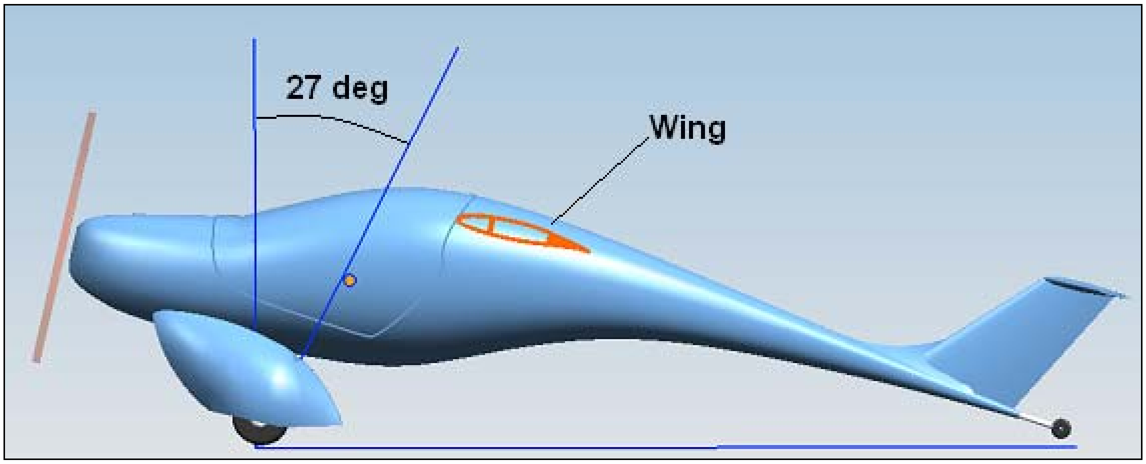


Figure 4. 17: Longitudinal Tip-over Criterion

4.7.2 Lateral Tip-over Criterion

As shown in Figure 4.6, this airplane's wheel track between the main gears is very wide. Therefore, the lateral tip-over criterion is clearly satisfied.

4.7.3 Ground Clearance Criterion

The required 5-degree lateral ground clearance angle is clearly satisfied as shown in the figure below. Also, the ground clearance of the propeller tip is more than 8 inches after rotation (when tail is lifted).

