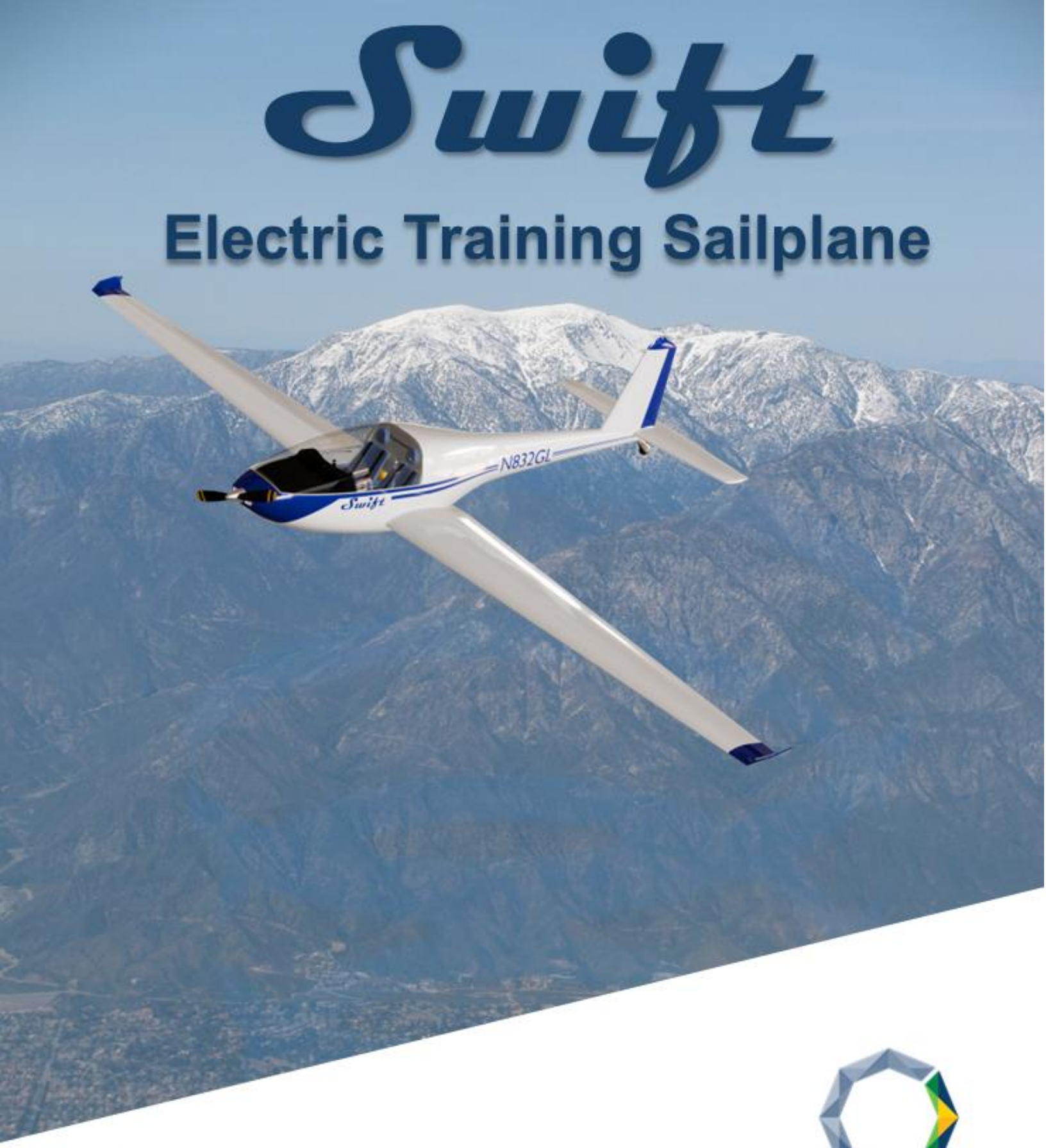
Swift

Electric Training Sailplane



AIAA

SHAPING THE FUTURE OF AEROSPACE

CalPolyPomona

College of Engineering

Swift

25 L/D Airspeed	**Self-Retrieve Range**	**Turning Sink Rate**	**Annual Cost**
50 Knots	176 Km	134 Ft/Min	$11,000
Cost Per Flight	**Climb Altitude**	**Unit Cost**	**Flights Per 6 Hours**
$21/Flight	16,000 Ft	$98,000	10 Flights

Clean, Affordable, Versatile

Glydetek

CalPoly Pomona

Signature Page

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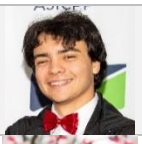
Sebastian Arteaga **#1441485**		
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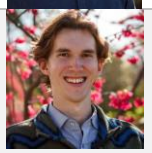
Kolya Kuzmenko **#1603772**		
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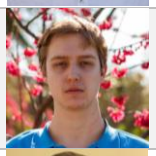
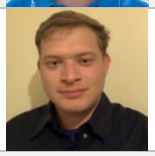
Stanley Ossyra **#1584235**		
Michael Rouse **#1603764**		
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This Proposal was created without the use Generative AI. All work is exclusively done by the members of the Cal Poly Pomona Glydetek team.

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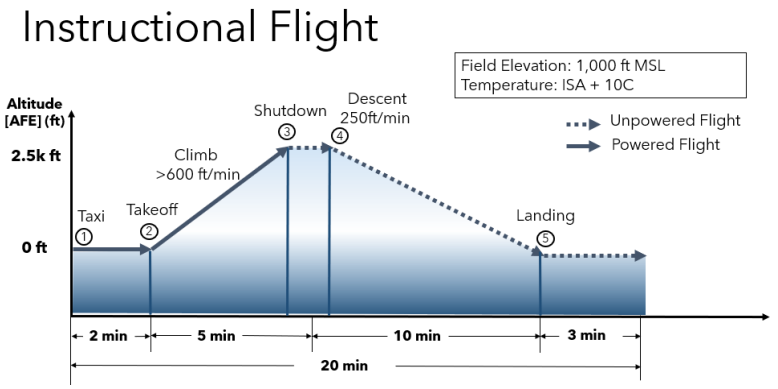
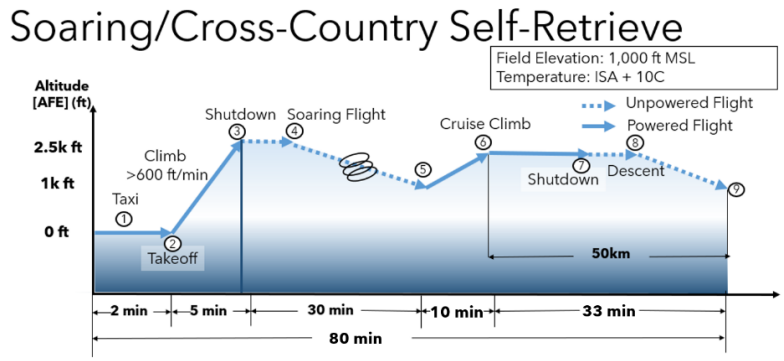
Executive Summary

In response to the 2023-2024 American Institute of Aeronautics and Astronautics (AIAA) Graduate Team Aircraft Design Competition Request for Proposal, Team Glydetek of California State Polytechnic University, Pomona (CPP) submits the Glydetek Swift, an affordable all-electric training sailplane for pilots of all skill levels. The aging fleet of current sailplanes and their gas-powered towplanes along with rapid improvements in battery technologies has established a market niche for self-launching electric sailplanes. With an **operational cost 35% lower than the current state-of-the-art**, and an **acquisition cost of $98,000**, the Swift is accessible to a wide range of operators, ranging from small gliding clubs and individual operators to large commercial flight training operations. The Swift is designed with training adaptability in mind. With a spacious side-by-side cockpit to promote ease of communication between the trainer and trainee**, seats capable of accommodating pilots ranging from 4 ft, 11 in to 6ft 2 in**, and a high-visibility canopy, the Swift enables highly efficient flight training. Split flaps and spoilers are provided, allowing novice pilots to familiarize themselves with their operation during takeoffs and approaches. To further support flight training efforts, as well as recreational operation, the Swift has a maximum Lift-to-Drag (L/D) ratio of 25 at a speed of 50 knots, enabling pilots to quickly traverse regions of sink to get to the





nearest thermal or source of ridge lift. In a coordinated sustained 250 ft radius turn, the Swift has a **minimum sink rate of 193 ft/min**, allowing pilots to soar on relatively weak sources of lift. With a maximum climb altitude of 16,000 ft on one charge, the Swift can climb into sources of convergence lift, enabling long-distance cross-country flights. The Swift's **self-retrieve range of 176 km** enables pilots to push the aircraft to its limits, searching for sources of lift further than they would with a traditional sailplane, knowing they have a reserve to return to the nearest airfield.

Case	Description	Market Size	Unit Cost (2024 USD)
RFP Low	Electric Sailplane Trainer: 500 25% → 125	125	$301,000
RFP Medium	Electric Sailplane Trainer: 500 50% → 250	250	$212,000
RFP High	Electric Sailplane Trainer: 500 75% → 375	375	$175,000
RFP (Low) + GA + LSA	Electric Sailplane Trainer: 500 25% → 125 General Aviation: 28,986 3% → 870 Light Sport Aircraft: 3,332 5% → 167	1162	$98,000

KPP	Threshold	Objective	Swift	Taurus	Elektra Trainer
Operational Cost Per Instructional Flight	<$50/flight	$20/flight	**$8.10/flight**	$25/flight	$34/flight
Unit Cost	**$300,000**	**$100,000**	**$98,000**	**$200,000**	**$225,000**
Flights Per 6 Hours	6	18	**10**	-	-
Sink Rate @ 250 ft Turn	250 ft/min	175 ft/min	**193 ft/min**	138 ft/min	~140 ft/min
Airspeed @ L/D = 25	45 kts	70 kts	**50 kts**	82 kt	65 kts
Annual Total Ownership Cost (600 Flights)	-	-	**$23,821**	$14,000	$21,000
Climb Altitude On One Charge	2,500 ft	10,000 ft	**16,000 ft**	- ft	- ft
Self-Retrieve Range	50 km	200 km	**176 km (268 with optional battery)**	- km	300 km

By complying with Fédération Aéronautique Internationale (FAI) Gliding Commission's 15 Meter Class and Two-Seater Class regulations, the Swift enables more experienced sailplane pilots to compete in championships worldwide. The Swift also **complies with FAA Light Sport Aircraft (LSA) regulations**.

Nomenclature

α = Angle of Attack
b = Wingspan
β = Sideslip
c = Chord
$\bar{c}$ = Mean Aerodynamic Chord
C_D = Drag Coefficient
C_{D_i} = Induced Drag Coefficient
C_{D_0} = Parasitic Drag Coefficient
C_H = Tail Volume Coefficient
C_l = 2-Dimensional Lift Coefficient
C_L = 3-Dimensional Lift Coefficient
C_{L_α} = Lift Curve Slope
C_{l_β} = Coefficient of Wing Dihedral Effect
$C_{l_{\delta r}}$ = Rolling Moment Response to Elevator Deflection
C_{l_p} = Rolling Moment Response to a Change in Roll Rate
C_{l_r} = Rolling Moment Response to a Change in Yaw
C_M = Pitching Moment Coefficient
$C_{M_{cg}}$ = Moment Coefficient about the Center of Gravity
C_{m_α} = Pitching Moment Response to Change in Angle of Attack
$C_{m_{\delta e}}$ = Pitching Moment Response to Elevator Deflection
C_{n_β} = Coefficient of Lateral Stability
C_{n_p} = Yawing Moment Response to a Change in Roll
C_{n_r} = Yawing Moment Response to a Change in Yaw
$C_{n_{\delta r}}$ = Yawing Moment Coefficient of Rudder Control Power
C_r = Root Chord
C_t = Tip Chord
C_V = Tail Volume Coefficient
C_{y_β} = Side Force Response to a Change in Sideslip
C_{y_p} = Side Force Response to a Change in Roll
δ = Deflection
ϕ = Bank Angle
γ_{Glide} = Glide Angle
γ_{Climb} = Climb Angle
$\gamma_{Descent}$ = Descent Angle
h_f = Flare Height
λ = Taper Ratio
Λ = Sweep
$\Lambda_{c/4}$ = Quarter Chord Sweep
L/D = Lift to Drag Ratio
r = Turn Radius
R = Thermal Max Radius
Re = Reynolds Number
S_A = Approach Distance Landing
S_{BR} = Braking Distance Landing
S_{Climb} = Climb Distance Take-Off
S_F = Flare Distance Landing
S_{FR} = Free Roll Landing
S_h = Horizontal Tail Area
S_{LOF} = Rotation Distance Take-Off
S_{ref} = Planform Wing Area
S_{TR} = Transition Distance Take-Off
S_v = Vertical Tail Area
t/c = Thickness to Chord Ratio
V_2 = Climb Velocity
V_{BA} = Best Sink Rate Airspeed
V_{BG} = Best Glide Airspeed
V_{Stall} = Stall Speed
V_{SC} = Sink Rate in Steady Turn
V_T = Thermal Velocity
V_{TO} = Max Thermal Velocity
V_{LOF} = Rotation Speed
V_i = Iterative Velocity

Compliance Matrix

Req #	Requirement Statement	Status	Section #
T 0.0-1	The aircraft shall be capable of completing the Design reference Instructional Flight where total pilot weight is 400 lbs, Airport elevation of 1,000 ft above sea level, ISA +10C, and Runway surface is cut grass.	Met	2.2
T 0.0-2	The aircraft shall taxi to the end of runway with motor on in 2 minutes at a speed less than 10 knots.	Met	2.2, 2.3
T 0.0-3	The aircraft shall have a climb rate greater than 600 ft/min at a speed between 1.3 Vso and 80 knots.	Met	2.2, 2.3
T 0.0-4	The aircraft shall be capable of completing the self-retrieve flight beginning with a self-launch and includes 30 minutes of soaring flight before the glider is unsuccessful in finding atmospheric lift to continue soaring flight and must use motor power to "self-retrieve".	Met	2.3
T 0.0-5	During descent the aircraft must cover a distance of at least 50 km, ending at an altitude at least 1000 feet above the airport	Met	2.3
T 0.0-6	The aircraft shall meet applicable certification rules in FAA 14 CFR Part 21, AC 21.17-2A (with JAR-22 replaced by CS-22), and CS-22 with Special Condition SC 22.2014-01.	Met	1.2
T 0.0-7	The aircraft should be capable of three design reference instructional flights without charging or changing batteries.	Met	11.3
M 0.0-1	All cost, life, performance, etc. analysis shall be done using a mission utilization spectrum at the conditions described above for each mission, including 600 instructional flights	Met	13.3
M 0.0-2	All cost, life, performance, etc. analysis shall be done using a mission utilization spectrum at the conditions described above for each mission, including 10 self-retrieves per year.	Met	13.3
T 0.0-8	In gliding flight, the aircraft should achieve a lift-to-drag ratio of at least 30:1 at an indicated airspeed speed not slower than 50 kt.	Met	9.1.1
T 0.0-9	The aircraft shall be operable in conditions colder than -15 deg C and warmer than 50 deg C surface temperature in full sun.	Met	9.3.5
T 0.0-10	The aircraft shall have a service ceiling at or above 14,000 ft MSL.	Met	9.1.5
T 0.0-11	The aircraft shall have a wingspan of ≤ 20 m.	Met	8.1
T 0.0-12	The aircraft should store in a hangar bay 9 m long and 18 m in span, configuration changes required to store the aircraft (i.e. removal of wing tips) should be accomplished by one person in less than 5 minutes.	Met	8.1
T 0.0-13	The aircraft shall be able to be assembled or disassembled by three people with simple mechanical aids in 30 minutes.	Met	11.2
T 0.0-14	The aircraft should be able to be assembled or disassembled by two people with simple mechanical aids in 15 minutes.	Met	—
T 0.0-15	All control connections shall connect automatically during assembly and disconnect automatically during disassembly.	Met	11.2
T 0.0-16	The disassembled aircraft shall fit into a box with dimensions of 35 feet x 6 feet x 6 feet.	Met	11.1
T 0.0-17	If batteries are to be removed for charging, removal and reinstallation shall require less than 15 minutes.	Met	11.3
T 0.0-18	If batteries are to be removed for charging, removal and reinstallation should require less than 5 minutes	Met	

Req #	Requirement Statement	Status	Section #
T 0.0-14	In any attitude supported by the landing gear, the flight controls shall not contact the ground at any deflection angle permitted by the control stops	Met	8.8
T 0.0-15	In a wings-level attitude the lowest point on the wingtips shall not be less than 3 feet above the ground.	Met	8.8
T 0.0-16	Configuration changes required to transition between gliding to powered flight or powered flight to gliding shall be accomplished via a single control action (i.e. a switch).	Met	8.10
T 0.0-17	During the transition between gliding and powered flight the aircraft shall not descend more than 250 feet.	Met	10.3.2
T 0.0-18	During the transition between gliding and powered flight the aircraft should not descend more than 100 feet.	Met	10.3.2
T 0.0-19	With the propulsion system in the launch configuration but without the motor operating (representing a failure to retract) the aircraft shall have a glide ratio greater than 15:1.	Met	9.1.1
T 0.0-20	The aircraft should be capable of launching via winch or aerotow.	Met	9.2.5
M 0.0-3	The aircraft entry into service shall be 2030 or sooner.	Met	9.3, 8.10
M 0.0-4	Use systems/technologies shall reflect a technology level which could be certified by 2029, at least a year prior to the airplane EIS.	Met	9.3.1, 9.3.4, 8.10
M 0.0-5	Assumptions on at least specific fuel consumption/efficiency, thrust/power and weight must be documented.	Met	9.3.1-9.3.4
M 0.0-6	Engine/propulsion system assumptions documented	Met	9.3.1, Appx. A
T 0.0-21	In any attitude supported by the landing gear, the flight controls shall not contact the ground at any deflection angle permitted by the control stops	Met	8.8
T 0.0-22	In a wings-level attitude the lowest point on the wingtips shall not be less than 3 feet above the ground.	Met	8.8
T 0.0-23	Configuration changes required to transition between gliding to powered flight or powered flight to gliding shall be accomplished via a single control action (i.e. a switch).	Met	8.10
T 0.0-24	During the transition between gliding and powered flight the aircraft shall not descend more than 250 feet.	Met	10.3.2
T 0.0-25	During the transition between gliding and powered flight the aircraft should not descend more than 100 feet.	Met	10.3.2
T 0.0-26	With the propulsion system in the launch configuration but without the motor operating (representing a failure to retract) the aircraft shall have a glide ratio greater than 15:1.	Met	9.1.1
T 0.0-27	The aircraft should be capable of launching via winch or aerotow.	Met	9.2.5
M 0.0-3	The aircraft entry into service shall be 2030 or sooner.	Met	9.3, 8.10
M 0.0-4	Use systems/technologies shall reflect a technology level which could be certified by 2029, at least a year prior to the airplane EIS.	Met	9.3.1, 9.3.4, 8.10
M 0.0-5	Assumptions on at least specific fuel consumption/efficiency, thrust/power and weight must be documented.	Met	9.3.1-9.3.4

Req #	Requirement Statement	Status	Section #
M 0.0-6	Engine/propulsion system assumptions documented	Met	9.3.1, Appx. A
M 0.0-7	Use of electric motor(s), controller(s) and batteries which could be in service by 2029 and document battery energy and power density assumptions based on reasonable technology trends.	Met	9.3, Appx. A
M 0.0-8	Document system efficiency including at least the efficiency of the batteries, wires, controllers, thermal management system, connectors, motors and propellers to calculate a total propulsive efficiency.	Met	9.3.1,9.3.4,9.3.5
T 0.0-28	The aircraft shall be capable of being operated by a single pilot at the solo stage of flight training.	Met	8.2
T 0.0-29	The aircraft shall be equipped with two crew stations with a complete set of controls (including propulsion) available at each.	Met	
T 0.0-30	The aircraft shall be capable of being operated with both crew stations occupied.	Met	
T 0.0-31	The crew stations shall be designed for a minimum pilot weight of 90 lbs. or less	Met	8.6.1
T 0.0-32	The crew stations shall be designed for a maximum pilot weight of 270 lbs. or more	Met	8.6.1
T 0.0-33	The crew stations shall be designed to accommodate 5th percentile or smaller and 95th percentile or larger dimensions	Met	8.2
T 0.0-34	The aircraft should be capable of being operated by Single pilot in one of the two crew stations meeting the weights described above	Met	8.6.1
T 0.0-35	The aircraft should be capable of being operated by Both crew stations simultaneously occupied Crew who both weigh 90 lb. or less	Met	8.6.1
T 0.0-36	The aircraft should be capable of being operated by Both crew stations simultaneously occupied Crew who both weigh 270 lb. or more	Met	8.6.1
T 0.0-37	A proportional throttle control shall be installed.	Met	8.2
T 0.0-38	Removable ballast required to achieve a safe CG with the range of pilot weights specified shall be rigidly affixed to the aircraft structure and be inspected, installed, and removed without tools by a single person in less than 5 minutes.	Met	8.6.1
T 0.0-39	The aircraft shall be capable of completing the Design reference Instructional Flight where total pilot weight is 400 lbs, Airport elevation of 1,000 ft above sea level, ISA +10C, and Runway surface is cut grass.	Met	2.2
T 0.0-40	The aircraft shall taxi to the end of runway with motor on in 2 minutes at a speed less than 10 knots.	Met	2.2, 2.3
T 0.0-41	The aircraft shall have a climb rate greater than 600 ft/min at a speed between 1.3 Vso and 80 knots.	Met	2.2, 2.3
T 0.0-42	The aircraft shall be capable of completing the self-retrieve flight beginning with a self-launch and includes 30 minutes of soaring flight before the glider is unsuccessful in finding atmospheric lift to continue soaring flight and must use motor power to "self-retrieve".	Met	2.3

T 0.0-43	During descent the aircraft must cover a distance of at least 50 km, ending at an altitude at least 1000 feet above the airport	Met	2.3

Report and Design Data Requirements

Req #	Requirement Statement	Status	Section #
R 0.0-1	A complete Design and Performance Summary Table/Mission Tables as provided in Appendix A.	Met	Appendix A
R 0.0-2	A description of the design missions defined for the proposed concepts for use in calculations of mission performance as per design objectives. This includes the selection of the parameters not otherwise specified in the reference mission profiles supported by pertinent trade analyses and discussion.	Met	1.2, 7.0, 10.0
R 0.0-3	Aircraft performance summaries shall be documented for each reference mission and the aircraft flight envelope shall be shown graphically	Met	9.1.5
R 0.0-4	A V-n diagram for the aircraft with identification of necessary aircraft velocities and design load factors.	Met	9.4.1
R 0.0-5	A diagram of indicated airspeed vs descent rate ("speed polar") in the gliding configuration.	Met	10.3.2
R 0.0-6	Materials selection for main structural groups and general structural design, including layout of primary airframe structure as well as the strength capability of the structure and how that compares to what is required at the ultimate load limits of the aircraft. The maximum dive speed of the aircraft shall be specified.	Met	9.4.4
R 0.0-7.0	Complete geometric description, including dimensioned drawings, control surfaces sizes and hinge locations, and internal arrangement of the aircraft illustrating sufficient volume for all necessary components and systems	Met	8.2, 8.4, 8.5
R 0.0-7.1	Scaled three-views (dimensioned) and 3-D model imagery of appropriate quality are expected. The three-view must include at least: i. Fully dimensioned front, left, and top views ii. Location of aircraft aerodynamic center (from nose) iii. Location of average CG location (relative to nose) iv. Tail moment arms	Met	8.2
R 0.0-7.2	Diagrams and/or estimates showing that internal volume requirements are met for the crew/baggage. i. Cross-section showing seats ii. Layout of cockpit and size/location of doors or canopies iii. Fuselage centerline diagram	Met	8.3
R 0.0-7.3	Diagrams showing the location and functions for all aircraft systems	Met	8.2
R 0.0-8	Important aerodynamic characteristics and aerodynamic performance for key mission segments and requirements	Met	9.1
R 0.0-9.0	Aircraft weight statement, aircraft center-of-gravity. Establish a forward and aft center of gravity (CG) limit for safe flight.	Met	8.11, 11.2

R 0.0-9.1	Weight assessment summary shall be shown at least at the following level of detail: i. Propulsion ii. Airframe Structure iii. Control system iv. Payloads v. Systems	Met	8.11
Req #	Requirement Statement	Status	Section #
R 0.0-9.2	A diagram depicting the safe center of gravity envelope with weight of each crew member, including a diagram for any removable ballast and the constraint which limits the safe CG range. For example:	Met	8.8.1
R 0.0-10.0	Propulsion system description and characterization including performance, dimensions, and weights. The selection of the propulsion system(s), sizing, and airframe must be supported by analysis, trade studies, and discussion.	Met	9.3.2
R 0.0-10.1	Breakdown of the battery system to include metrics (at least specific energy and power densities) at the cell level and pack/system level, and also include a technical overview of pack integration strategies.	Met	9.3.4
R 0.0-11	Summary of basic stability and control characteristics; this should include, but is not limited to static margin, pitch, roll and yaw derivatives.	Met	9.2
R 0.0-12.0	Summary of cost estimate and a business case analysis. This assessment should identify the cost groups and drivers, assumptions, and design choices aimed at the minimization of production costs.	Met	13.2
R 0.0-12.1	a. Estimate the non-recurring development costs of the airplane including engineering, FAA/EASA certification, production tooling, facilities and labor. b. Estimate the fly away cost. c. Estimate the price to generate at least a 15% profit i. Show how the airplane could be produced profitably at production rates ranging from 3-6 airplanes per month or a rate that is supported by a brief market analysis. d. Estimate of direct operating cost per airplane flight hour i. Tires, brakes, battery, and other consumable quantities ii. Estimate of maintenance cost per flight hour	Met	13.2.1, 13.2.2, 13.2.3, 13.3

Special Considerations

Req #	Requirement Statement	Status	Section #
S 0.0-1	The proposal should identify all systems functionality and components that are required for the aircraft to operate in both controlled and uncontrolled airspace.	Met	2.1
S 0.0-2	The proposal should list the equipment required.	Met	2.1, 8.3
S 0.0-3	The proposal should consider what features will be basic and which will be optional to a customer	Met	2.3, 13.2.3
S 0.0-4	The proposal should minimize production cost by choosing materials and manufacturing methods appropriate for the annual production rate that is supported by the team's assessment of the potential market size	Met	8.10, 9.4.4, 13.2
S 0.0-5	The aircraft should be visually appealing so it will be marketable and the proposal shall identify what features are important to the operators for different missions.	Met	8.2

S 0.0-6	The aircraft reliability should be equal or better than that of comparable aircraft.	Met	8.1
S 0.0-7	The aircraft maintenance should be equal or better than that of comparable aircraft.	Met	11.4

1.0 Mission Needs

There are two primary missions detailed in the American Institute of Aeronautics and Astronautics (AIAA) Electric Training Sailplane request for proposal (RFP), an instructional flight and a self-retrieve flight. The goal of the instructional flight mission is to provide training to new glider pilots, teaching how to take-off, climb, shut-off engines, glide while unpowered, and land. In the self-retrieve flight mission, experienced pilots learn how to ride thermals, ridges, and waves to climb before returning to the field using motor power. This mission also fits pilots flying recreationally and for gliding competitions.

1.1 RFP Needs and Goals

There is a growing popularity of self-propulsion in the sailplane market due to their ability to take-off without needing winches and towplanes at fields, while the goal of applying electrical propulsion technologies to sailplanes is to simplify propulsion systems, improve reliability, and to reduce maintenance costs. Sailplanes are also becoming more popular for recreational flights due to low acquisition and operations costs, with estimations of more than 500 new glider pilots every year. For these reasons, the Electric Training Sailplane RFP from AIAA seeks a low-cost electric self-launch sailplane suitable for training and recreational flying.

1.2 Key Requirements

The Glydetek electric sailplane trainer, Swift, is designed to enter into service by 2030 to complete instructional and self-retrieve flight missions. It can also disassemble into a 35x6x6 feet box by three people with simple mechanical aids in 30 minutes (Sec 11.2). The assembled aircraft can be stored in a hanger sized 9 meters by 18 meters in span with no modifications. The crew stations are designed to accommodate 90 lbs. or less and 270 lbs. or more, with a removable ballast to maintain proper CG (Sec 8.8.1). The Swift is equipped for visual flight rules (VFR) day flight and meets certification rules compliant with FAA 14 CFR Part 21, AC 21.17-2A, and CS-22 with Special Condition SC-22.2014-01. FAA 14 CFR Part 21 is a set of regulations from the United States Federal Aviation Administration (FAA), the AC 21.17-2A is an FAA advisory for certification of powered sailplanes, and CS-22 contains European certification of electric propulsion units in sailplanes. The aircraft is designed to meet all threshold key performance parameter (KPP) requirements and is optimized using cost/benefit function to achieve objective goals in the RFP, as seen in Table 1.2.1 and Sec 7.2.

Table 1.2.1: KPP Table with Exceeding Objective Parameters

KPP	Threshold	Objective	Parameters
Operational Cost Per Instructional Flight	<$50/flight	$20/flight	**$21/flight**
Unit Cost	$300,000	$100,000	**$98,000**
Flights Per 6 Hours	6	18	**10**
Sink Rate @ 250 ft Turn	250 ft/min	175 ft/min	**193** $\frac{ft}{min}$
Airspeed @ L/D = 25	45 kts	75 kts	**50 kts**
Annual Total Ownership Cost (600 Flights)	-	-	**$23,821**
Climb Altitude On One Charge	2,500 feet	10,000 feet	**16,000 ft**
Self-Retrieve Range	176 km	200 km	**176 km (268 km with optional battery)**

2.0 CONOPS and Mission Profile

The Swift is capable of self-propelled, winch tow, or aerotow take-offs, and can complete both instructional and self-retrieve missions. The cockpit features a built-in radio using very high frequency (VHF), Automatic Dependent Surveillance-Broadcast (ADS-B) mode-S transponder, and flight alarm (FLARM) for local air traffic. The aircraft uses a 45 kW REB 60 electric motor to perform self-propelled take-offs and climbs, while its design allows the Swift to reach a max L/D of 28.2. Coupled with a 68.8 $lbs.$ ***main battery and the optional installation of a 68.8*** $\mathrm{lbs.}$ ***battery in the nose, the aircraft satisfies key RFP mission requirements by reaching a climb rate of 600*** $\frac{ft}{min}$***, maximum range of 162 miles, and 10 minutes flight endurance without power or thermals from requirement 0.0-32.***

2.1 Concept of Operations

The Swift's cockpit accommodates a suite of modular electronic equipment, including a built-in radio system that uses VHF signals to communicate with local air traffic, winch and aerotow launch operators, and air traffic control when needed, as noted in figure 2.1.1, the concept of operations (CONOPs). The aircraft is also fitted

with an ADS-B transponder and FLARM system to warn pilots of an impending collision. FLARM is a special lower power consumption system specially designed for gliders and acts like a traditional Traffic Collision Avoidance System (TCAS). However, since gliders can safely operate in closer proximity in the air than commercial aircraft, FLARM takes that into account when sending alerts to its pilots. These features can be seen in sections 8.3 and 8.12.

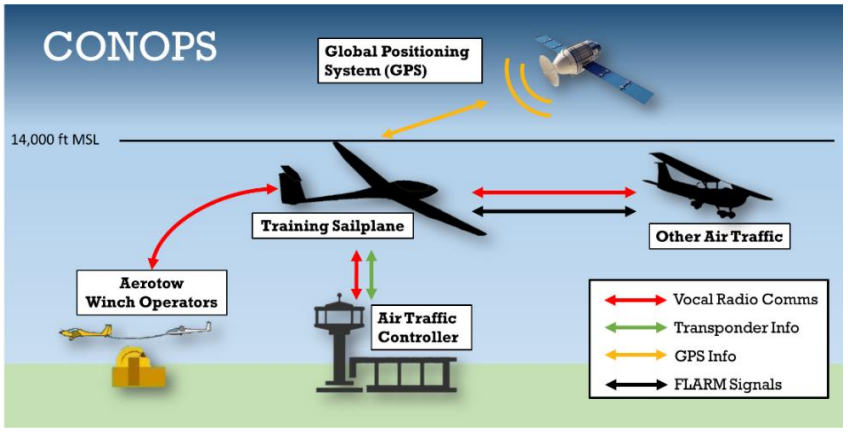


Figure 2.1.1: Concept of Operation

2.2 Instructional Flight

In both instructional and self-retrieve flight missions, performance values provided are from the Swift at ISA +10 °C and 1,000 ft MSL conditions. As seen in Table 2.2.1, the Swift satisfies the climb rate requirement of greater than 600 $\frac{ft}{min}$ within the speed range requirement of 1.3 times stall speed and 80 knots during climb segment 3 (Sec 10.0). Figure 2.2.1 visualizes such a mission with numbered transition points, showing the aircraft's time and altitude in feet AFE at every segment.

Table 2.2.1: Instructional Flight Mission

Segment	Motor On?	Segment Time (min)	Speed (kts)	Altitude (ft)	Vertical Speed (ft/min)
Taxi to end of runway	Yes	2 mins	<10 kts	Airport elevation	N/A
Takeoff	Yes	0.5 mins	55.3	Airport elevation	562
Climb	Yes	5 mins	70 kts	Constant climb to motor shutdown	600 $\frac{ft}{min}$
Shutdown	No	0 mins	N/A	2,500 ft above airport elevation	N/A
Descent	No	10 min	70 kts	Constant descent from shutdown	-243 $\frac{ft}{min}$
Landing	No	3 min	50 kts	Airport elevation	-265 $\frac{ft}{min}$

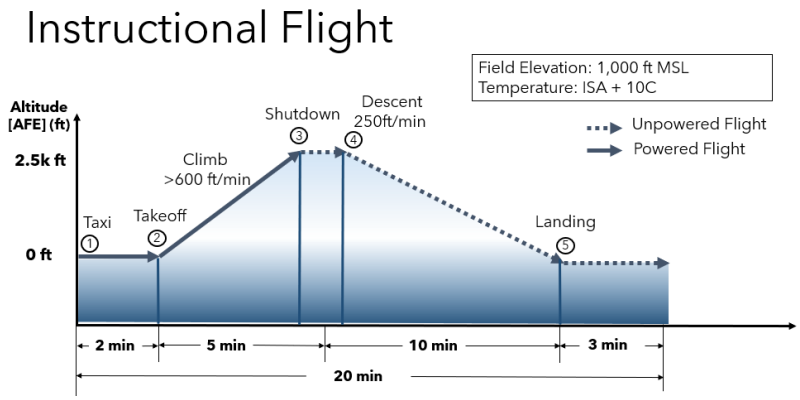


Figure 2.2.1 Instructional Flight Mission Profile

2.3 Soaring/Cross-Country Self-Retrieve

For the self-retrieve flight, the first four segments are the same, as seen in Table 2.3.1. The Swift satisfies the minimum range of 50 kilometers and minimum altitude requirements T 0.0-35 during cruise-climb segment 6 and descent segment 8. This is represented in Figure 2.3.1, where the mission is estimated to take 80 minutes.

Table 2.3.1: Self-Retrieve Flight Mission

Segment	Motor On?	Segment Time (min)	Speed (kts)	Altitude (ft)	Vertical Speed (ft/min)
Taxi to end of runway	Yes	2 mins	<10 kts	Airport elevation	N/A
Takeoff	Yes	0.5 mins	55.3	Airport elevation	562
Climb	Yes	5 mins	70 kts	Constant climb to motor shutdown	600 $\frac{ft}{min}$
Shutdown	No	0 min	N/A	2,500 ft AFE	N/A
Soaring Flight	No	30 min	48 knots	Various	-194$\frac{ft}{min}$
Climb	Yes	10 min	70 kts	Begins 1000 feet AFE and ends at 2000 ft AFE	100$\frac{ft}{min}$
Cruise-Climb	Yes	30 min	50 knots	2000 feet AFE	100 $\frac{ft}{min}$
Shutdown	No	0 min	N/A	2000 feet AFE	N/A
Descent	No	4 min	70 knots	1000 feet AFE	-243$\frac{ft}{min}$

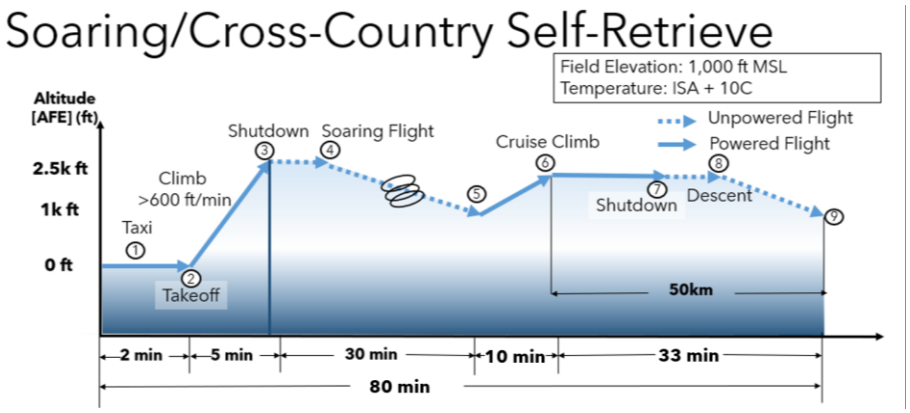


Figure 2.3.1: Cross Country Self Retrieve Flight Mission Profile

3.0 Market Analysis

The 2024 AIAA graduate request for proposal highlights an inadequacy of self-launched electric sailplanes in the market. The ability to self-launch with an electric propulsion system allows such an aircraft to operate from a less accessible field as well as providing additional safety measures for trainer missions. As the current operational sailplanes continue to age, battery technology improves, and demand for environmentally conscience platform increases, the ability for a new electric self-launched sailplane to enter the sailplane, general aviation, and light sport aircraft market grows.

3.1 Sailplane Market

Due to the growing capabilities and popularity of electric propulsion systems plus an aging population of training sailplanes and towplanes, there is ample opportunity to fill the growing gap in the market. Electric self-launching sailplanes have the potential to serve as a low-cost alternative to relatively costly aerotows while remaining environmentally friendly and low maintenance. This market opportunity coincides with the Federal Aviation Administration's (FAA) push for a clean Net-Zero carbon emission aviation system by 2050. The sailplane market, while already environmentally conscious, provides an excellent steppingstone for future net-zero technologies.

With 500+ new glider pilots joining annually, the electric sailplane market is primed to grow significantly in the following years. The 2024 AIAA Graduate RFP predicts a demand of 500 units for an electric sailplane training platform over the next 15 years.

"Market analysis suggests a total international market of 500 [electric self-launching training sailplane] aircraft over the next 15 years."

– 2024 AIAA Graduate RFP

With a generous market capture of 75% (375 units sold) of the electric self-launching training sailplane market, a program that only sells to this market would have to place a high markup on each sold unit and represent a reasonable net present value. Alternatively, if an aircraft could also be sold to alternative markets, the markup on each unit could be reduced to allow the acquisition cost of the plane to be vastly lowered to compete with existing alternatives more adequately.

3.2 General Aviation + Light Sport Aircraft Market

The General Aviation (GA) and Light Sport Aircraft (LSA) market are significant sources of potential demand for clean, sustainable, inexpensive training aircraft. Figure 3.2-1 General Aviation and Light Sport Aircraft Market Predictions shows data points coinciding with the sales numbers between 2009 and 2022[1]. The values have been extrapolated with conservative outlooks to approximate a market size between 2030 and 2045.

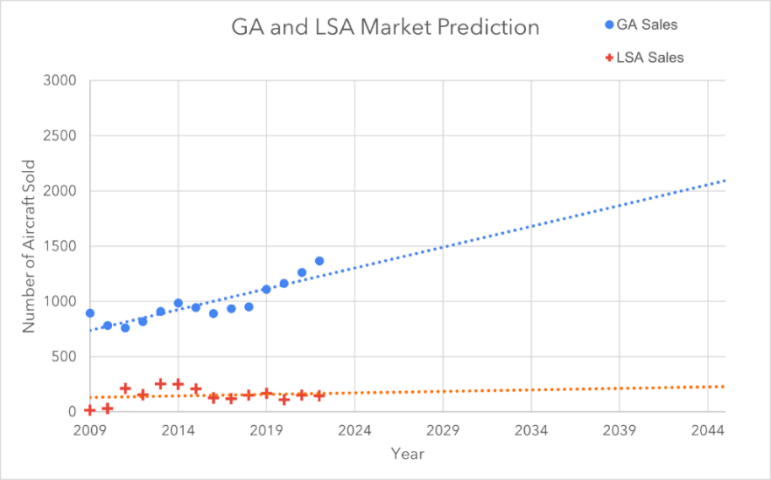


Figure 3.2.1 General Aviation and Light Sport Aircraft Market Predictions

With the FAA's finalization of the Modernization of Special Airworthiness Certification (MOSAIC) rules, the LSA market is expected to "grow at a CAGR of 5.21% to reach USD 1.49 billion by 2029"[21]. The sustained growth rate will yield an approximate LSA demand of 3,332 aircraft between the years 2030 and 2045. The relatively fragmented nature of the LSA market suggests the possibility of a higher potential market capture due to the unconsolidated nature of the space.