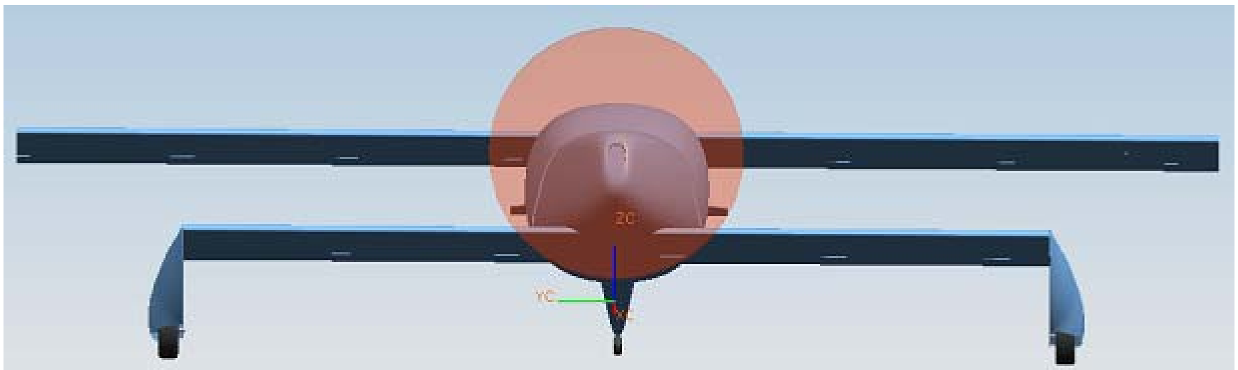


Figure 4. 18: Ground Clearance Criterion

4.8 Class I Structural Arrangement and Design

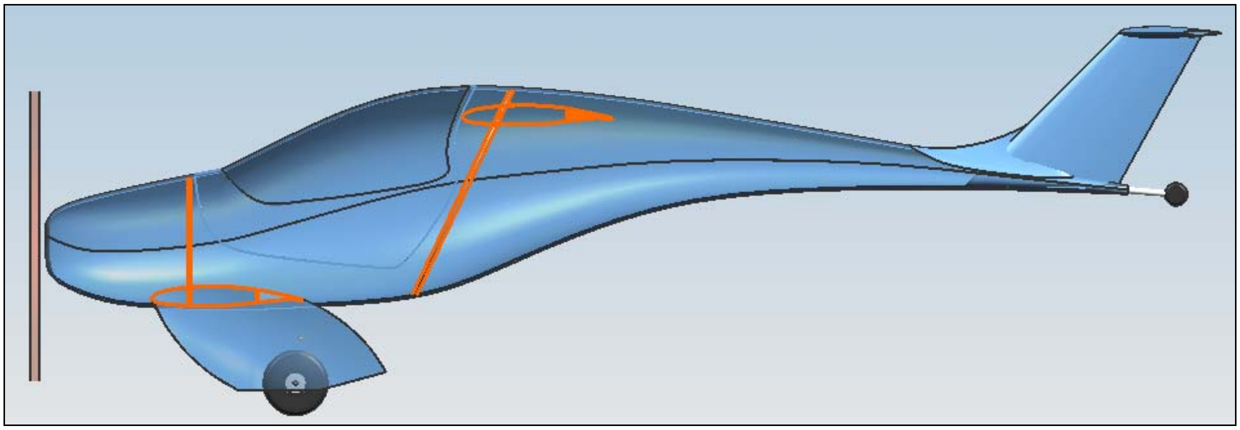


Figure 4. 19: Preliminary Structural Layout

The figure above is showing the location of forward and aft bulkhead. As shown, the foreplane lift load is supported by the forward bulkhead, and the wing lift is supported by the aft bulkhead. There are structural hard points within the main gear fairings, which is connecting the main gears to the wing structure. The engine will be supported by the forward bulkhead, and the crew seats will be attached to the aft bulkhead to support the crew weight.

5. Class II Design Procedures

5.1 Class II Drag Polar and Performance

Class II drag calculation can be done using the AAA program. The trimmed drag polars are obtained as follows. The speed range shown in the figure is from 45 knot (M = 0.07) to 120 knot (M = 0.19).