Due to the appeal of an ecofriendly electric aircraft with long range that is 14 CFR Part 23 certified, the Swift will very likely see a small market capture with its extended range variant.

Table 3.2-1 shows how the unit cost for the Swift aircraft addressable market size and capture assumptions. Section 13 of the business case provides a detailed explanation of the process used to produce these numbers.

Table 3.2-1 Market Case vs Unit Cost

Case	Description	Market Size	Unit Cost (2024 USD)
RFP Low	• Electric Sailplane Trainer: 500 • 25% → 125	125	$301,000
RFP Medium	• Electric Sailplane Trainer: 500 • 50% → 250	250	$212,000

RFP High	• Electric Sailplane Trainer: 500 • 75% → 375	375	$175,000

RFP (Low) + GA + LSA	• Electric Sailplane Trainer: 500
	  • 25% → 125
	• General Aviation: 28,986
	  • 3% → 870
	• Light Sport Aircraft: 3,332
	  • 5% → 167
		1162	$98,000

3.3 Market Competitors

As of May 2024, the Taurus Electro and Elektra Trainer are the primary electric self-launched trainer sailplane market competitors. Both aircraft meet all the set RFP thresholds (where data is available). The Taurus is notable in the market due to its low operational cost per flight, and the Elektra Trainer has a range of 300km, which comfortably exceeds the RFP set objective value of 200km.

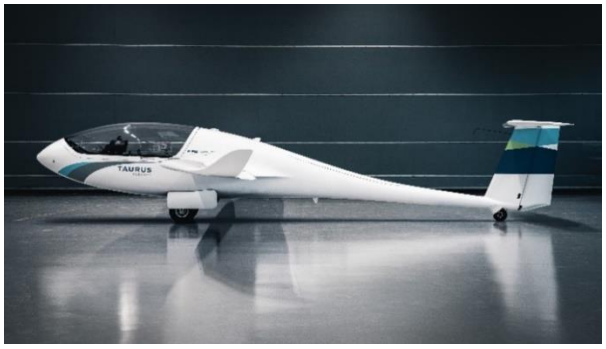


Figure 3.3.1: Taurus Electro

Figure 3.3.2: Elektra Trainer

Due to the capabilities of alternative aircraft within the market, a new aircraft entering the market must be capable of distinguishing itself from the competitors by vastly outperforming in a metric that is appealing to the customer, such as cost or self-retrieve range. Throughout Swift's design, efforts were made to minimize the acquisition cost, while maximizing the KPP benefits of the aircraft. Such an aircraft would be the primary option for glider flight schools and recreational pilots and thus hold a majority market capture.

4.0 Initial Sizing

4.1 Constraint Diagram

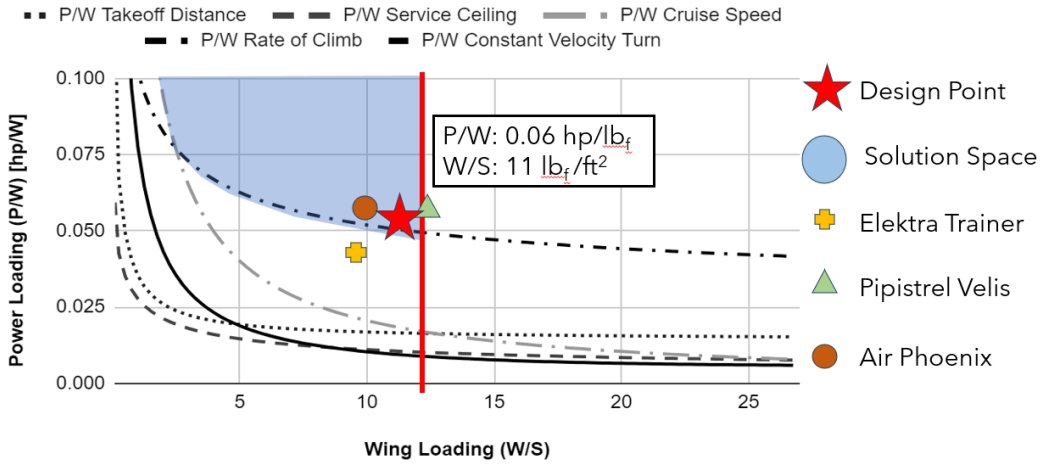


Figure 4.1.1 - Powered Constraint Diagram

An assessment of the design requirements yielded the Constraint Diagram seen in Figure 4.1.1, constructed as per the methods described in Gudmundsson[30] for propeller-driven aircraft. The performance requirements established in 14 CFR Part 23, along with those given in the RFP were used to generate the applicable design curves. The generated design space, seen in blue, is constrained by Takeoff Distance, Service Ceiling, Cruise Speed, Rate of Climb, Constant Velocity Turn, and Braking Distance requirements. The most critical requirements binding the design space, primarily the Rate of Climb, Cruise Speed, and Braking requirements, drive the selection of the design point, highlighted in the figure. The lower bound of the design requirements, the Rate of Climb (ROC) requirement becomes the most stringent sizing case over most of the design space due to the considerations taken for atmospheric conditions at +10˚ C ISA. The minimum weight solution, with a 10% margin, lies at a Wing Loading (W/S) of 11 lb/ft^2, and a Power-to-Weight Ratio of 0.06 hp/lb. Adjustments towards a lower Wing Loading would necessitate an increase in Power Loading of the design point, yielding additional challenges relating to the wing area (encountering constraints in the wingspan of the vehicle) as well as technological challenges with modern electric propulsion systems. The selected design point is proximate to numerous similar electric training aircraft, including the Elektra Solar's "Trainer"[10], Pipistrel's "Taurus Electro"[32], as well as Phoenix's "Air Phoenix". The proximity of the design point is listed in Table 4.1.1.

Table 4.1.1: Design Point and Proximate Design Comparison

Vehicle	Wing Loading (W/S)	Power Loading (P/W)	Wing Loading Difference (%)	Power Loading Difference (%)
Design Point	11.0 lb/ft^2	0.06 hp/lb		
Elektra Trainer	13.1 lb/ft^2	0.047 hp/lb	17.43%	24.3%
Velis Electro	12.92 lb/ft^2	0.058 hp/lb	16.05%	3.39%
Air Phoenix	9.94 lb/ft^2	0.0605 hp/lb	10.12%	0.83%

In addition to the traditional Constraint Diagram, Gudmundsson's text[30] recommends an approximate method unique for sailplanes to relate wing loading to the design's max L/D ratio by setting expectations for the minimum drag coefficient ($C_{D_{min}}$) and Oswald's efficiency factor (e). By varying aspect ratio (AR), the team can find the optimal combination of AR and wing loading to reach a target max L/D. This approach is coupled with minimum sink rate airspeed (V_{BA}) and best glide airspeed (V_{BG}), the importance of which will be elaborated upon in section 10.3.2. The intersection between V_{BA} and V_{BG} lines of the same AR gives the required wing loading and max L/D capable at that AR, V_{BA}, and V_{BG}. The team also added constraint lines to the design based on required max lift coefficients ($C_{L_{Max}}$) for a desired stall speed to constrain the design even further, as seen in Figure 4.1.2. The assumed $C_{D_{min}}$ was 0.01 and e was 0.95, while desired V_{BA} and V_{BG} were 45 kts and 70 kts respectively.

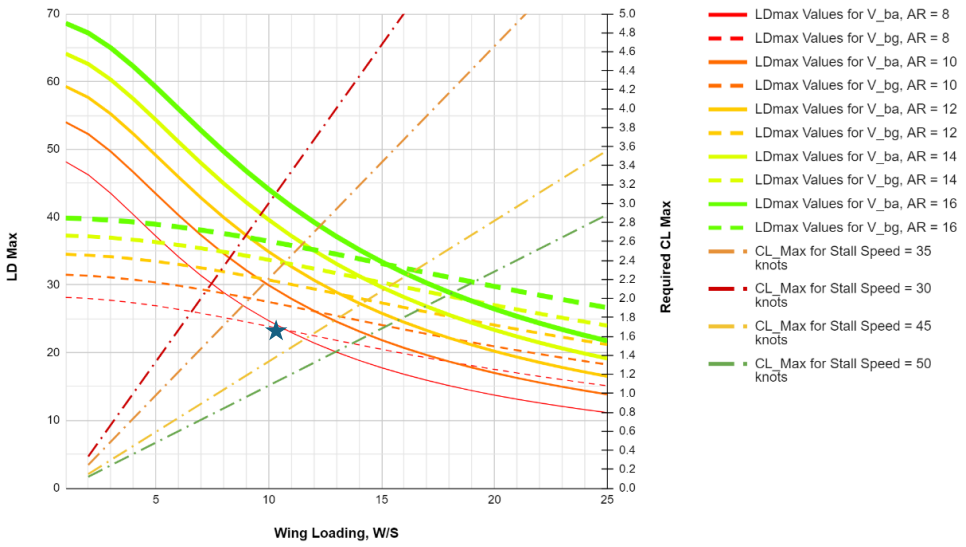


Figure 4.1.2: Sailplane Constraint Diagram and Max CL at Stall Speeds

Requirement T 0.0-3 dictates that the max L/D of the aircraft must be greater than 25. Using the wing loading from the first constraint diagram, 11, that point coincides with the V_{BA} and V_{BG} lines of AR equals 12, where the design point is marked by the blue star in Figure 4.1.2. This means that at a wing loading of 11 and AR of 12, the design will have a max L/D around 27 and achieve V_{BA} and V_{BG} were 45 kts and 70 kts respectively. Using the wing loading determined and the $C_{L_{Max}}$ line for 45 knots, which is the stall speed limit for light sport aircraft (LSA), the aircraft must have a $C_{L_{Max}}$ of 1.48.

5.0 Candidate Concepts Exploration

To achieve the most cost/benefit competitive new electric sailplane trainer, three distinctly different approaches were explored. Each concept was developed to the same fidelity level for the purpose of downselecting to the final concept to pursue for further design definition. Each concept details are tabulated throughout this section.

5.1 Condor

The Condor features a traditional designed aircraft with side-by-side seating, low wing, taildragger, and tractor propeller configuration. The construction is made of a cloth material called Ceconite and aluminum. The seating configuration allows easier instructor-trainee interactions for training effectiveness, while its traditional design and material choice lower the acquisition cost. Important dimensions of the Condor are listed in Table 5.1.1, where the max take-off weight is estimated through the sizing methods listed in section 4.2. The motor power and wing area was determined through the constraint diagram in section 4.1. The aspect ratio was determined in section 4.2, leading to the wingspan.

Table 5.1.1: The Max Take-Off Weight of the Condor is 1166 lbs.

MAJOR DIMENSIONS	
Max Take-Off Weight	1166 $lbs.$
Motor Power	60 kW
Battery Weight	137.5 $lbs.$
Aspect Ratio	14.5
Wingspan	60.8 ft
Wing Area	250 ft^2
Tip to Tail	28 ft
Height	10 ft
Tip-Back	8.9°

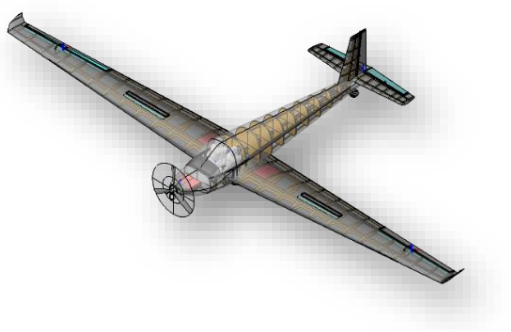


Figure 5.1.1: Condor Isometric View

Figure 5.1.2: Condor Cut Out

The traditional design of the Condor drives down acquisition cost to $216,000 while still satisfying the technical requirements and KPPs, as seen in Table 5.1.2, where important performance specifications are listed.

Table 5.1.2: The Acquisition Cost of the Condor at $216,000 is the Lowest of the Three Concepts

Condor Performance Specifications	
Speed at 25 L/D Ratio	66 knots
Max L/D Ratio	32.7
Acquisition Cost	$216,000
Climb Altitude on Single Charge	12,000 ft
Training Flights Per 6 Hours	10
Self-Retrieve Range	115 miles
Sink Rate in 250 ft Turn	185 $\frac{ft}{min}$

To accurately compare the Condor platform with the following candidates, a set production of 145 aircraft was used across all concepts with a 17% liability insurance and a markup of 15% per unit. This allowed for a simple cost comparison between platforms when down-selecting. A detailed look at the costing method can be found in 13.0 Business Case. The fly away cost of the Condor, with 145 units produced, is $146,811.

Table 5.1.3: Condor costs with 145 units produced.

Condor Costing Table		
Engineering	$2,875,839	Fixed Cost per Unit $14,226
Development Support	$70,415	
Flight Test	$226,801	
Tooling	$1,972,650	
Manufacturing	$17,067,300	Variable Cost per Unit $174,188
Quality Control	$1,109,374	
Materials	$2,384,751	
Vendor Supplied Components	$3,111,220	
Liability Insurance (17% of at cost price)	$4,062,609	
Markup		15% per unit
Final Sale Price per Unit		**$216,000**

5.2 Kingfisher

The Kingfisher is a high-wing taildragger with high tail tractor prop, akin to modern competitive sailplanes. Its tandem seating allows for a minimized drag profile and features a composite sandwich structure to reduce its empty weight. Important dimensions of the Kingfisher are listed in table 5.2.1. Like the Condor, the max take-off weight, the motor power, wing area, AR, and wingspan was determined through the constraint diagram in and methods outlined in 4.2.

Table 5.2.1: The Max Take-Off Weight of the Kingfisher is 1121 lbs.

MAJOR DIMENSIONS	
Max Take-Off Weight	1121.8 $lbs.$
Motor Power	50 kW
Battery Weight	137.5 $lbs.$
Aspect Ratio	19.6
Wingspan	59.4 ft
Wing Area	200 ft^2
Tip to Tail	28.6 ft
Height	11.1 ft
Tip-Back	9.5°

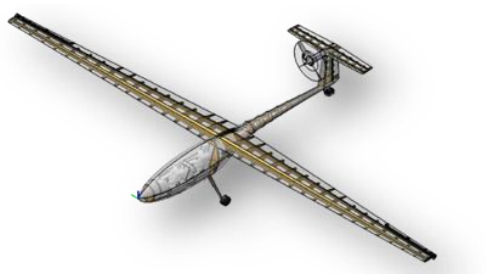


Figure 5.2.1: Kingfisher Isometric View

Figure 5.2.2: Kingfisher Cut Out

Table 5.2.2: The Max Take-Off Weight of the Kingfisher is 1121.8 lbs.

Kingfisher Performance Specifications	
Speed at 25 L/D Ratio	54 knots
Max L/D Ratio	34.6
Acquisition Cost	$287,000
Climb Altitude on Single Charge	13,200 ft
Training Flights Per 6 Hours	10
Self-Retrieve Range	190 miles
Sink Rate in 250 ft Turn	$214\frac{ft}{min}$

The design of the Kingfisher satisfies the thresholds of the technical requirements and KPPs, as seen in Table 5.2.2, where important performance specifications are listed. As mentioned in the Condor concept exploration, a set production and markup rate has been set to accurately compare the different concepts. A detailed look at the costing method can be found in 13.0 Business Case. The fly away cost of the kingfisher is $184,288.

Table 5.2.3: The Max Take-Off Weight of the Kingfisher is 1121.8 lbs.

Kingfisher Costing Table		
Engineering	$4,831,067	Fixed Cost per Unit $29,957
Development Support	$121,525	
Flight Test	$251,133	
Tooling	$4,217,790	
Manufacturing	$22,073,078	Variable Cost per Unit $219,504
Quality Control	$2,152,125	
Materials	$2,483,266	
Vendor Supplied Components	$2,993,268	

Liability Insurance (17% of at cost price)	$5,787,728	
Markup		15% per unit
Final Sale Price per Unit		**$287,000**

5.3 Albatross

The Albatross is a tricycle-geared pusher-driven tailless blended-wing-body (BWB) aircraft, enabling high-performance soaring capabilities while sustaining Level I handling qualities in all dynamic modes. Important dimensions of the Albatross are listed in table 5.3.1, like the other concepts the max take-off weight, the motor power, wing area, AR, and wingspan was determined through the constraint diagram in section 4.1 and methods outlined in 4.2.

Table 5.3.1: Albatross Major Dimensions

MAJOR DIMENSIONS	
Max Take-Off Weight	1165 $lbs.$
Motor Power	52 kW
Battery Weight	151.3 $lbs.$
Aspect Ratio	8.96
Wingspan	56 ft
Wing Area	350 ft^2
Tip to Tail	14.2 ft
Height	9.5 ft
Tip-Back	17.8°

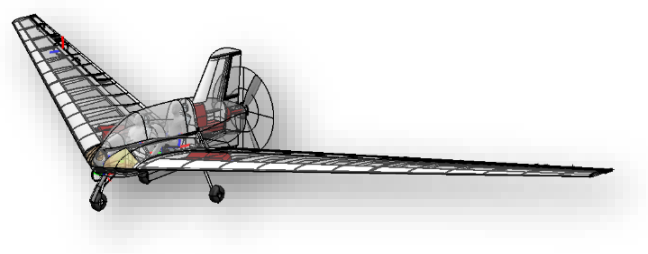


Figure 5.3.1: Albatross Isometric View

Figure 5.3.2: Albatross Cut Out

Table 5.3.2: Albatross Performance Specifications.

Albatross Performance Specifications	
Speed at 25 L/D Ratio	78 knots
Max L/D Ratio	30.4
Acquisition Cost	$289,000
Climb Altitude on Single Charge	16k ft
Training Flights Per 6 Hours	10
Self-Retrieve Range	192 mile
Sink Rate in 250 ft Turn	196 $\frac{ft}{min}$

The unconventional design of the Albatross allows it to satisfy the technical requirements and excel at most KPPs, as seen in Table 5.3.1, where important performance specifications are listed. As mentioned in the Condor candidate concept exploration, a set production and markup rate has been set to accurately compare the different concepts. A detailed look at the costing method can be found in 13.0 Business Case. The fly away cost of the albatross is $184,782.

Table 5.3.3: Albatross Costing Table

Albatross Costing Table		
Engineering	$4,859,052	Fixed Cost per Unit $29,990
Development Support	$122,812	
Flight Test	$248,876	

Tooling	$4,192,408	
Manufacturing	$21,938,403	Variable Cost per Unit $221,293
Quality Control	$2,138,994	
Materials	$2,475,071	
Vendor Supplied Components	$3,358,409	
Liability Insurance (17% of at cost price)	$5,824,094	
Markup		15% per unit
Final Sale Price per Unit		**$289,000**

6.0 Down-Select Criteria and KPPs

The architecture down-select criteria were derived from the Key Performance Parameters (KPPs), training viability factors, and Cost as an Independent Variable (CAIV) analysis to maximize performance and optimize cost. By combining traditional KPPs alongside additional training efficacy parameters, a perspective on the less directly quantitative aspects of functional and operational performance can be gleaned, yielding a design more suitable to its intended use case. Furthermore, the CAIV analyses show the relationship between performance and individual acquisition cost, providing an overarching perspective while also considering the lower-level acquisitions considerations of the consumer.

6.1 KPPs

Given three different sailplane designs, it was necessary to down-select and choose a final candidate. The down-select process requires appropriate down-select criteria to compare the three candidate aircraft, as well as compare those aircraft to the ones already available on the market. The RFP provided Key Performance Parameters [KPP's], which are listed in Table 6.1.1 below. KPP's are tailored to a specific mission/goal to compare how well an aircraft can fulfill all the requirements of that mission/goal. Since the final design is to be sold on the market, almost half the KPP's are related to cost. The rest of the KPP's are focused on performance characteristics that are crucial for sailplanes, such as sink rate in a turn or climb altitude on one charge.