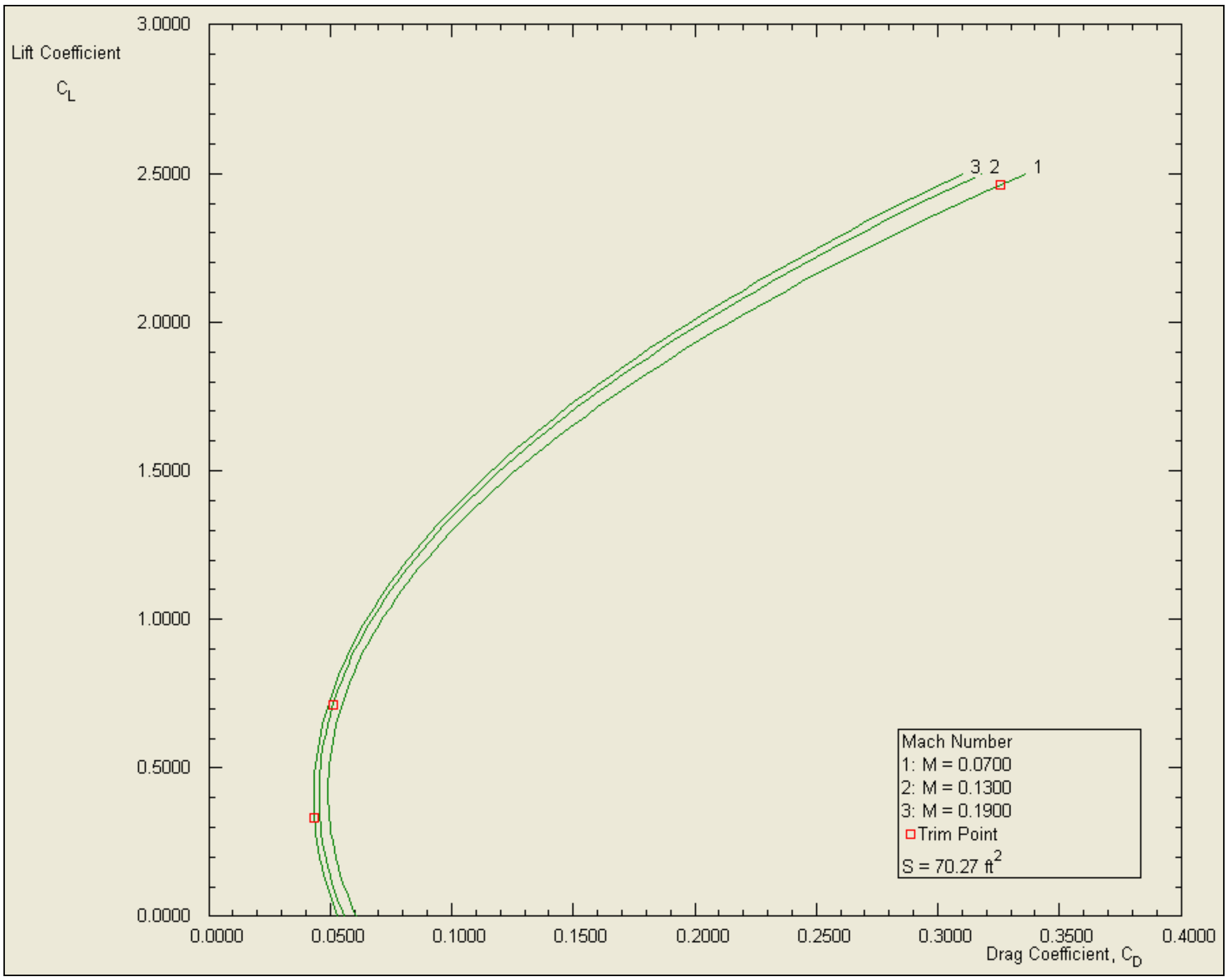


Figure 5. 1: Class II Trimmed Drag Polar

Also, the trimmed drag build-up is obtained as follows.

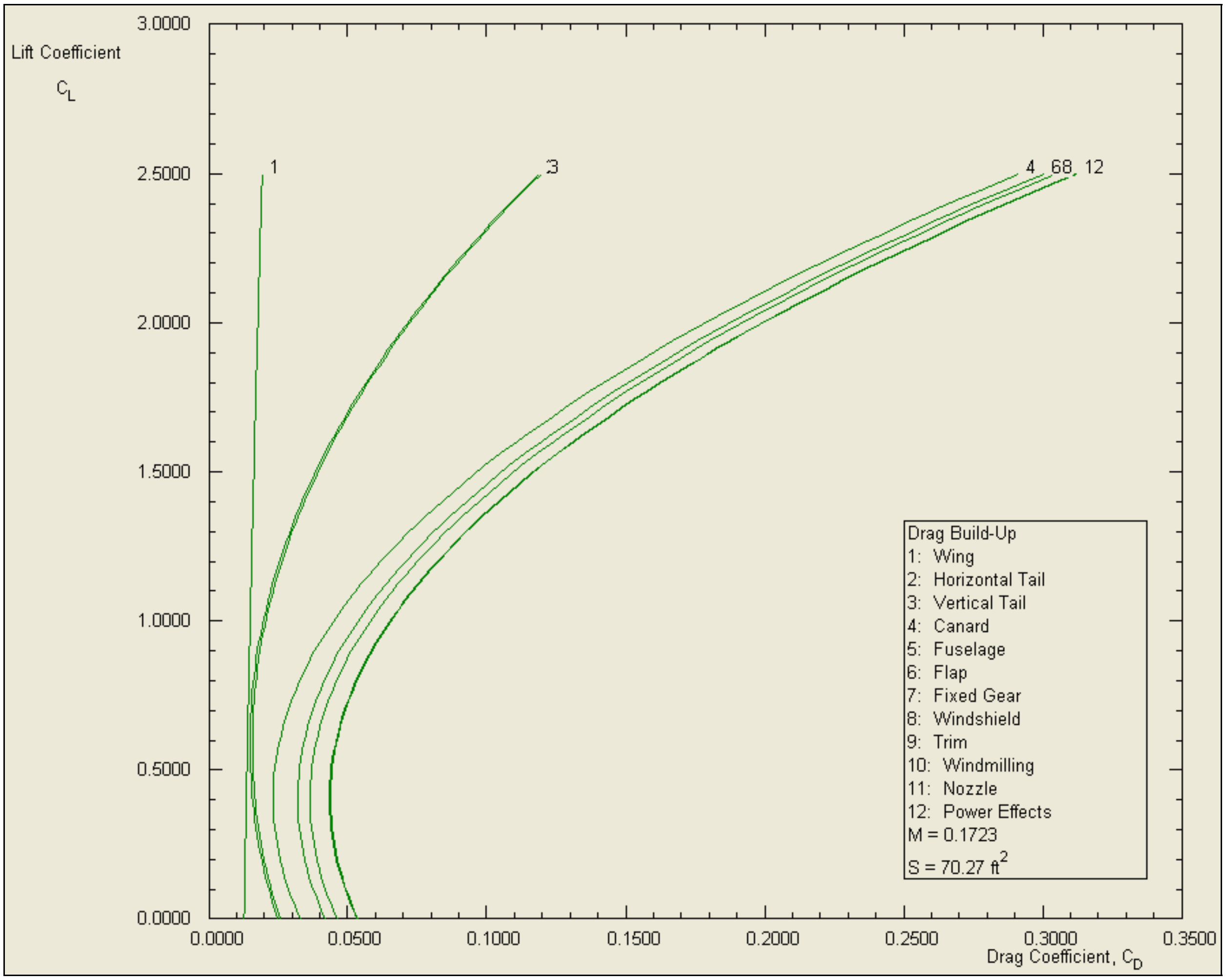


Figure 5. 2: Class II Trimmed Drag Build-up

5.2 Class II Weight, Balance, and Inertias

The Class II weight & balance calculation is done by AAA program. The following final component weight values are obtained.

#	Weight Component	$W_{Average}$ lb
1	Wing	95.6
2	Horizontal Tail	12.6
3	Vertical Tail	6.1
4	Canard	67.1
5	Fuselage	140.0
6	Main Landing Gear	37.3
7	Tail Landing Gear	6.0
8	Propeller	21.5
9	Engines	77.2
10	Fuel System	44.4
11	Air Induction System	9.1
12	Propulsion System	21.9
13	Flight Control System	23.7
14	Hydraulic and Pneumatic System	3.1
15	Instruments/Avionics/Electronics	32.2
16	Electrical System	25.0
17	Air Cond./Press./Icing System	2.4
18	Oxygen System	0.0
19	Auxiliary Power Unit	0.0
20	Furnishings	27.9
21	Cargo Handling Equipment	35.2
22	Other Items	3.7

Output Parameters

W_{fix}	153.2	lb	W_{pp}	174.1	lb	W_F	117.7	lb	W_{TO}	1256.1	lb
$W_{structure}$	364.8	lb	W_E	692.1	lb	W_{tfo}	6.3	lb			
W_{gear}	43.3	lb	$W_{F_{used}}$	94.1	lb	W_{useful}	557.7	lb			