6.1.1 TAB. KPPS

Table 6.1.1.1: Key Performance Parameters Required by the RFP

Operating cost per design reference instructional flight. Assume $0.1287/kWh US residential electricity average.	Minimize	<$50/flight	<$20/flight
Aircraft unit acquisition cost.	Minimize	<$300,000	<$100,000
Number of instructional flights which can be performed in 6 hours	Maximize	6	18
Minimum sink rate in a turn with radius of 250 feet (3000 feet MSL ISA+10C)	Minimize	250 ft / min	175 ft / min
Indicated airspeed at which a lift-to-drag ratio of 25 is achieved	Maximize	45 kt	70 kt
Total cost of ownership per year (600 flights).	Minimize	-	-
Climb altitude on one charge	Maximize	2500 feet	10,000 feet
Self-retrieve range	Maximize	50 km	200 km

6.2 Cost as an Independent Variable

Comparing KPP's is effective in assisting to select an aircraft from a few designs that are well-defined, however it does not consider the entire solution space available per the RFP. Therefore, to find other options it is necessary to perform other types of analysis. Cost as an independent variable [CAIV] is an analysis that considers the whole solution space as well as factors such as cost, schedule, performance, and risk. The analysis is based heavily on cost estimating relationships [CER's], which define the relationship between an aircraft's design parameters and the resulting cost. The CAIV analysis uses existing CER's to make new relationships that compare KPP's to cost. CAIV makes it possible to see the whole solution space on a per dollar basis. Using this analysis unlocks insights that result in potential Total Ownership Cost [TOC] savings.

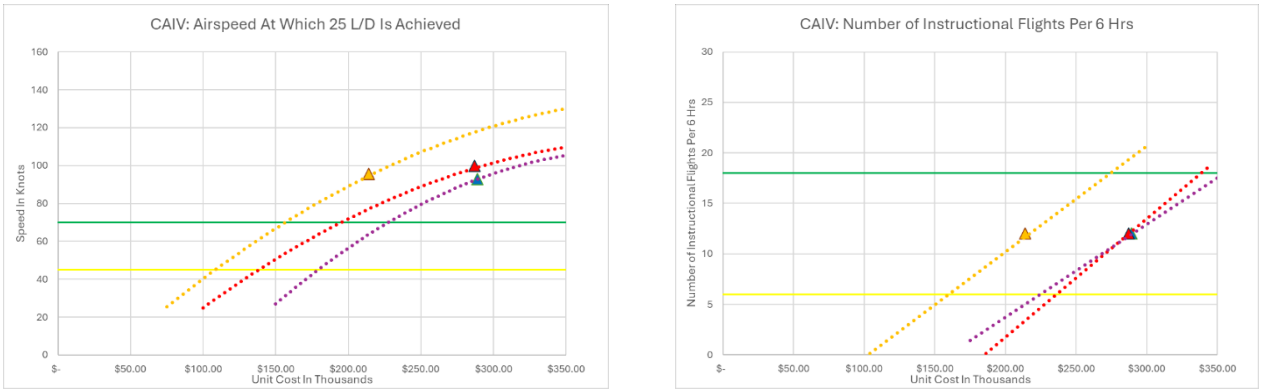
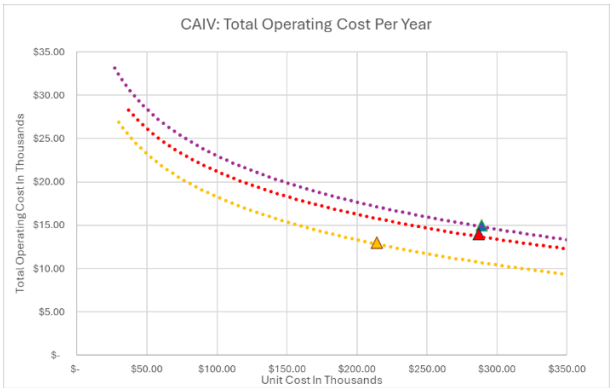


Figure 6.2.1: CAIV Analysis for L/D Airspeed & Instructional Flights



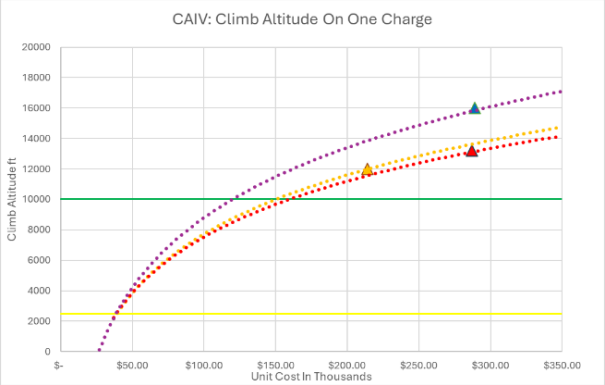


Figure 6.2.2: CAIV Analysis for Operating Cost & Climb Altitude

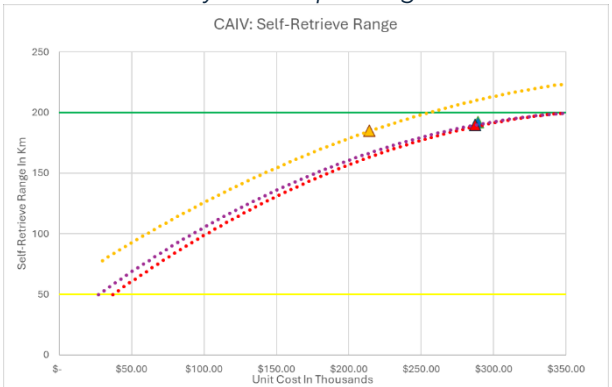


Figure 6.2.3: CAIV Analysis for Range

6.3 Trainer Viability

Per the RFP, one of the designed aircraft's main goals is to perform as a trainer aircraft. Therefore, it is important to consider how effective each design will be for a training mission. For example, a design that has both pilots sitting side-by-side, rather than front-and-back, would be more favorable for a training mission. This would favor Condor over Kingfisher or Albatross. The control aspects of the aircraft are also important to consider. An aircraft that has a more conventional design will be similar to most aircraft that trainees will be flying in the near future. However, if a trainee is learning on a blended-wing-body design, there will be control variances as they eventually transition to flying a more conventional aircraft. This would favor Condor and Kingfisher over Albatross.

6.4 Candidate Concepts Evaluation

6.4.1 Performance Versus Other Concepts

Given the KPP's and the results from the CAIV analysis, the down-select process was now well-defined. As mentioned previously, the KPP's are heavily focused on cost with about half of them being cost-related. As seen

in Table 6.4.1, Condor is cheaper than the Kingfisher and Albatross across the board, whether it be unit or operational costs. The CAIV analysis also demonstrated that certain performance characteristics of the designs were beyond the objective provided by the KPP's. Therefore, the solutions that were designed were in a high-cost trade space, where performance could be optimized to create a more cost-efficient design that would still meet the RFP requirements. As a result, Condor was chosen because it fulfilled the requirements while keeping costs low.

Table 6.4.1.1: Comparison of Designs

KPP	Threshold	Objective	Condor	Kingfisher	Albatross
Operational Cost Per Instr Flight	<$50/flight	$20/flight	$29/flight	$33/flight	$31/flight
Unit Cost	$300,000	$100,000	$214,000	$287,000	$289,000
Flights Per 6 Hrs	6	18	10	10	10
Sink Rate @ 250 ft Turn	250 ft/min	175 ft/min	197 ft/min	214 ft/min	196 ft/min
Airspeed @ L/D = 25	45 kts	70 kts	66 kts	54 kts	78 kts
Annual Total Ownership Cost	-	-	$23,600	$31,000	$30,800
Climb Altitude On One Charge	2,500 ft	10,000 ft	12,000 ft	13,200 ft	16,000 ft
Self-Retrieve Range	50 km	200 km	185 km	190 km	192 km

6.4.2 Performance Versus Existing Vehicles

The Condor design was a great choice as it met all the requirements while maintaining relatively low costs. However, it was also necessary to compare the Condor to existing electric, two-seater, training sailplanes. The comparison was done based on the same KPP's and the results are shown in Table 6.4.2. The Condor was compared against the Pipistrel Taurus [32]as well as the Solar Elektra Trainer. The Taurus has a lower operational cost and a much higher speed at which an L/D of 25 can be achieved. At the same time, the Solar Elektra Trainer has a range of 300 km[10], which is almost double that of the Condor. The Condor also has a significantly greater sink rate than the other two aircraft. Overall, even though the Condor meets all RFP requirements, it lacks performance and cost-efficiency compared to the Taurus and Elektra Trainer.

Table 6.4.1.2: Analysis of Alternatives

KPP	Threshold	Objective	Condor	Taurus	Elektra Trainer
Operational Cost Per Instr Flight	<$50/flight	$20/flight	$29/flight	$25/flight	$34/flight
Unit Cost	$300,000	$100,000	$214,000	$200,000	$225,000

Flights Per 6 Hrs	6	18	10	-	-
Sink Rate @ 250 ft Turn	250 ft/min	175 ft/min	197 ft/min	138 ft/min	~140 ft/min
Airspeed @ L/D = 25	45 kts	70 kts	66 kts	82 kt	65 kts
Annual Total Ownership Cost	-	-	$23,600	~$15,000	~$20,000
Climb Altitude On One Charge	2,500 ft	10,000 ft	12,000 ft	- ft	- ft
Self-Retrieve Range	50 km	200 km	185 km	- km	300 km

6.4.3 Down-Select Conclusion

Based on cost, performance, and training viability, the Condor was selected as the superior design. It met all threshold KPP values as well as maintaining low costs relative to the Kingfisher and Albatross. However, the analysis of alternatives pointed to the fact that the Condor was still too expensive and lacked performance compared to the Taurus and Elektra Trainer. The final design of this aircraft will enter the sailplane market. Glydetek will be competing for a market share within that sailplane market. If the Condor does not have any advantages over existing designs, then Glydetek will simply not have any sales nor market share. Therefore, it is imperative that a new design must be created that implements CAIV data and that has a clear advantage over sailplanes that are already on the market.

7.0 Analysis of Alternatives and MDO Approach

The defined selected concept, as drawn, needed to be redefined to satisfy CAIV results and be cost/benefit optimized to address the KPP objective values. Using Condor as the initial starting point, Multidisciplinary Design Optimization analysis (MDO) method was used to further refine and to define the optimized electric sailplane trainer, the Swift aircraft. The final results versus the KPP are shown in Table 7.1.

7.1 MDO Approach

The Cost as an Independent Variable (CAIV) analysis provided us with a high-level survey of the cost-performance design space, establishing performance thresholds and providing possible cost-performance tradeoffs. While flight performance metrics were satisfied within objective tolerances, the designed aircraft were not competitive when considering acquisition costs, costing 8% more than contemporary aircraft. This

poor value proposition suggested the need for an extensive redesign effort. Development of the Cal Poly Aircraft Design tool (CalPAD), a Multi-Disciplinary Analysis and Optimization tool, enabled automated rapid design space exploration to converge on a solution which met all performance requirements. Inputs for the program consist of an Objectives parameter list, a Constraints Parameter list, and the Design Parameters. The program uses a Genetic Algorithm to generate viable configurations within the design space, analyze their performance and constraint violation, and finally culls and mutates the most performant solutions. Lower order surrogate models are used in this process, due to the exponential computational complexity of higher order simulations for design space survey tasks. The 50 design parameters are listed in Table 7.1.1. 70 solutions are generated per generation, and design studies are typically run over 5,000 iterations, at which point the solutions are converged toward local optima.

Table 7.1.1: CalPAD Design Variable List and Description

CalPAD Program Design Variable Listing					
Variable		Parameter	Variable		Parameter
1	C_r	Root Chord of Main Wing (ft)	26	H_1	Height of 1st Cross Section
2	C_t	Tip Chord of Main Wing (ft)	27	H_2	Height of 2nd Cross Section
3	B	Wingspan (ft)	28	H_3	Height of 3rd Cross Section
4	Cl_r	Lift Coefficient of Root	29	H_4	Height of 4th Cross Section
5	Cl_t	Lift Coefficient of Tip	30	L_1	Length of 1st Cross Section
6	Le_swp	Leading Edge Sweep (deg)	31	L_2	Length of 2nd Cross Section
7	X_wing	Longitudinal Position of Wing (ft)	32	L_3	Length of 3rd Cross Section
8	Tc_wing	Thickness-to-Chord Ratio of Wing	33	L_4	Length of 4th Cross Section
9	C_hr	Root Chord of Horizontal Stabilizer (ft)	34	W_1	Width of 1st Cross Section
10	C_ht	Tip Chord of Horizontal Stabilizer (ft)	35	W_2	Width of 2nd Cross Section
11	Bh	Horizontal Stabilizer Wingspan (ft)	36	W_3	Width of 3rd Cross Section
12	Le_hswp	Leading Edge Sweep of Horizontal Stabilizer (deg)	37	W_4	Width of 4th Cross Section
13	X_hstab	Longitudinal Position of Horizontal Stabilizer (ft)	38	Tc_hstab	Thickness-to-Chord Ratio of Horizontal Stabilizer
14	Tc_hstab	Thickness-to-Chord Ratio of Horizontal Stabilizer	39	H_1	Height of 1st Cross Section
15	Hp	Motor Power (hp)	40	H_2	Height of 2nd Cross Section

16	W_Batt	Battery Weight (lb)	41	H_3	Height of 3rd Cross Section
17	C_hr	Root Chord of Horizontal Stabilizer (ft)	42	C_vr	Root Chord of Vertical Stabilizer (ft)
18	Cf_elev	Elevator Chord Fraction	43	C_vt	Tip Chord of Vertical Stabilizer (ft)
19	Cf_rud	Rudder Chord Fraction	44	Bv	Vertical Stabilizer Wingspan (ft)
20	T_skin	Average Skin Thickness (mm)	45	Le_vswp	Leading Edge Sweep of Vertical Stabilizer (deg)
21	C_ht	Tip Chord of Horizontal Stabilizer (ft)	46	X_vstab	Longitudinal Position of Vertical Stabilizer (ft)
22	Bh	Horizontal Stabilizer Wingspan (ft)	47	Tc_vstab	Thickness-to-Chord Ratio of Vertical Stabilizer
23	Le_hswp	Leading Edge Sweep of Horizontal Stabilizer (deg)	48	Type _Cockpit	Cockpit Type – Tandem or Side-by-Side
24	X_hstab	Longitudinal Position of Horizontal Stabilizer (ft)	49	D_Prop	Propeller Diameter (ft)
25	Tc_hstab	Thickness-to-Chord Ratio of Horizontal Stabilizer	50	RPMmot	Motor RPM

The variables given in Table 7.1.1 are used in the Design Generation phase before being evaluated as per Figure 7.1.2. There, the variables are first fed into an implementation of Raymer's Weights[25][25], then into implementations of DATCOM Method[20][26] and Raymer[25] and Douglas corrections for 3D wings, allowing lift calculations to be performed. Raymer[25][25][25], DATCOM[26][26][26][26][26], Nicolai and Carichner[23][23][23][23][23][23][23][23], as well as Gudmundsson[30][30] methods are used in determining vehicle performance, including takeoff, climb, cruise, and landing performance parameters. Predictions of static and dynamic stability, including Cooper-Harper scale predictions are calculated according to Robert Nelson's Flight Stability and Automatic Control[22][22]. An implementation of the Development And Procurement Cost of Aircraft (DAPCA) IV Model[5], alongside statistical corrections to increase agreement with existing sailplane data is used for cost predictions, including operating costs, acquisition costs, and overall development costs.

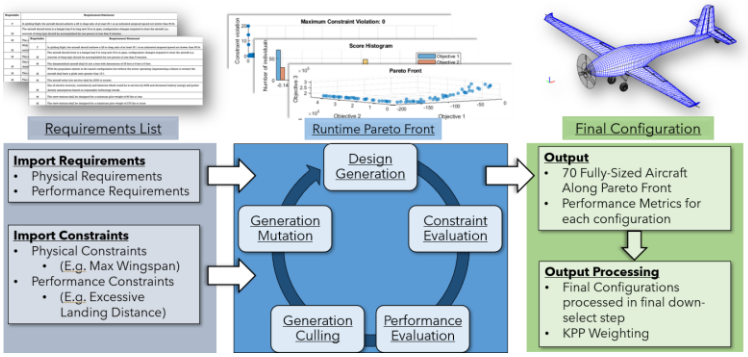


Figure 7.1.1: High-Level Functional Flow of CalPAD MDAO Architecture

The outputs from the Runtime Analysis and Optimization (Seen in Blue in Figure 7.1.1) are 70 fully sized vehicles that satisfy the performance targets and constraints given in the RFP per generation, alongside their respective performance metrics. The final converged results are then post-processed in a final down-selection step. Individual weighting factors are assigned to KPPs, and the generated Pareto Front of solutions is evaluated against these weights, allowing for a final convergence upon a singular solution.

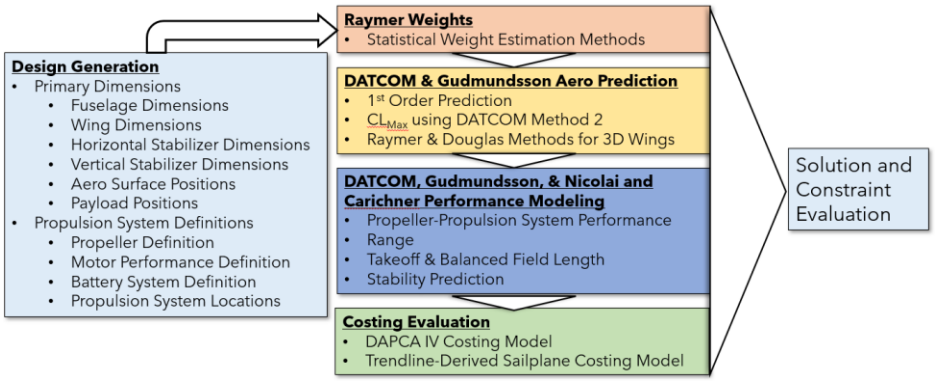


Figure 7.1.2: Runtime Analysis Functional Flow of CalPAD Architecture

7.2 MDO Results

The finalized solution generated by CalPAD satisfied all performance requirements while remaining competitive against contemporary aircraft on the market. Performance values are shown in Table 7.2.1, where the Glydetek Swift outperforms competitor systems in 5 KPP categories.

Table 7.2.1: MDO Solution KPP Comparison Table

KPP	Threshold	Objective	Taurus	Elektra Trainer	Glydetek Swift
Operational Cost Per Instr Flight*	<$50/flight	$20/flight	$25/flight	$34/flight	**$8.10/flight**
Unit Cost	**$300,000**	**$100,000**	**$200,000**	**$225,000**	**$98,000**
Flights Per 6 Hrs	6	18	-	-	**10**
Sink Rate @ 250 ft Turn	250 $\frac{ft}{min}$	175 $\frac{ft}{min}$	138 $\frac{ft}{min}$	~140 $\frac{ft}{min}$	**193** $\frac{ft}{min}$
Airspeed @ L/D = 25	45 kts	70 kts	82 kt	65 kts	**50 kts**
Annual Total Ownership Cost (600 Flights)*	-	-	$14,000	$21,000	**$23,821**
Climb Altitude On One Charge	2,500 ft	10,000 ft	- ft	- ft	**16,000 ft**
Self-Retrieve Range	50 km	200 km	- km	300 km	**176 km**

7.3 MDO Validation

Validation of any MDO architecture is essential to ensure reasonable and reliable results. Data from Jane's All the World's Aircraft glider and motor glider database was compiled, and prediction trendlines were generated. All R^2 values were greater than 0.85, suggesting a strong curve fit agreeing with the data. The predicted

performance values of the Swift fall in line with these performance curves within a 15% margin (compensating for future propulsion technologies).