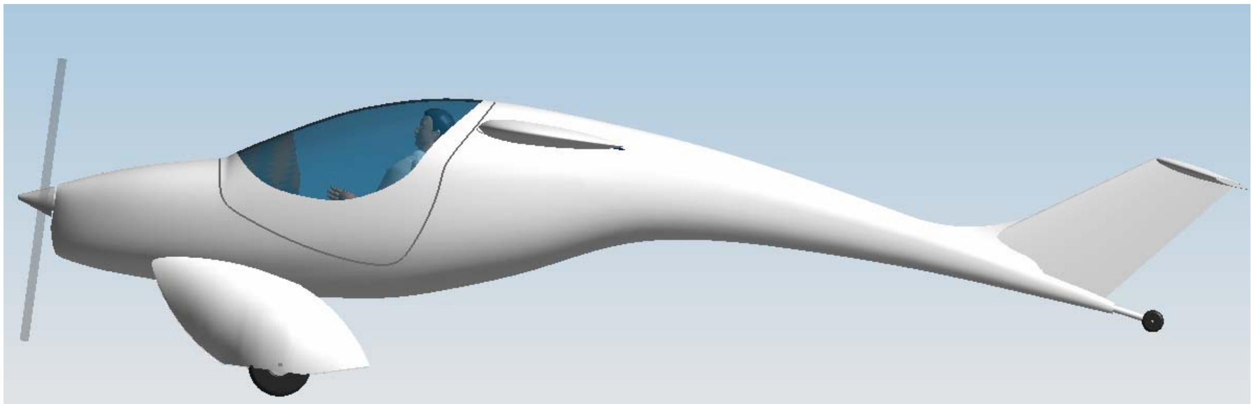
5.3 Class II Stability and Control

Class II stability and control is also verified by AAA program. The following is the summary.

- Static Margin: 9.31 % at cruise, 13.85 % at landing
- Yawing Moment Coefficient due to Side Slip Derivative, C_{n_β} : 0.0424 rad^{-1}
- Take-off Roll: The horizontal tail area required to initiate take-off roll is satisfied. The airplane can even initiate take-off roll with wing and canard only.

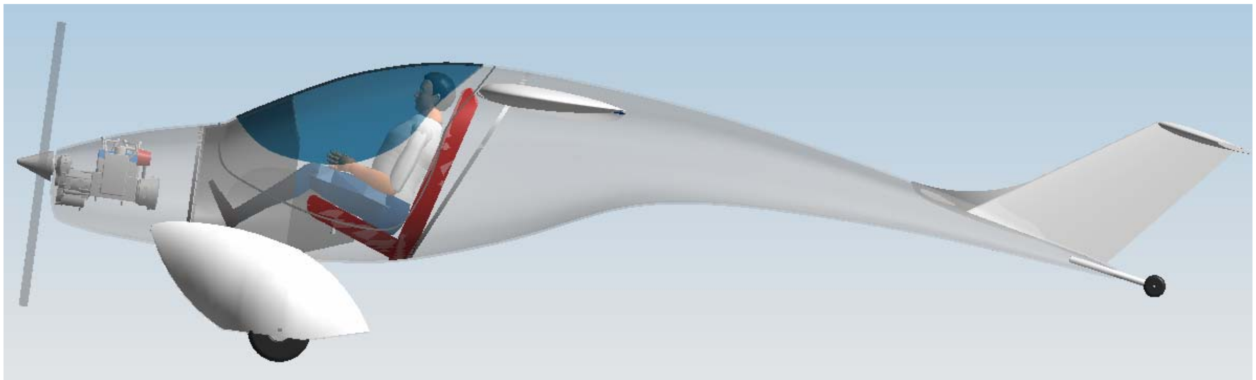
5.4 Class II Landing Gear Layout, Tip-Over, Rotation and Clearance