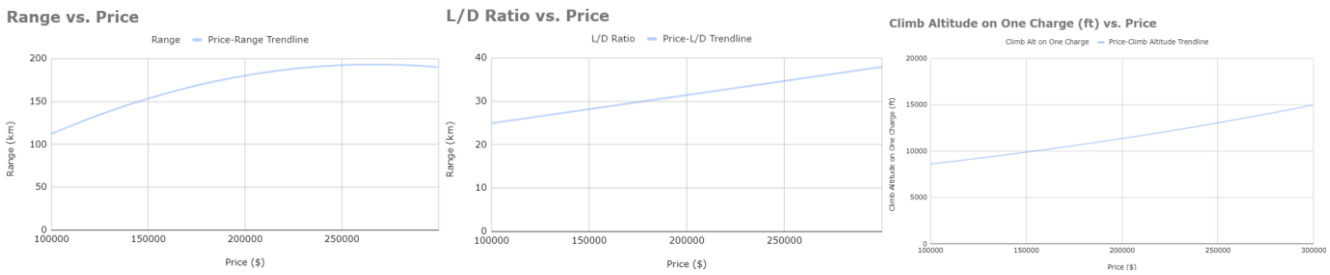


Figure 7.3.1 MDO Validation Charts

8.0 Configuration

The Glydetek Swift is a low wing electric-powered sailplane trainer, featuring side-by-side seating for both the instructor and trainee inside the semi-monocoque fiberglass fuselage. Featuring a conventional empennage, taildragger landing gear, high lift devices and spoilers, as well as a folding electric propeller, the Swift is a vehicle which can adapt to pilots of all skill levels, from absolute beginners to professional competition pilots.

8.1 Configuration Decisions

There were three configurations considered for wing location: low wing, mid wing, and a high wing, as seen in Figure 8.1.1. According to Gudmundsson[30][30][30], these configurations impact pilot field of view, airframe design, and flight & operational characteristics, which are explored in Table 8.1.1.

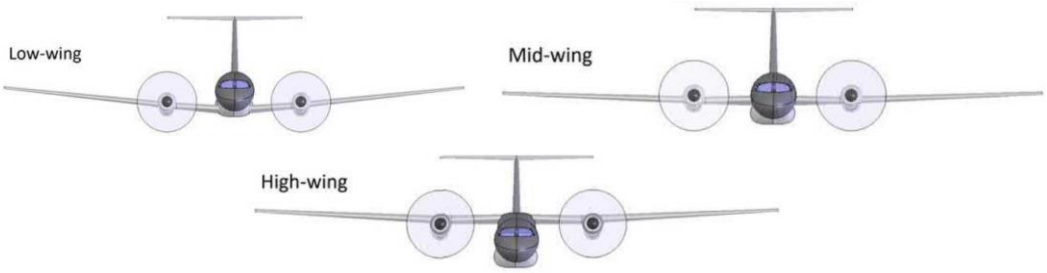


Figure 8.1.1: Examples of Low, Mid, and High Wings

Table 8.1.1: Benefits and Cons of Wing Placements

	Low-Wing	Mid-Wing	High-Wing
Pilot Field of View	Clear View During Turns Poor Visibility Down	Compromise Visibility	Clear View Downwards Poor Visibility in Turns

Structural Weight	Light Landing Gear Heavy Wing Root for Pilot Boarding	Heavy Wing Root for Pilot Boarding	Lighter Wing Root due to Pilot using Side Door
Fuselage Battery Space	Space Available	Restricted Space	Space Available
Flight Characteristics	Unstable Lateral Stability	Neutral Lateral Stability	Stable Lateral Stability
Ease of Assembly	Easy to get Wing into Position and push	Easy to get Wing into Position and push	Difficult to get Wing into Position and push

Referencing Gudmundsson's[30] approach[30] to configurations, the team made a "decision matrix", deciding that the importance of visibility during VFR flight conditions is equal to that of saving airframe weight to reduce cost, and ease of assembly. Lack of fuselage battery space can be supplemented with space in the nose, while flight characteristics can be addressed through dihedral and anhedral angles.

Table 8.1.2: Wing Position Decision Matrix

Parameters	**Weight**	**Configuration Score 1 – Good, 2 – Better, 3 - Best**		
		Low-Wing	Mid-Wing	High-Wing
Pilot Field of View	2	3	2	1
Reduce Structural Weight	2	2	1	3
Fuselage Battery Space	1.5	2	1	2
Flight Characteristics	1	1	2	3
Ease of Assembly	2	2	2	1
Total Weight x Score		18	13.5	16

There were three configurations for propulsion system location: retractable mid-fuselage, non-retractable tail-mounted, and non-retractable nose-mounted as seen in Figure 8.1.2. These configurations impact structural weight, drag build-up, reliability, consequence of failures, flight characteristics and altitude sink during powered to unpowered transition as described in Table 8.1.3.

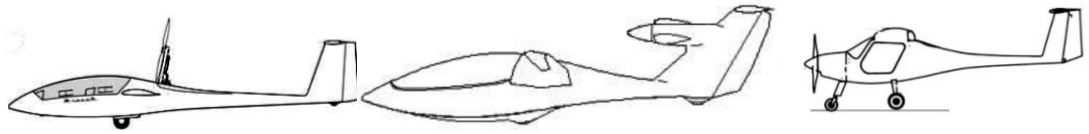


Figure 8.1.2: Examples of Different Propulsion System Locations

Table 8.1.3: Benefits and Cons of Propulsion System Location

	Retractable mid-Fuselage	**Non-Retractable Tail-Mounted**	**Non-Retractable Nose-Mounted**
Reduce Structural Weight	Large Increase to Required Empennage	Moderate Increase to Required Tail	Minimal Increase, Uses Fuselage Strength

Minimize Drag	No Increase to Drag when Retracted, Offset Thrust Trim when on	Folded Prop Drag, Offset Thrust Trim when on	Folded Prop Drag
Reliability	Extra Moving Parts, Higher Chance of Failure	No Extra Moving Parts	No Extra Moving Parts
Consequence of Failure to Retract	High Drag + Moment	Moderate Propeller Drag	Moderate Propeller Drag
Flight Characteristics	Poor Pitch Up Performance	Aft CG, Poor Stability, Ok Pitch Up Performance	Forward CG, Very Stable
Sink During Transition	Long Transition Time, More Lost Altitude	Short Transition Time, No Lost Altitude	Short Transition Time, No Lost Altitude

It's stated in the RFP that the goal of implementing electric propulsion should be to simplify the system and increase reliability, therefore the team decided it to be the most important. Structural weight, drag produced, consequence of failure, and sink during transition largely influences key requirements such as T0.0-13 requiring 50 km range, T0.0-3 requiring 30 L/D at certain 50 knots, and T0.0-16 requiring a sink rate of 100 $\frac{ft}{min}$ during transition. These are more important than flight characteristics, which can be supplemented by other layout choices such as planform choice and battery placement.

Table 8.1.4: Benefits and Cons of Configuration Choice

Parameters	**Weight**	**Configuration Score 1 – Good, 2 – Better, 3 - Best**		
		Retractable mid-Fuselage	Non-Retractable Tail-Mounted	Non-Retractable Nose-Mounted
Reduce Structural Weight	2	1	2	3
Minimize Drag	2	3	2	1
Reliability	3	1	2	2
Consequence to Failure	2	1	2	2
Flight Characteristics	1	2	2	3
Sink During Transition	2	1	2	2
Total Weight x Score		17	24	25

There were two configurations for cockpit layout: tandem seating, and side-by-side seating as seen in Figure 8.1.3. These configurations impact pilot visibility, inter-pilot communication, longitudinal C.G. shift, structural integrity, drag build-up during flight, and pilot comfort as seen in Table 8.1.5.

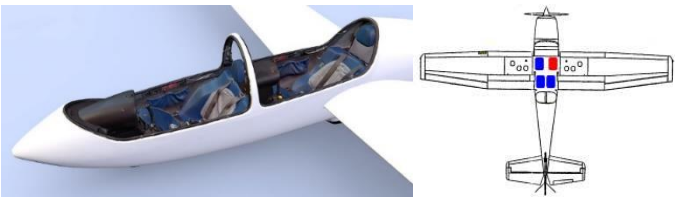


Figure 8.1.3: Examples of Tandem and Side-by-Side Seating Configurations

Table 8.1.5: Benefits and Cons of Seating Configuration

	Tandem	Side-by-Side
Maximize Pilot Visibility	Complete 360 View	Restricted Visibility of Other Side
Inter-pilot Communication	Only Audio Through Microphone	Visual and Audio
Minimize Longitudinal C.G. shift	CG Shifts Drastically with Additional Pilot Weight in Front	CG Shifts Equally with each Seat
Structural Integrity	Less Cross-Section Less Structure Required	Bigger Cross-Section More Structure Required
Reduce Drag Build Up	Minimal Frontal Cross-Section	Increased Frontal Cross-Section
Pilot Comfort	Cramped Cockpit Leads to Anxiety in Fearful Pilots[30]	Uncluttered Cockpit, Extra Room

Considering the RFP needs for a trainer sailplane, inter-pilot communication is ranked the highest to ensure the instructor can effectively communicate the lesson to the trainee. Pilot visibility is also valued similarly due to the importance of visibility in VFR flight rules. Structural integrity and pilot comfort are ranked second, due to the downstream effects sailplane weights have on its performance (Sec 10.0) and the need to ensure trainees are not intimidated by cramped cockpit space. CG shift and drag build up are ranked second due to the moderate weight increases from ballasts required to keep the aircraft stable if the shift is too drastic and decreased glide performance preventing the aircraft from complying with requirement T 0.0-3.

Table 8.1.6: Benefits and Cons of Configuration Choice

Parameters	Weight	Configuration Score 1 – Good, 2 - Best	
		Tandem	Side-by-Side
Maximize Pilot Visibility	3	1	1
Inter-pilot Communication	3	1	2
Minimize Longitudinal C.G. shift	2	1	2
Structural Integrity	2	2	1
Reduce Drag Build Up	2	2	1
Pilot Comfort	2	1	2
Total Weight x Score		18	21

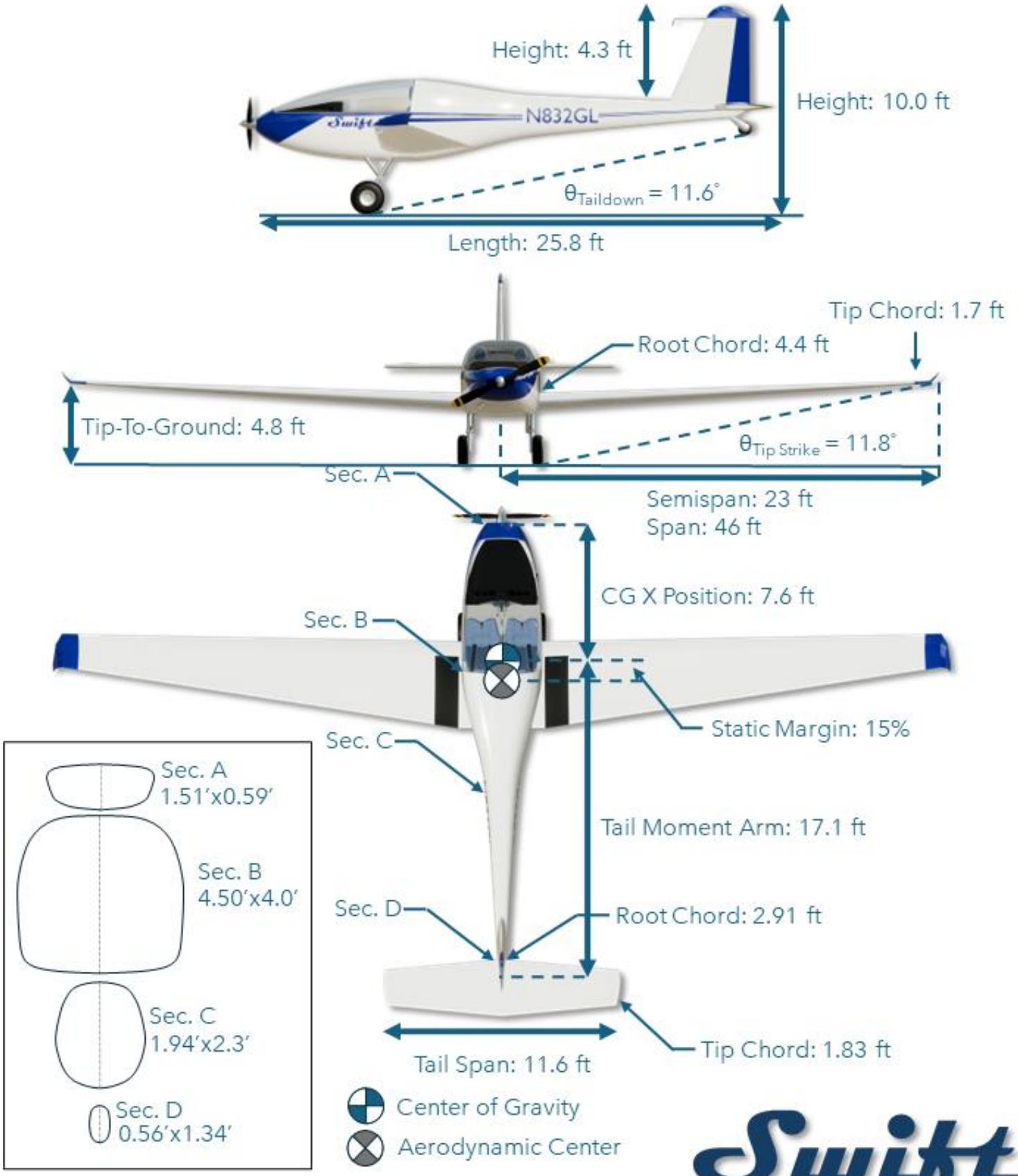
8.2 Concept Definition/ 3 View Drawing

The Swift shown in Figure 8.2.1 fully rendered on the runway, while the three views in Figure 8.2.2, where visual parameters such as wingspan, tip to tail length and aircraft height are measured, along with a 6-ft man for reference. Major non-visual dimensions of the aircraft are shown in Table 8.2.1. Aircraft weights will be elaborated on in section 8.10, and the propulsion system will be explained in section 9.3. It is important to note that the MTOW to wingspan squared ratio is 0.471 $\frac{lbs.}{ft^2}$, which is below the maximum 0.62 $\frac{lbs.}{ft^2}$ set by AC 21.17-2A. The wingspan and tip to tail length is also compliant with requirement 0.0-7 regarding required hanger space.

Table 8.2.1: Swift Major Dimensions

MAJOR DIMENSIONS	
Max Take-Off Weight	997 lbs
Empty Weight	597 lbs
Battery Weight	137.5 lbs
Motor Power (Peak)	86 kW
Motor Power (Continuous)	56 kW
Aspect Ratio	14.35
Wing Area	146 ft^2

Figure 8.2.1: Glydetek Swift 3-View Drawing


Height: 4.3 ft
Height: 10.0 ft
N832GL
θTaildown = 11.6°
Length: 25.8 ft
Tip Chord: 1.7 ft
Root Chord: 4.4 ft
Tip-To-Ground: 4.8 ft
θTip Strike = 11.8°
Sec. A
Semispan: 23 ft
Span: 46 ft
CG X Position: 7.6 ft
Sec. B
Static Margin: 15%
Sec. C
Sec. A
1.51'x0.59'
Tail Moment Arm: 17.1 ft
Sec. B
4.50'x4.0'
Sec. D
Root Chord: 2.91 ft
Sec. C
1.94'x2.3'
Tip Chord: 1.83 ft
Tail Span: 11.6 ft
Sec. D
0.56'x1.34'
Center of Gravity
Aerodynamic Center

8.3 Fuselage Design

The Swift is designed to accommodate a wide range of pilots, ranging from 5th Percentile Female Pilots to 95th Percentile Male pilots. The potential reach lengths of these minima and maxima are seen in Figure 8.3.1, with the 5th percentile reach given in green, and the 95th in blue. All flight controls, instruments, and required systems are accessible for any pilot falling within this dimensional range.

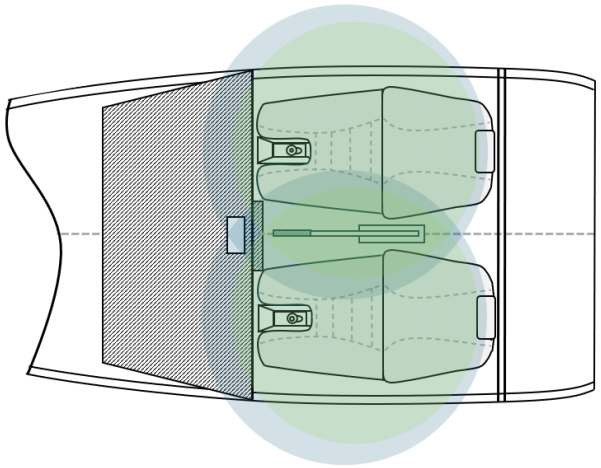


Figure 8.3.1: 5th and 95th Percentile Male and Female Reach Limits

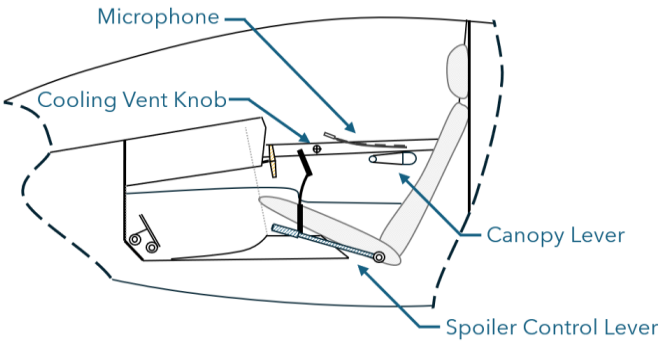


Figure 8.3.2: Cockpit Side View

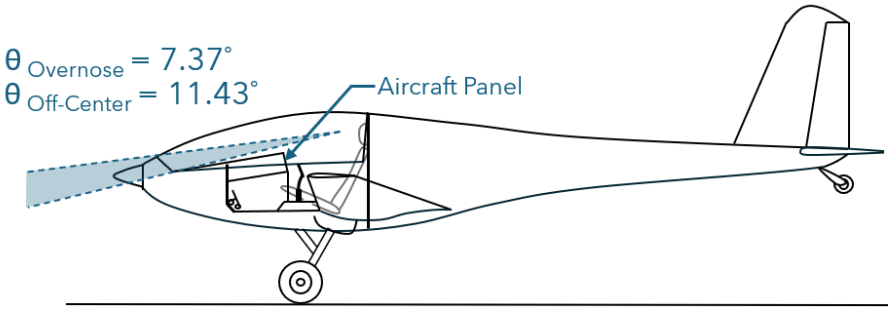


Figure 8.3.3: Swift Cockpit Side View and Overnose View Angles

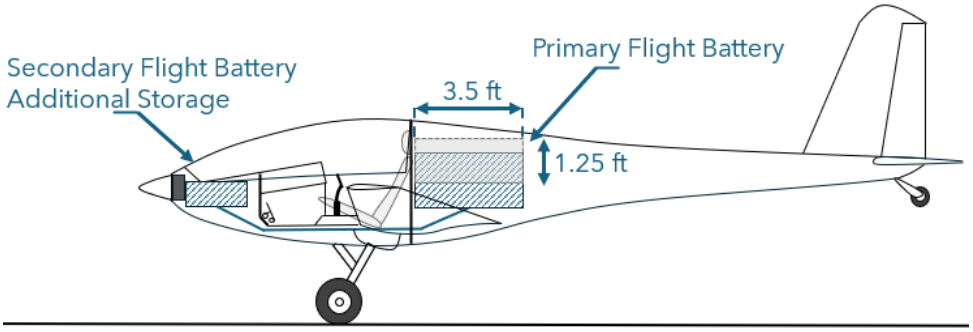


Figure 8.3.4: Battery Locations and Storage Compartment

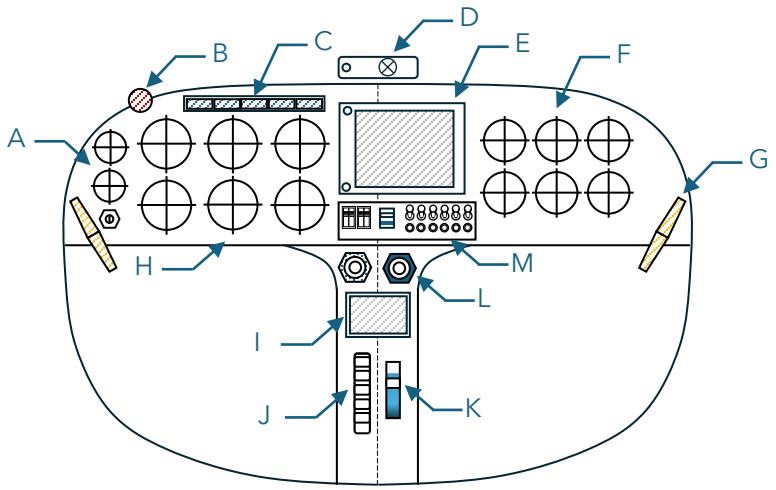


Figure 8.3.5: Swift Panel

Table 8.3.4: Swift Panel

Aircraft Panel Legend	
A	Engine Temperature Indicator Hobbs Meter Aircraft Ignition
B	Canopy Ejection Handle
C	Annunciator Panel
D	FLARM Indicator
E	Primary Flight Display (PFD)
F	Instructor "6 Pack" Instruments
G	Tow Hook/Winch Hook Release
H	Airspeed Indicator (ASI), Vertical Speed Indicator (VSI), Attitude Indicator (AI), Altimeter, Turn Coordinator (TC), Heading Indicator (HI)
I	Battery Monitoring System
J	Elevator Trim Wheel
K	Flap Handle
L	Engine Throttle, Propeller Retract Handle
M	Master Power Switches, Avionics Power Switches, Motor Power Switch, Subsystems Switches, Subsystem Fuses

The Swift incorporates two separate battery locations, the Primary Flight Battery (PFB), located aft of the Rear Cockpit Firewall, and the Secondary Flight Battery (SFB), located at the front of the vehicle. To access the SFB, the canopy must be opened, and the SFB Battery Hatch accessed on the nose of the vehicle. The Swift accommodates the addition of a Secondary Flight Battery as an additional purchase to extend the range of the vehicle. Without the additional battery, the space may be used for storage, with a compartment volume of 2'x3.5'x1.5', able to accommodate small additional payloads, including maintenance equipment, small backpacks, or additional supplies.