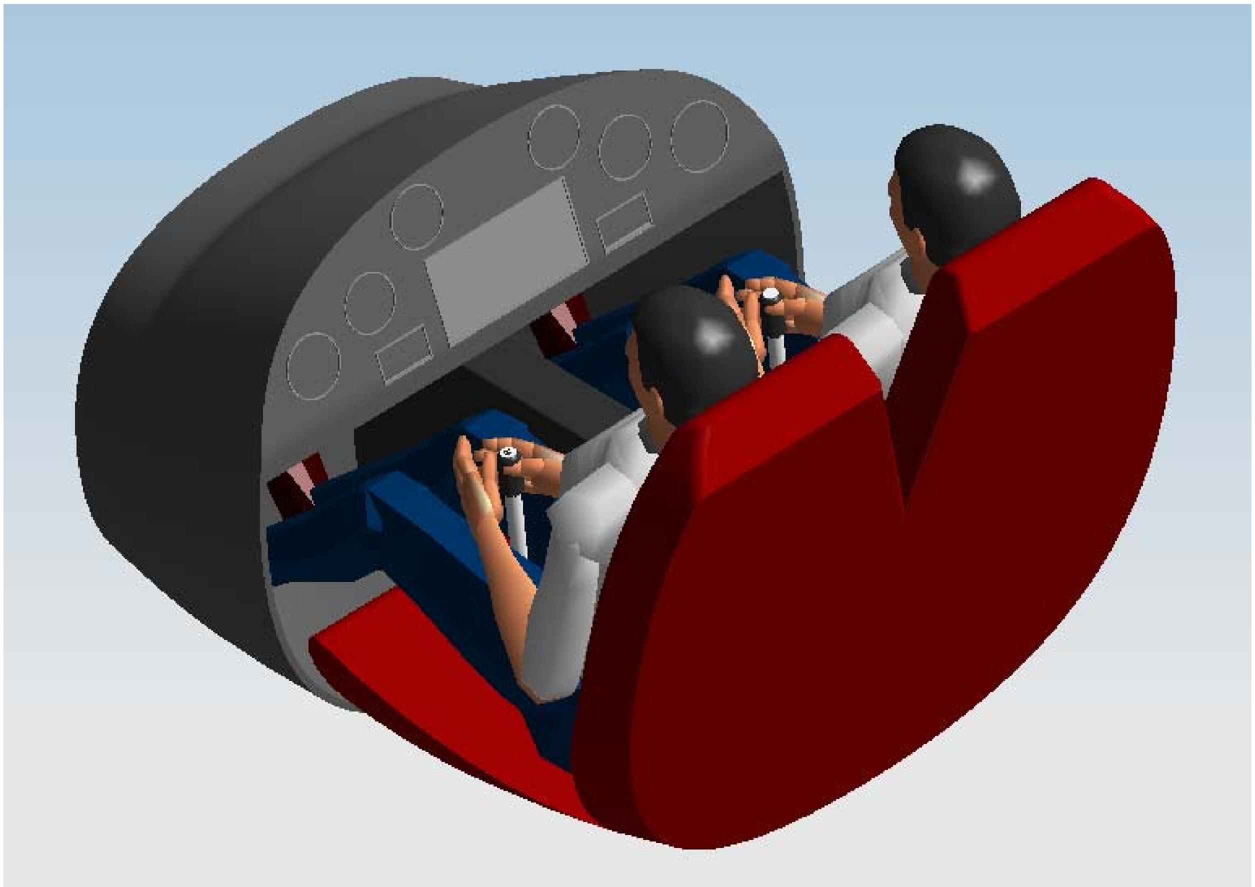
No major change from Class I. All criteria are satisfied.



5.5 Inboard Profiles

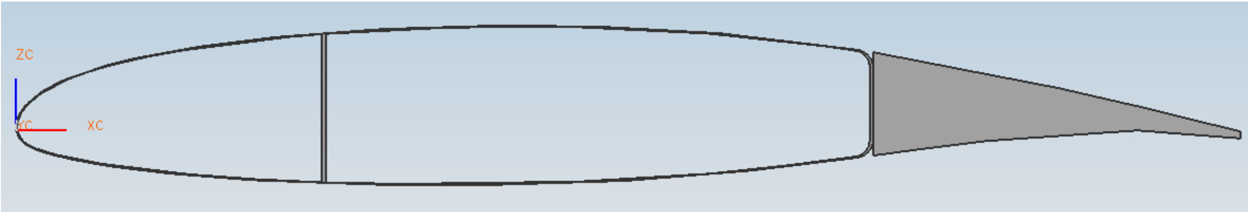
The following figures are showing the inboard profiles.





6. Manufacturing Feature

The design featured of this airplane is the wing manufacturing technique. Both of the wings are manufactured by a carbon composite pull-winding technique. This technique produces the continuous leading edge structure as shown below. The trailing edge portion is manufactured separately and joined together. Pull-winding is a very fast and cheap manufacturing technique for composite structure. Since the two wing surfaces have the same cross section, the manufacturing efficiency will be greatly increased. The problem of the pull-winding technique is that it lacks diagonal fibers to resist wing torsion. Therefore, in addition to the cross fibers, a prepreg cloth should be placed on top by post-process room-temperature curing. The ribs and fuselage joint bay are inserted from the side openings into the pull-winded wing box.