8.4 Wing Design

Establishing a planform-airfoil coupled design process is mandatory for the performance-critical process of wing design. Following the initial selection of major wing parameters, including the wing area, root chord, tip chord, and the respective Section Lift Coefficients (C_l's), localized optimization is conducted. These "ballpark" design space survey estimates are refined, and an airfoil performance-coupled planform design process is pursued. The low-wing configuration for Swift was chosen due to a major emphasis on training performance – situational awareness of the pilot must be maximized. Locating the wing aft and below the pilot allows for an effectively unconstrained field of view forward and above the pilot, allowing them to maintain situational

awareness when soaring along ridges, in sailplane gaggles with thermals, and when entering airfield patterns. A dihedral angle of 3˚ provides roll stability, providing improved lateral handling qualities for novice pilots.

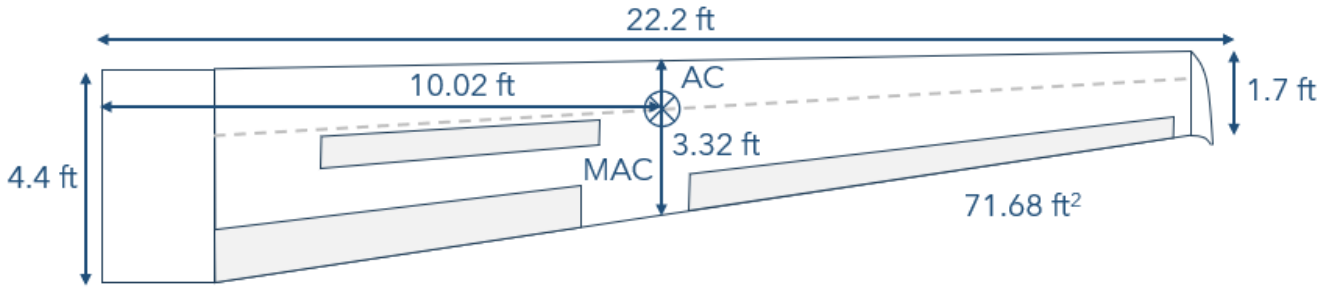


Figure 8.4.1: Wing Planform View

The high Aspect Ratio (AR) wing provides low induced drag due to the high Oswald efficiency parameter. The Taper Ratio (λ) of 0.385 was selected to improve the aerodynamic efficiency of the wing, according to literature by Hoerner[17] in Figure 8.4.2, where the induced drag of tapered wings is minimized at λ = 0.36.

Table 8.4.1 – Wing Planform Parameters

Wing Properties	
Property	Value
Aspect Ratio (AR)	14.35
Taper Ratio	0.385
Root Incidence	1.30˚
Tip Incidence	-0.75˚
$C_{L\alpha}$	0.103
Total Wing Area	143.36 ft²

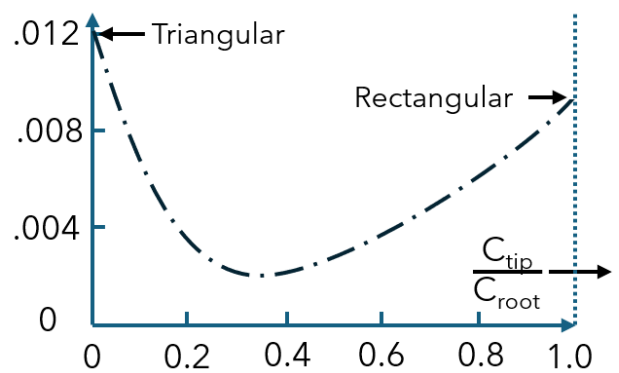


Figure 8.4.2: Hoerner Tapered Wing Induced Drag, Fluid-Dynamic Drag Chapter 7

The wing twist was computationally optimized for two primary objectives: mitigating tip stall and maximizing aerodynamic efficiency at the cruise condition. Establishment of heuristic proxies for a stall behavior (providing a quantifiable metric for how "sharp" a stall is), alongside more traditional wing optimization metrics, such as L/D_{Max}, Cm_{α}, and L/D_{Cruise}, enabled a computational approach to multi-foil wing airfoil selection.

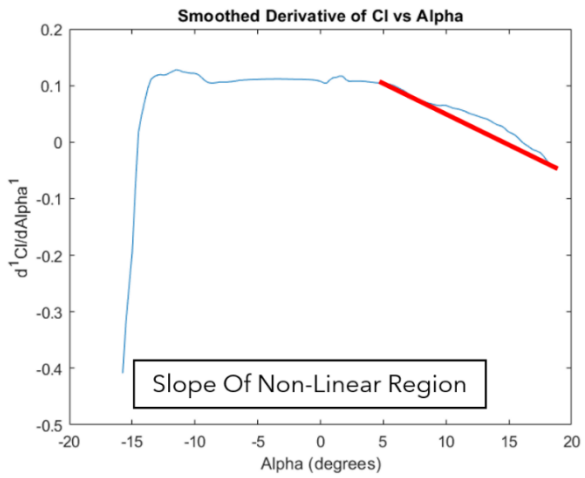


Figure 8.4.3: Stall Behavior Heuristic Proxy

To predict the handling qualities in a stall, the first and second derivatives of the composite CL vs. α curve were computed for a MAC-compensated composite foil curve. The MAC for the platform, located at 10.02 ft from the center as per Figure 8.4.1, was used to calculate an influence metric for the root and tip foils for the weight polar averaging process. After the weighted average of the polars was calculated, a 3D wing correction was applied to the composited polar, giving a low order prediction of the behavior of the multi-foil wing. The second derivative of this Cl v Alpha curve is taken in the non-linear region, and the average slope is used as a heuristic proxy for how "sharp" a stall is – that is, how rapid the loss of lift is following the stall. Figure 8.4.3 illustrates this analysis method.

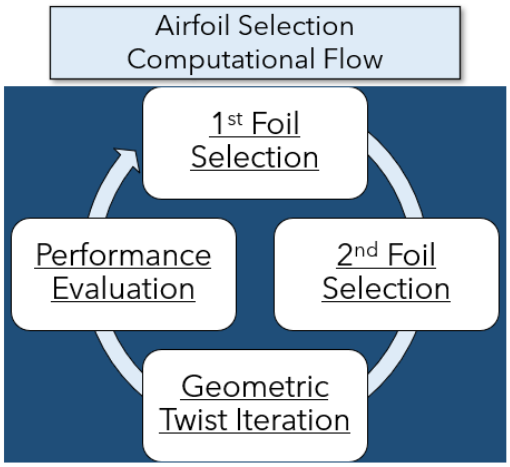


Figure 8.4.4: Airfoil Selection Optimization Computational Flow

This method, coupled with the aforementioned traditional wing optimization metrics, forms the basis of the Airfoil Selection Optimization (ASO) code. The computational flow of the ASO code, seen in Figure 8.4.4, starts with selecting a root foil. Pulling from an airfoil performance database of 1562 common airfoils with data generated using XFOIL, every combination of the 1562 airfoils is analyzed, and the performance metrics are output to a final performance evaluation equation.

The ASO Code produces a final combination of root foil, tip foil, and geometric twist, according to the performance metric formula given in Equation 8.4.1, wherein the individual performance metrics are evaluated, normalized, and weighted according to their relative importance.

$$Perf = A\frac{(C_m)_i}{\left(\frac{\sum_{i=1}^{n}(C_m)_i}{n}\right)} + B\frac{(L/D_{Cruise})_i}{\left(\frac{\sum_{i=1}^{n}(L/D_{Cruise})_i}{n}\right)} + C\frac{\left(\frac{d^2Cl}{da^2}_{Nonlinear}\right)_i}{\left(\frac{\sum_{i=1}^{n}\left(\frac{d^2Cl}{da^2}_{Nonlinear}\right)_i}{n}\right)} + D\frac{(L/D_{Max})_i}{\left(\frac{\sum_{i=1}^{n}(L/D_{Max})_i}{n}\right)} \qquad \text{Eq. 8.4.1}$$

The selected airfoils are shown in Figure 8.4.5, Wortmann FX 06-S-176 (a popular sailplane foil), and the NACA 64-210 (another common Natural Laminar Flow (NLF) foil) for the root and tip of the wing, respectively.

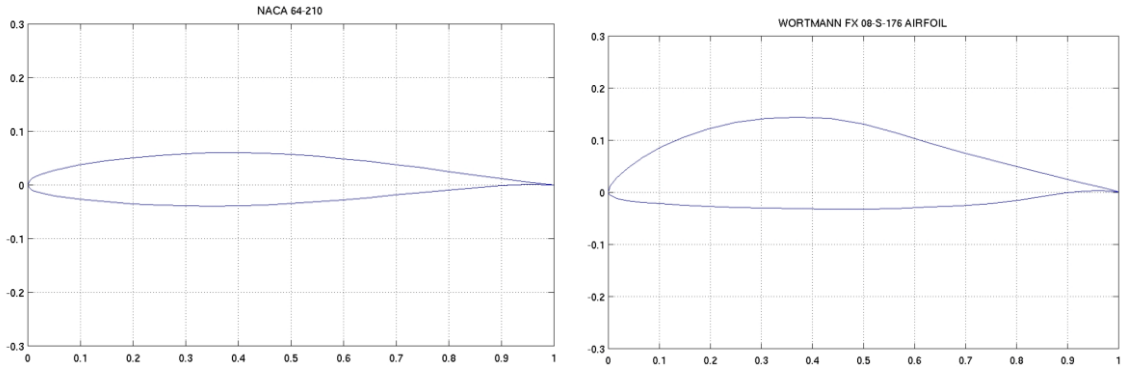


Figure 8.4.5: Selected Airfoils (Wortmann FX 06-S-176 Root, NACA 64-210 Tip)

The performance of the foils, shown in section 9.1.1, demonstrates the ability to meet the multi-point design requirements specified in Section 1.2. A L/D Ratio of 25 is met at a speed of 50 knots, and a minimum sink speed within a sustained 250 ft turn of 134 ft/min in thermals is enabled.

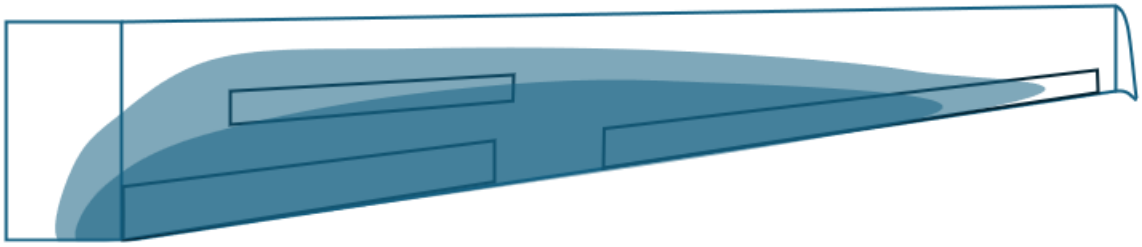


Figure 8.4.6: Stall Progression at $\alpha = \alpha_{Stall}$

8.5 Wing Control Surfaces

To accommodate sailplane pilots of all skill levels—from beginners to experienced professionals—the Glydetek Swift features a variety of control surfaces for fine-tuning the vehicle. As seen in Figure 8.4.1, the Swift's wing has split flaps, spoilers, and ailerons.

The Split Flaps were selected to enable training exercises using flaps. While flaps are not essential for the standard operation of the vehicle, the system allows trainee pilots to become acclimated to their use before transitioning to other high-performance sailplanes. The flaps were designed according to the methods

specified in the DATCOM[26], and performance was evaluated using a viscous-coupled panel method code named FlightStream. The properties of the flaps, shown in Table 8.4.1, show both the size of the flaps and the performance of the Swift with the flaps extended. The flaps may be used to decrease the takeoff roll to 404.3 ft, as seen in section 10.1.1, as well as increase the maximum approach angle from 10˚ to 16 ˚ at maximum deflection as seen in section 10.4.

Table 8.5.1: Flap Parameters

Property	Value
Flap Type	Split Flap
Flap Chord %	25% of Chord
Flap Span Start	32.0% of Span
Flap Span End	41.0% of Span
Total Flap Area	15.40 ft^2
$C_{L\ Max\ (0^\circ\ Flap\ Deflection)}$	1.7
$C_{L\ Max\ (45^\circ\ Flap\ Deflection)}$	2

The ailerons of the Swift were sized according to the methods given in Gudmundsson[30] and Raymer[25].

$$Roll\ Helix\ Angle = \frac{\left(\frac{C_{La}\tau(b_2^2 - b_1^2)}{b^2}\right)}{\left(\frac{C_{La} + C_{D0}}{6}\right)} \cdot \delta_{Ail} \qquad \text{eq. 8.5.1}$$

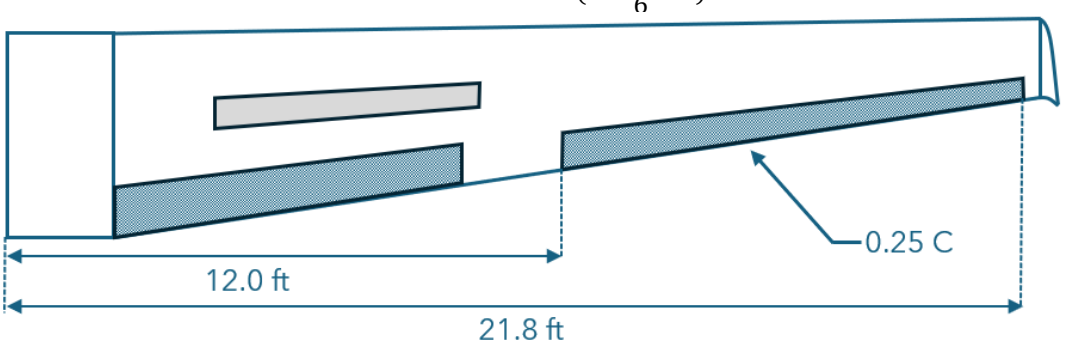


Figure 8.5.1 – Aileron Sizing

Figure 8.5.1 depicts the aileron position on the Swift's wing. To meet the established requirement for a roll-helix angle of $pb/2V \geq 0.09$ at the Stall Speed, Cruise Speed, and Vne speeds, the required span positions are calculated as per Equation 8.5.1. This provides the Swift with equivalent handling qualities to other similar aircraft. The 3˚ forward sweep of the wing provides additional control authority, which along with the reduction in tip-stall behavior, ensures that the ailerons still maintain a degree of efficacy even during flow separation, making low-speed flight during flight training, as well as in thermals a comfortable operation.

8.6 Empennage Selection

The objective of this section is to find the minimal size of the tail area and tail structural area that can provide adequate control to the pilots. Figure 8.5.1 shows how the rudder was sized based on crosswind requirements during take-off and landing of 20% of stall velocity (V_{Stall}). The initial sizing assumed a constant vertical tail length, and the target yaw moment with respect to side slip angle (C_{N_β}) was set at 0.3 radians, as recommended by Gudmundsson[30]. By varying the lift curve slope of the vertical tail ($C_{L_{a_v}}$) and vertical tail area and calculating C_{N_β} at each step, minimum values of $C_{L_{a_v}}$ and vertical tail area can be found. However, volumes should exceed these minimums to achieve desirable handling qualities.

To find the optimal tail volume sizing, a similar optimization approach to MDO section 7.0 was used, as seen in figure 8.6.1. Using a local genetic algorithm the team minimized tail area and tail structure area, using a simplified beam model to predict tail weight and area. These variables were consolidated to the x-axis for total area (A_{tot}) with C_{N_β}on the y-axis in Figure 8.6.1. A visualization of these calculations is shown in figure 8.6.2. After setting an iteration limit of 500, the optimized values can be seen in Table 8.6.1, where the target C_{N_β} is reached with minimal tail area and length.

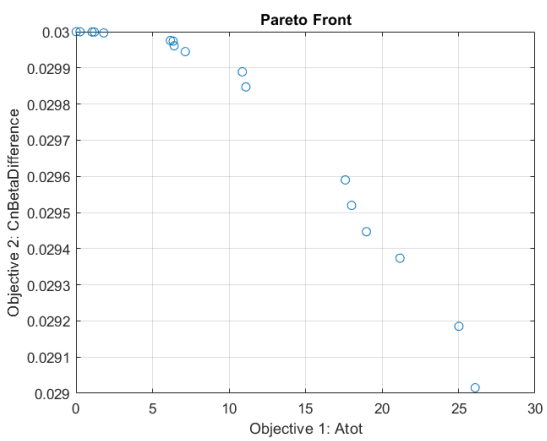


Figure 8.6.1: Rudder Sizing Diagram

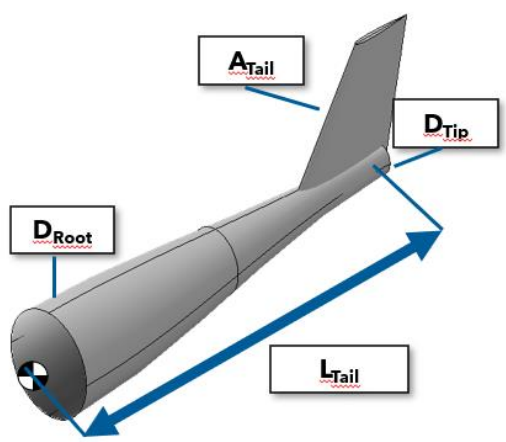


Figure 8.6.2: Rudder Sizing Optimization

Table 8.6.1: Optimized Tail Parameter Values

Optimized Values	Condor
Tail Area	13.1 ft^2
Tail Length	15.35 ft
C_{N_β}	0.03 radians

To determine the horizontal tail volume, the notch chart in Figure 8.6.3 was constructed with the design point being constrained by the landing flare, nosewheel lift off and rear stability limit using methods outlined in Raymer[25][25] and Hays.[35]

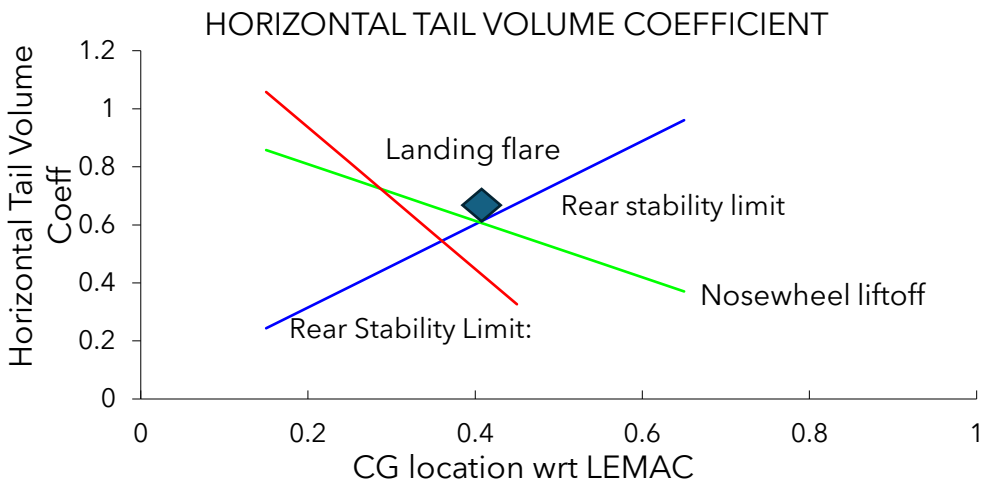


Figure 8.6.3: Notch Chart

8.7 Sliding Battery Rack

To accommodate the optional 68.8 lbs. half battery in the nose, the main battery is attached onto a sliding rack with pins every four inches, which is elaborated upon in section 8.81. This configuration can be seen in Figure 8.7.1, where the red is the battery, and the racks can be seen underneath. After pinning it into place, the cover will be latched down firmly for flight.

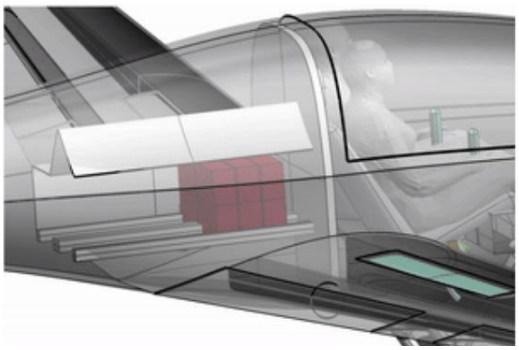


Figure 8.7.1 Sliding Main Battery Rack to Accommodate Forward Battery

8.8 Payloads.

8.8.1 CG Envelope

The team conducted a static analysis of the aircraft CG in respect of the MAC, setting an acceptable range from 25% to 35% of MAC as recommended by Gudmundsson's text[30][30]. The default configuration's CG envelope

can be seen in Figure 8.8.1.1, where the Swift cannot accommodate for a 90 $lbs.$ solo pilot as required by the RFP.

To address this issue, a 45 $lbs.$ ballast is installed, the change being reflected in the dotted blue line in Figure 8.8.1.2. The ballast will be thin plates each weighing 15 $lbs.$ each, placed into built-in seat cushion, satisfying the RFP requirement T 0.0-31.

The sliding battery must be utilized in the optional 1065.9 $lbs.$ configuration with the 50% battery in the nose, as shown in Figure 8.8.1.3. The sliding battery has pin inserts at 4-inch intervals, each interval marking a black dotted line on the plot. With the sliding battery, the aircraft can handle solo pilots down to any weight.

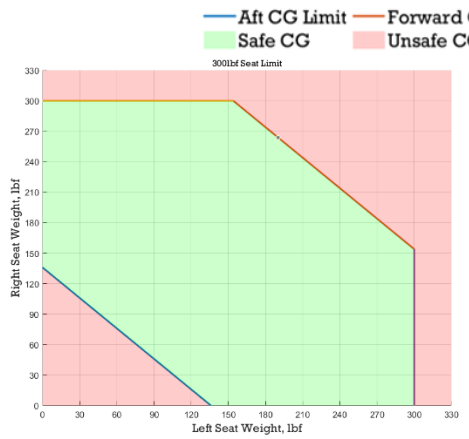


Figure 8.8.1.1: CG Envelope Default Configuration

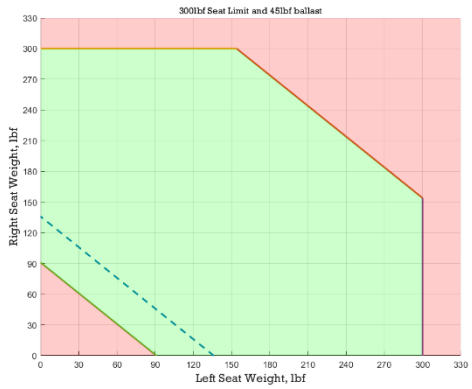


Figure 8.8.1.2: CG Envelope with 45 lbs. Ballast Represented by Dotted Blue Line

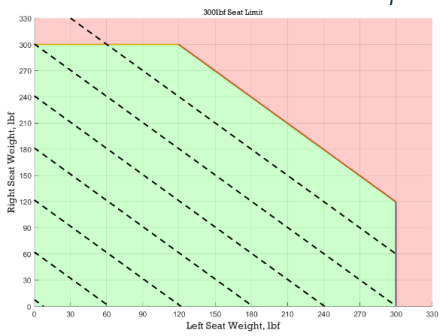


Figure 8.8.1.3: CG Envelope with Half Battery in front and Sliding Battery in Dotted Black Lines

8.9 Landing Gear Design

The taildragger landing gear configuration was chosen for a shorter take-off distance and less overall drag, while the main gear was decided to be retractable to reduce drag and improve overall gliding performance. The landing gear was designed using Gudmundsson's[30] approach, as seen in figures 8.9.1 and 8.9.2. First, the loaded and unloaded CG locations are calculated. Then, the angles between that and the main landing gears are calculated to be 17.7° and 21.3°, which are within the range of acceptable angles of 15° to 25°. Then, the rear wheel is placed at a 11.6° incline behind the main wheels, within the recommended 10° to 15° range.

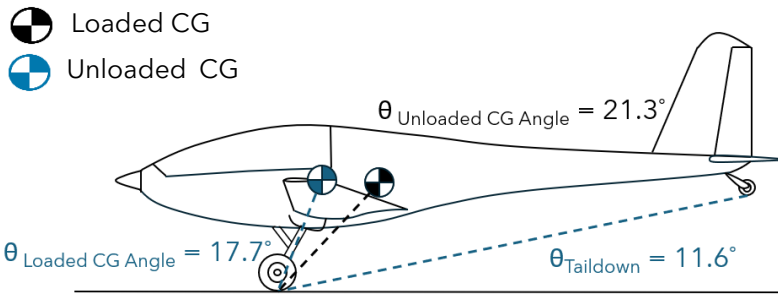


Figure 8.9.1: Landing Gear Design Side View

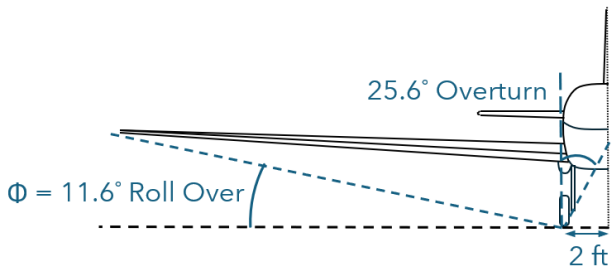


Figure 8.9.2: Landing Gear Design Side View

Then, the main wheel and CG from the front is calculated to find an overturn angle of 25.6°, above the recommended 25°. The roll over angle is found to be 11.6°, leading to a wing tip of 4.56 ft above the ground, satisfying RFP requirement T 0.0-15. The tires were selected based on the method outlined in Raymer's[25] text[25] and the max downward loading case to determine an approximate diameter and width which was then compared to of the shelf commercial tires.

Table 8.9.1: Tire Selection Data

Goodyear Tire	
Tire Size	5.00-4
Pressure (PSI)	95
Max Diameter (in)	13.25
Number of Plys	14
Cost	$674.95
Min. Margin of Safety	1.3

8.10 Material Selection

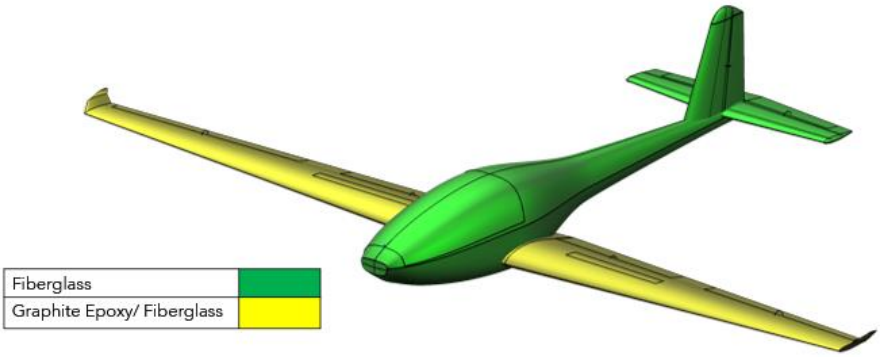


Figure 8.10.1: Swift Material Selection

8.11 Final Mass Properties.

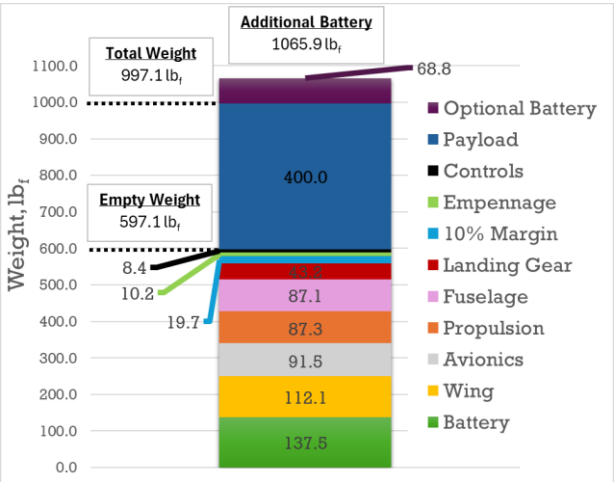


Figure 8.11.1: Weight Breakdown

The final mass distribution of the Swift is shown in Figure 8.11.1, where individual weights were calculated using Gudmundsson's[30][30] equations based on historical data. A 10% margin was applied to the wing structure to account for weight build-up and additional wing structure relating to training safety. The forward sweep of the wing is also accounted for within this margin. The empty weight of the aircraft includes the skeletal weight, electronics, propulsion system and battery weights, summing up to 597.1 lbs. The total weight includes the weight of payload, or the pilots, which reaches 400 lbs. according to the RFP mission profiles. This leads to a MTOW of 997.1 lbs. With the optional battery installation in the nose, the Swift's heaviest weight configuration is 1,065.9 lbs., compliant with AC 21.17-2A's 1,874 lbs. restriction.

8.12 Avionics

The Swift will utilize an IGC-certified standalone avionics system called LX Navigation Zues 7.0 Flight Computer. The avionics system has low power consumption and will be powered by a separate 12V avionics battery. It can provide an Airport, Turnpoint, Task, and Nearest Landable location. Zeus has a smaller footprint and can

provide 3D terrain, a backup battery, and a flight recorder that enhances the trainee experience. The Zeus is compatible with most sailplanes today and the necessary technology is ready by the EIS date in 2030.

9.0 Aircraft Analysis

The Swift provides a glide-to-weight ratio of 28.2 without flaps. With level 1 handling qualities and additional aerodynamic implementation of a drag bucket for a gentle stall, it provides an effective flying experience for the trainee and the pilot. Additionally, the propulsion system design and future battery technology allow for a cruise-climb range of up to 176 km with a maximum rate of climb up to 650 ft/min t 70 knots, allowing pilots to climb in any terrain.

9.1 Aerodynamics

9.1.1 Lift Analysis

Figure 9.1.1 demonstrates lift along the wing semi-span section. The lift distribution is bell-shaped around the wingtip with a gradual exponential rise in a lift near the root. The lift distribution is odd but provides an L/D of 28.2, as shown in Figure 9.1.4.1.

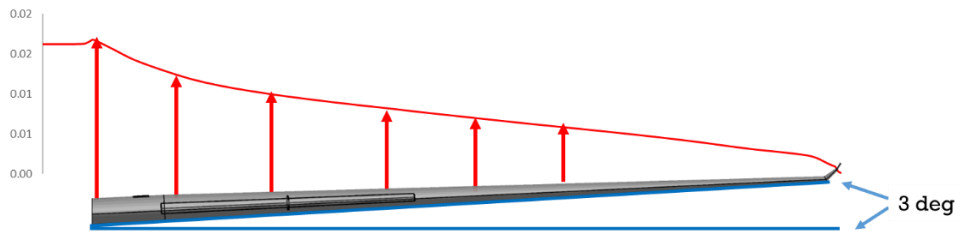


Figure 9.1.1.1 Lift Distribution of a Wing Semispan Section

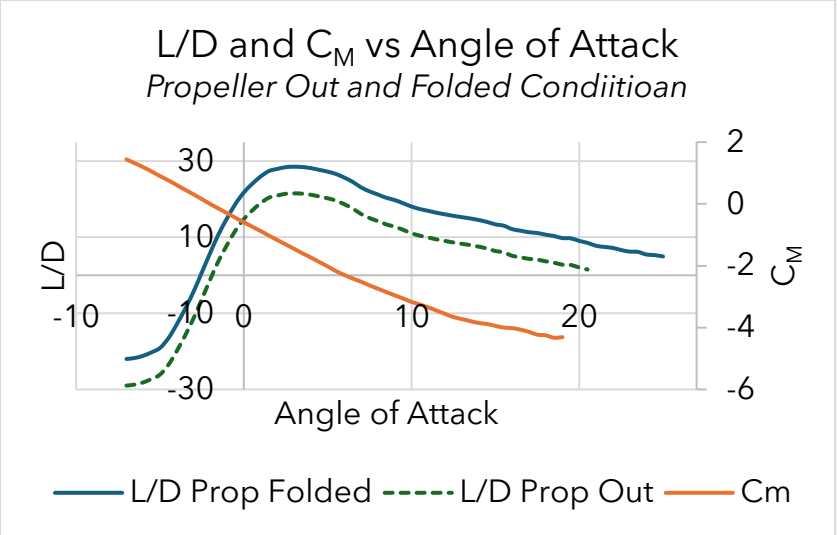


Figure 9.1.1.2 L/D and C_M vs AoA

9.1.2 Flap Performance

Split flaps are used to increase the C_L during takeoff and drag during landing and enhance aerodynamic performance during the missions. Figure 9.1.2.1 shows the drag polar with varying C_L and C_D. The flap is extended in 15-degree increments. The C_L increases varying with the flap deflection with the highest C_L of 2.0 at 45 degrees deflection.

9.1.3 Spoiler Analysis

Spoilers are integrated into the wing, as shown in Figure 9.1.3.1. The spoiler disturbs the flow over the wing, reducing the C_L and drastically increasing the drag shown in Figure 9.1.4.1. suited best for landing. In turn, the L/D ratio is reduced, as seen in Figure 9.1.3.2, which shows its effectiveness in short landings.

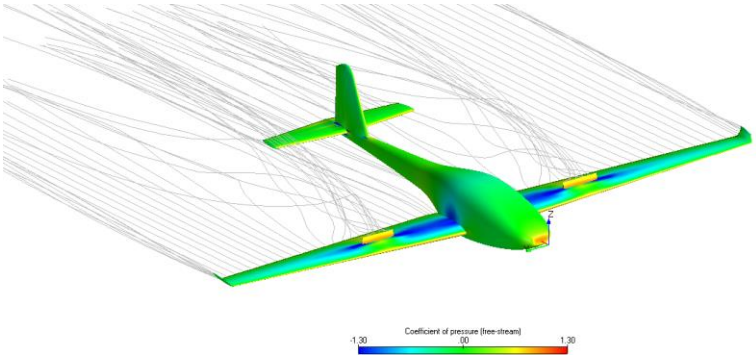


Figure 9.1.3.1 Spoiler Analysis using FlightStream Panel Method Solver

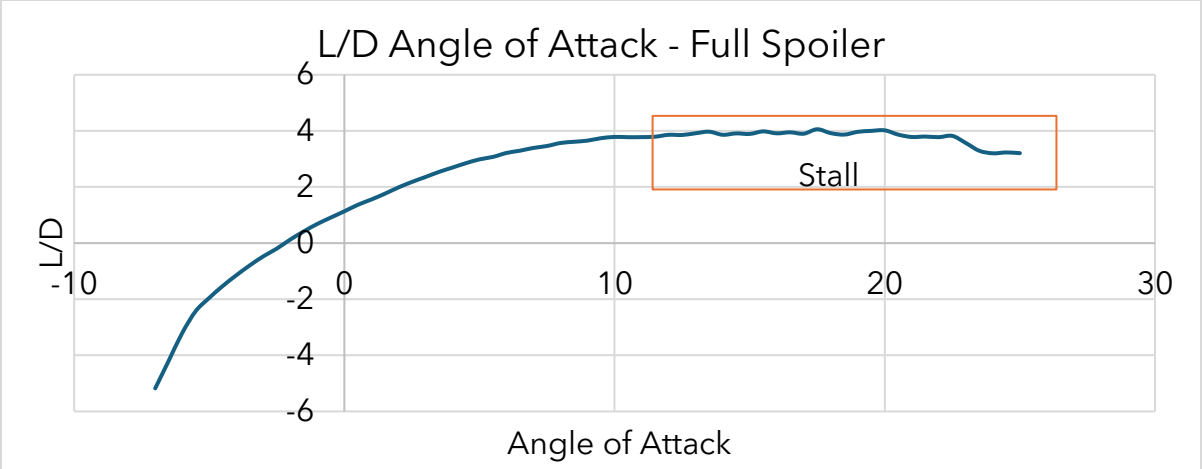


Figure 9.1.3.2 L/D vs AoA for Full Spoiler

9.1.4 Drag Analysis

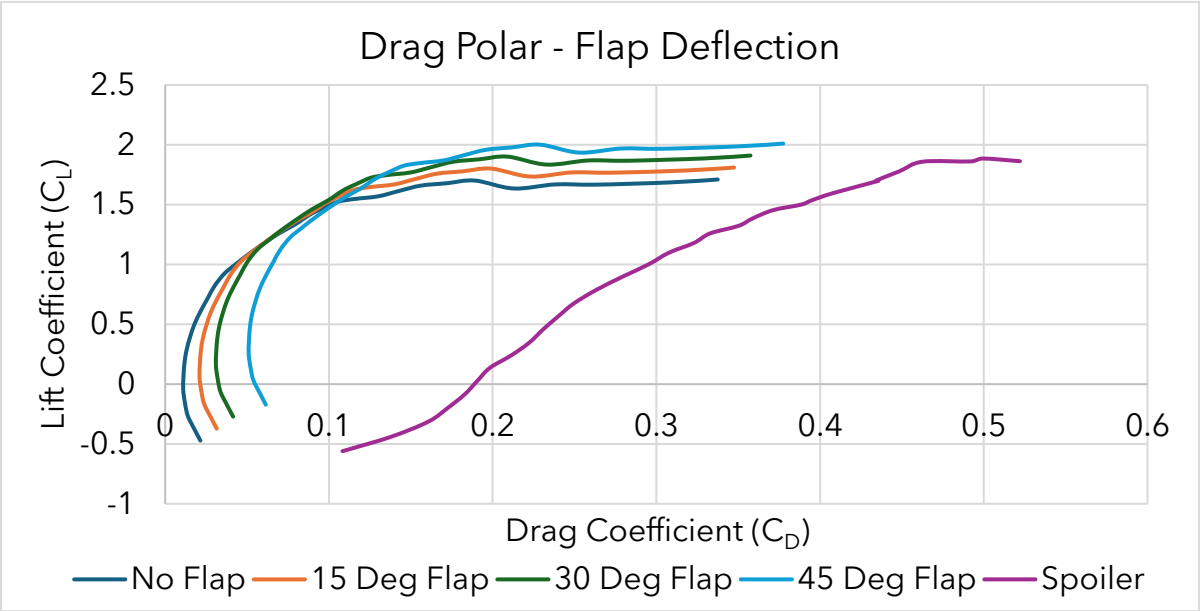


Figure 9.1.4.1 Drag Polar at Various Flap Deflections and Spoiler

9.1.5 Flight Envelope

The flight envelope shows the limits of the aircraft bounded by the stall speed, service ceiling rate of climb and max speed where thrust is equal to drag. Figure 9.1.5.1 shows the Swift can satisfy the requirement of a minimum service ceiling of 14,000 ft ASL.