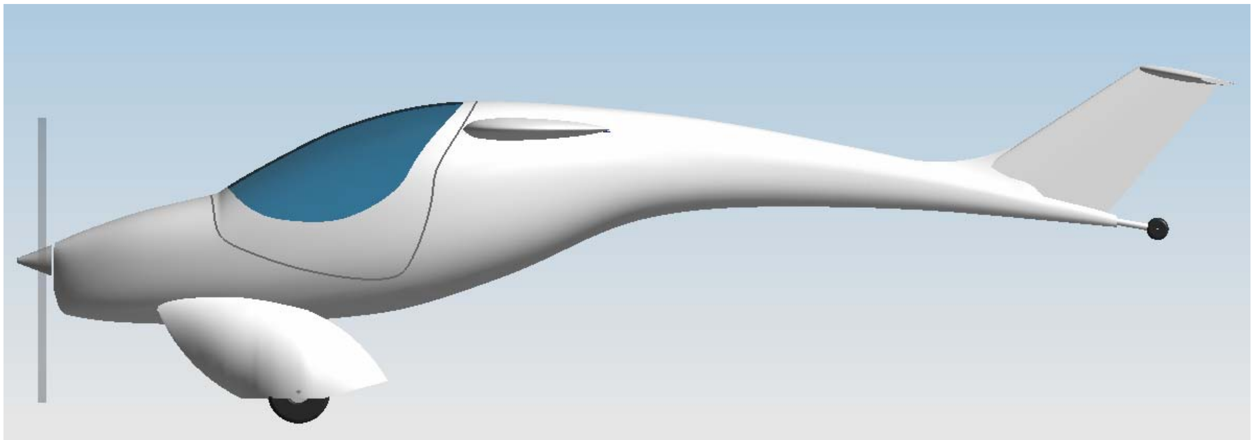


7. Final 3-View

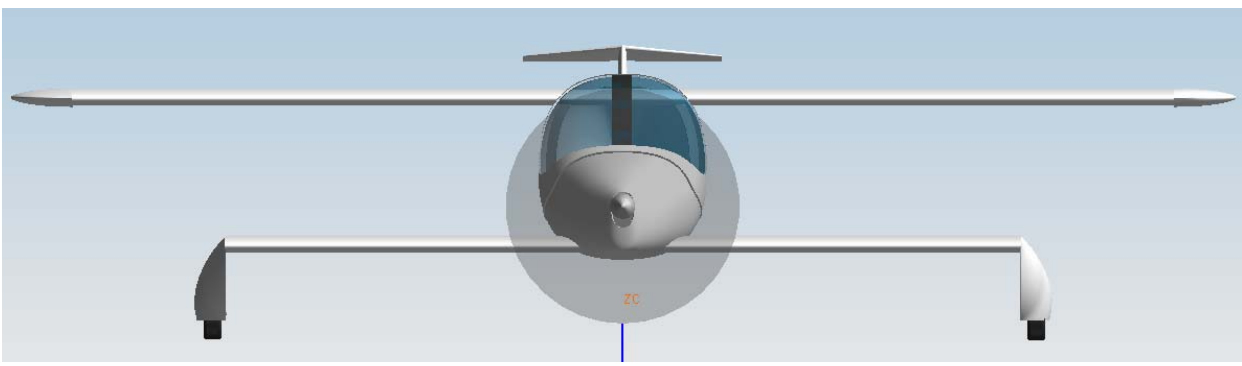
Final Geometry:

- Wing span: 25.1 ft
- Wing area: 70.27 ft^2
- Wing chord: 2.8 ft
- Foreplane span: 18.1 ft
- Foreplane area: 45.91 ft^2
- Foreplane chord: 2.8 ft
- Horizontal tail span: 4.53 ft
- Horizontal tail area: 5.74 ft^2
- Vertical tail span: 2.81 ft
- Vertical tail area: 6.16 ft^2
- Overall length: 23.0 ft

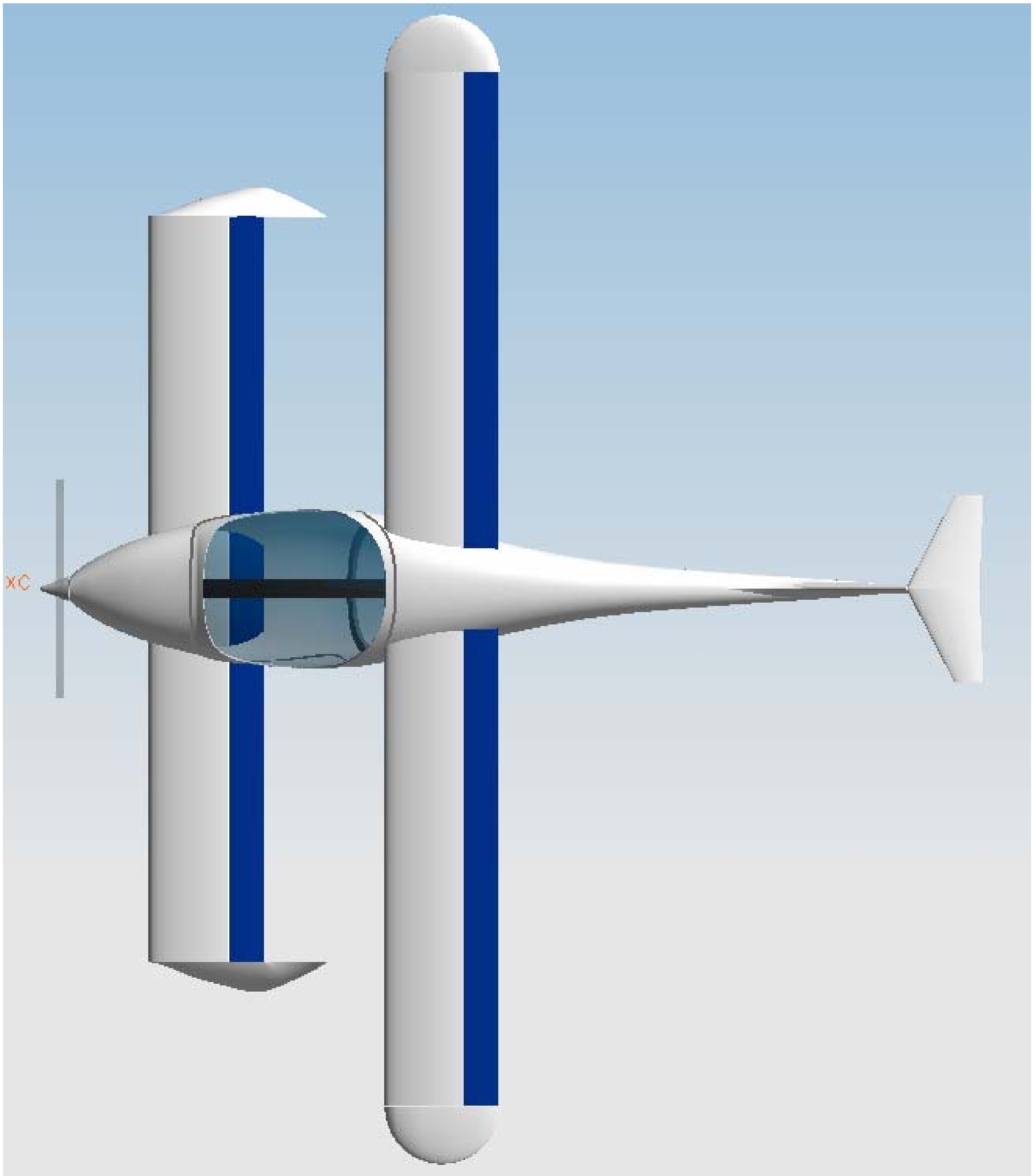
Side View:



Front View:



Top View:



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