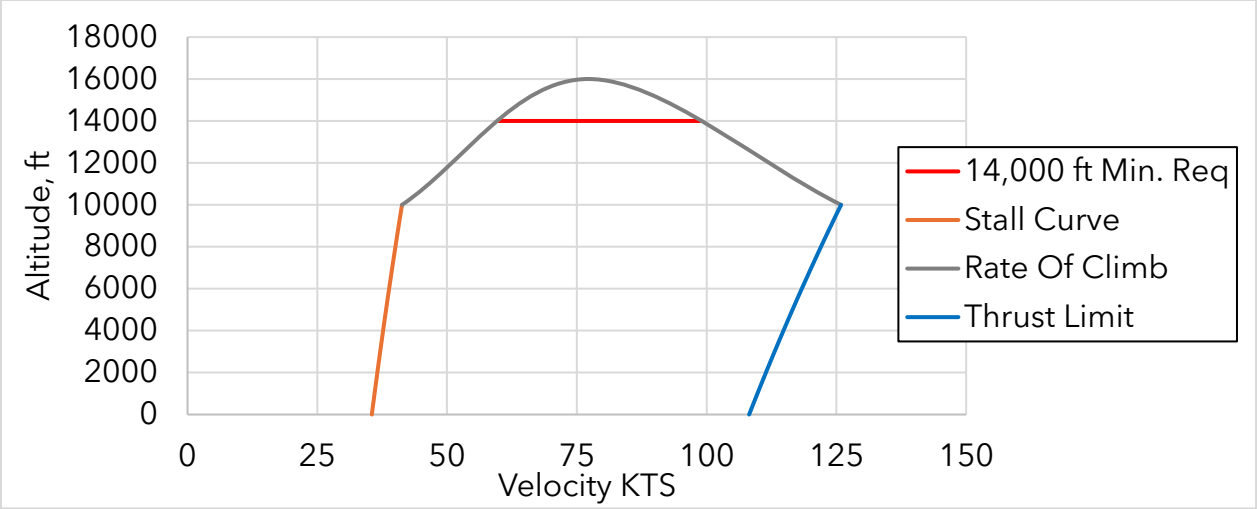


Figure 9.1.5.1: Swift Flight Envelope, Max Altitude of 16000 ft

9.2 Stability and Control

As part of RFP requirements, basic stability and control characteristics must be calculated, including but not limited to static margin, pitch, roll and yaw derivatives.

9.2.1 Static Stability

For the static stability analysis of the Swift in each configuration, steady flight assumptions were made, meaning that the aircraft's acceleration and rotation would be 0. When the aircraft is in its equilibrium state, this condition would be calculated, the attitude it will return to when there is no pilot input.

The static margin (SM) is used to evaluate pitch stability. It is given by the distance between the CG and neutral point as a percentage of MAC. The Swift's neutral point is 8.105 ft from the nose, while the CG ranges from 7.62 ft at the lightest to 7.98 ft. at its heaviest. The static margin calculated is shown in Figure 9.2.1.1.

Another aspect of static stability is the change in pitching moment relative to α (C_{M_α}). It is ideal for commercial aircraft that $C_{M_\alpha} < 0$ so that when the pilot pitches upwards, the aircraft will naturally try to pitch down, and vice versa when the pilot pitches downwards. The plot of pitching moment (C_M) versus α can be seen in Figure 9.2.1.2, where C_{M_α} is seen in Figure 9.2.1.3.

$$\frac{\delta C_M}{\delta \alpha} < 0$$

In lateral stability, the change in yaw moment relative to sideslip angle (C_{N_β}) is crucial, as it determines the aircraft's ability to correct a sideslip angle (β). To maintain lateral stability, it's ideal for $C_{N_\beta} > 0$, where a positive β produces a positive yaw moment (C_N), acting in the opposite direction of the positive sideslip.

$$\frac{\delta C_N}{\delta \beta} > 0$$

The Swift is naturally trimmed for a $C_{m\alpha}$ at 3˚, at a Cruise C_L of 0.41 and a L/D ratio of 28. This trim position is at the 400 lb seat limit, and enables the Swift to require minimal trim to achieve the highest L/D ratio.

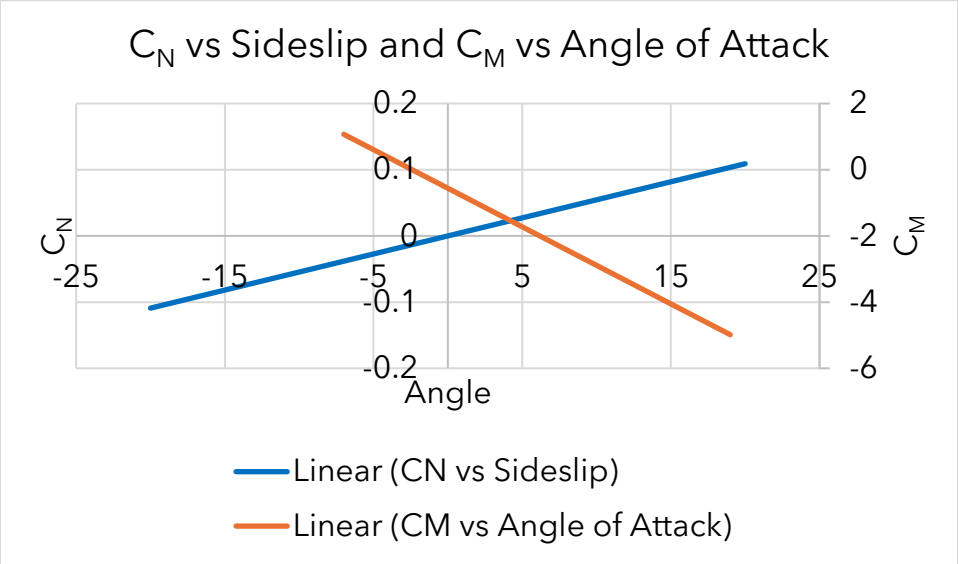


Figure 9.2.1.3: C_N and C_m versus β, (/Deg)

9.2.2 Dynamic Stability

The dynamic stability of an aircraft pertains to the aircraft's time-domain response to disturbances. The dynamic modes of an aircraft are categorized into two primary groups – longitudinal and lateral-directional, the latter representing the inherently coupled nature of the roll-yaw responses. Prediction of the dynamic modes of an aircraft is an inherently challenging process due to the wide range of variables affecting the performance of the system. Determination of Longitudinal and Lateral-Direction stability derivatives is done through the application of a variety of approximations, discarding higher-order terms and applying small-angle approximations. The results of these approximations are further reinforced through computational predictions performed using a Vortex-Lattice-Method (VLM) code named Athena Vortex Lattice (AVL). The results of these methods are shown in Table 9.2.1.1, showing strong agreement between the two methods.

Table 9.2.1.1 Dynamic Stability Coefficients

Stability Coefficient	Value (AVL)	Value (Approx.)	Stability Coefficient	Value (AVL)	Value (Approx.)
C_{Xu}	-0.0181	-0.212	$C_{Y\beta}$	-0.2690	-0.255
C_{Lu}	0.00032	0	$C_{L\beta}$	-0.0563	-0.071
C_{Mu}	0.0007	0	$C_{N\beta}$	0.08594	0.069
$C_{X\alpha}$	0.1103	0.098	C_{yp}	-0.1023	-0.101
$C_{L\alpha}$	6.0393	6.302	C_{Lp}	-0.6399	-0.654
$C_{M\alpha}$	-2.334	-2.105	C_{Np}	-0.0192	-0.020
C_{Xq}	0.0774	0	C_{yr}	0.1987	0.1846
C_{Lq}	12.291	12.34	C_{Lr}	0.0408	0.
C_{Mq}	-37.154	-34.011	C_{Nr}	-0.0632	-0.023

The predicted Cooper Harper Scale Handling Qualities, assessed as per the methods prescribed in Nelson[22], meet Level I handling qualities in all dynamic modes, supporting the Swift's use as an introductory trainer, providing a comfortable and stable behavior for novice pilots, and a stable and predictable platform for longer endurance flights.

Table 9.2.1.2 – Handling Qualities

Mode	Cooper Harper Level (AVL Data)	Critical Value	6-DOF Flight Simulation (X-Plane 11 HQ)
Phugoid Mode	Level I	$\zeta = 0.07$	Level I
Short Period Mode	Level I	$\zeta = 0.75$	Level I
Roll Mode	Level I	TTD – 16 sec	Level I
Dutch Roll Mode	Level I	$\Omega_n = 1.4$ Hz	Level I
Spiral Mode	Level I	$\tau = 0.35$	Level I

9.2.4 6-DOF Flight Simulation

To further validate the controllability and handling qualities of the Swift, real-time flight simulation using X-Plane 11 (A Blade Element Theory (BET) – based simulation software) was developed. 20 flights were run, using the CPP UAV Lab's full-motion flight simulation hardware and Virtual Reality (VR) headsets. 5 students were tasked to fly both reference missions, with 2 flights per mission. Live assessment of handling qualities was conducted, and the aggregate of pilot responses was recorded in Table 9.2.1.2. 2 of the simulated test pilots had their PPL, one was undergoing training for their PPL, one was undergoing training for their GPL, and a final one had their multi-engine certification, making them the prime demographic for flight training in the *Swift*.

Figure 9.2.4.1 – 6-DOF X-Plane 11 Flight Simulation

9.2.5 Aerotow and Winch Launch Performance

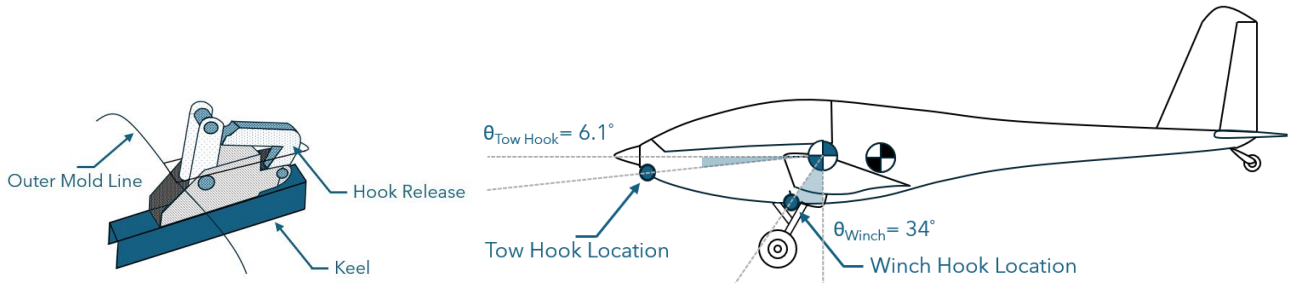


Figure 9.2.5.2 Aerotow and Winch Launch Mechanism

Figure 9.2.5.1 depicts the Tow Hook and Winch Hook assembly, as mounted to the keel of the Swift. The hook locations are indicated in Figure 9.2.5.2, aligning with design recommendations for hook positions. The Aerotow hook, mounted slightly aft of the propeller, has only a small vertical offset from the CG position, allowing the pilot to compensate for the offset with minor elevator deflections. The Winch Hook location, aligning with the average 30˚ angle relative to the CG.

9.3 Propulsion and Power

9.3.1 Motor and Controller Selection

Figure 9.3.1.1: Motor selection – EMRAX 208

The power requirement established in the 4.1 Constraint Diagram governs the selection of a necessary propulsion system. Table 9.3.1.1 provides currently available off-the-shelf motors that satisfy the 45-kW continuous power requirement during the climb, which is constraining the mission. EMRAX 208 is the selected candidate with up to 10kW/kg motor energy density, 86 kW of peak power, and 56 kW of continuous power to the propeller before the inefficiencies shown in Figure 9.3.2.1.1

Table 9.3.1.1: Motor Candidates

Motor Candidates	Motor Weight	Motor Dimension Diameter x Length	Peak Power	Continuous Power	RPM	Max Voltage
REB 60	15.3 kg (33.7 lb.)	10.7″ x 5.4″	60 kW	45 kW	4000	400 VDC
EMRAX 188	7.9 kg (17.38 lb.)	7.4″ x 3″	60 kW	37 kW	6500	490 VDC
EMRAX 208	10.3 kg (22.7 lb.)	8.2″ x 3.4″	86 kW	56 kW	6000	580 VDC
REX 90	17.3 kg (38.1 lb.)	8.7″ x 8.3″	70 kW	50 kW	4000	400 VDC

The EMRAX will be used for entry into service in 2029, paired with the HBCI 400400 motor controller. The motor controller can provide up to 100kW continuous power that can be air-cooled. Alongside a fuse, the motor controller has other safety features, a mechanical switch that allows for safe disconnection during an emergency, satisfying CS22.1353.

9.3.2 Propeller sizing and performance

Equation 9.3.2.1 (Gudmundsson[30]) [30] determines the propeller diameter using motor power in BHP, and the propeller factor estimates the propeller diameter that matches the reference sailplane. The propeller pitch is field adjustable, shown in Table 9.3.2.3, and the required pitch can be followed to adjust pitch based on intended cruise airspeed and desired RPM. The propeller will fold instantly (<5 sec) which will sink the sailplane 16 ft according to the glide polars in section 10.3.2, which satisfies KPP requirement.

$D_p = k_p \sqrt[4]{P_{BHP}}$, using k_p value of 0.56, D_p = 63 inches | Eqn. 9.3.2.1 Propeller Sizing

Table 9.3.2.1 Factor Kp for typical propeller types

TABLE 15-2 Factor K_p for typical propeller types.

Type of propeller	K_p for P in BHP and D_p in inches	K_p for P in kW and D_p in m
2-bladed	20.4	0.56
3-bladed	19.2	0.52
4- or more blades	18.0	0.49

Table 9.3.2.2 Propeller Pitch Adjustment Chart

Propeller RPM	Intended Airspeed											
	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0
400.0	125.1	156.4	187.7	218.9	250.2	281.5	312.8	344.0	375.3	406.6	437.9	469.1
600.0	83.4	104.3	125.1	146.0	166.8	187.7	208.5	229.4	250.2	271.1	291.9	312.8
800.0	62.6	78.2	93.8	109.5	125.1	140.7	156.4	172.0	187.7	203.3	218.9	234.6
1000.0	50.0	62.6	75.1	87.6	100.1	112.6	125.1	137.6	150.1	162.6	175.1	187.7
1200.0	41.7	52.1	62.6	73.0	83.4	93.8	104.3	114.7	125.1	135.5	146.0	156.4
1400.0	35.7	44.7	53.6	62.6	71.5	80.4	89.4	98.3	107.2	116.2	125.1	134.0
1600.0	31.3	39.1	46.9	54.7	62.6	70.4	78.2	86.0	93.8	101.6	109.5	117.3
1800.0	27.8	34.8	41.7	48.7	55.6	62.6	69.5	76.5	83.4	90.4	97.3	104.3
2000.0	25.0	31.3	37.5	43.8	50.0	56.3	62.6	68.8	75.1	81.3	87.6	93.8
2200.0	22.7	28.4	34.1	39.8	45.5	51.2	56.9	62.6	68.2	73.9	79.6	85.3
2400.0	20.9	26.1	31.3	36.5	41.7	46.9	52.1	57.3	62.6	67.8	73.0	78.2
2600.0	19.2	24.1	28.9	33.7	38.5	43.3	48.1	52.9	57.7	62.6	67.4	72.2
2800.0	17.9	22.3	26.8	31.3	35.7	40.2	44.7	49.1	53.6	58.1	62.6	67.0
3000.0	16.7	20.9	25.0	29.2	33.4	37.5	41.7	45.9	50.0	54.2	58.4	62.6
3200.0	15.6	19.5	23.5	27.4	31.3	35.2	39.1	43.0	46.9	50.8	54.7	58.6
3400.0	14.7	18.4	22.1	25.8	29.4	33.1	36.8	40.5	44.2	47.8	51.5	55.2

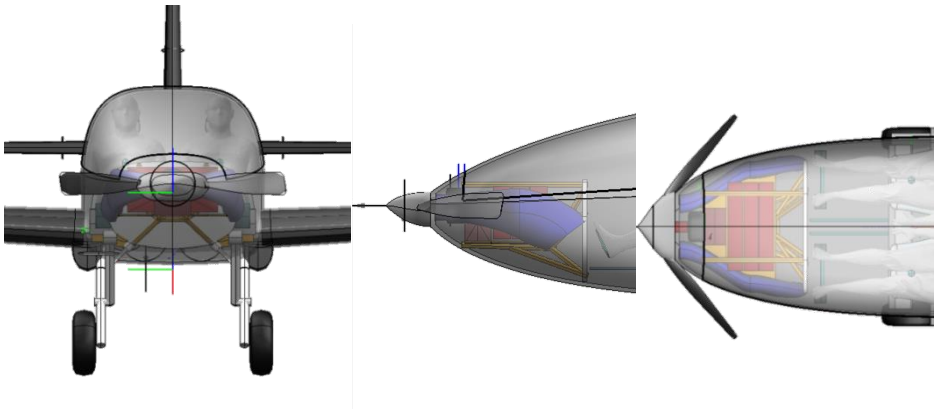


Figure 9.3.2.1: Propeller Folding During Shutoff and Soaring Mission

The performance is categorized by calculating the required thrust and power shown in Eqn. 9.3.2.1 and Eqn. 9.3.2.2 at each mission segment to accurately size propeller and batteries for Cruise and Climb. Figure 9.3.3.2 demonstrates conservative estimations of inefficiencies for each component in the powertrain (Figure 9.3.5.1) used to calculate thrust and power required at each mission stage. During the initial stages of the Takeoff-Climb portion, the entire powertrain will consume ~50 kW of power <15 seconds until a steady climb is reached. During the steady climb phase, an airspeed of 70 kts is reached at a 600 FPM rate, required by the RFP, which requires 35 kW power to maintain the climb until the desired altitude is reached. The cruise-climb phase requires ~10kW power to maintain a 100 FPM rate of climb at 50-60 knots airspeed. The Eqn 9.3.2.3 is used to calculate static thrust with 61-inch diameter propeller with assumed 4 inch diameter hub which provides 300 lbf of thrust, which can allow for quicker takeoff and high climb. The calculation was validated by unsteady simulation in FlightStream software (by DarCorp) giving 275 lbf thrust at 3500 RPM, shown in Figure 9.3.2.2.

Required Thrust	$T_{Req} = Drag + (ROC \div V_\infty) \times W_{TO}$	Eqn. 9.3.2.1
Required Power	$P_{Req} = T_{Req} \times (V_\infty + W_{TO})$	Eqn. 9.3.2.2
Static Thrust	$T_{Static} = P_{Motor}^{2/3} \times (2 * \rho * A_{Prop})^{1/3} \times (1 - \frac{A_{Spinner}}{A_{Prop}})$	Eqn. 9.3.2.3

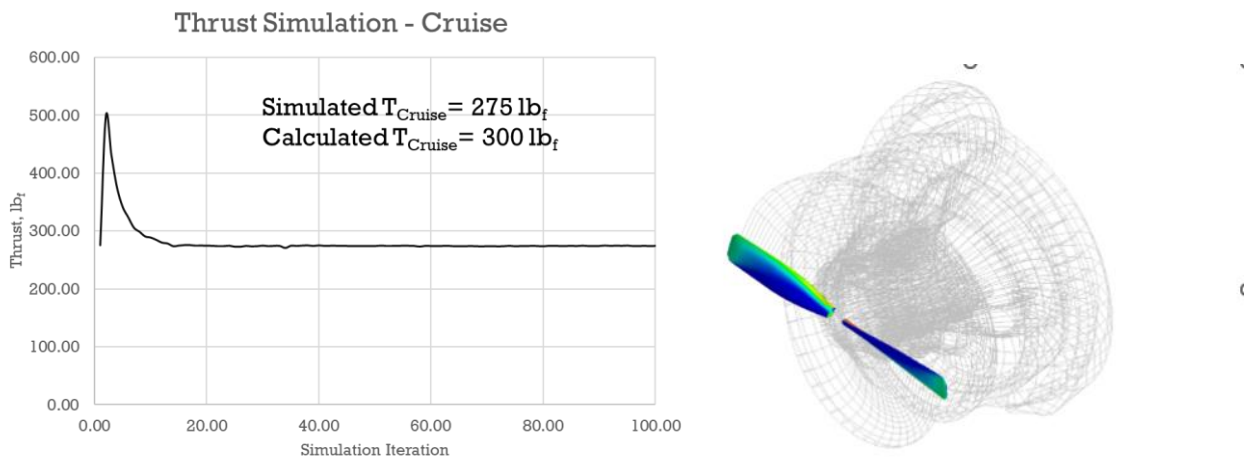


Figure 9.3.2.2 Unsteady Simulation of 61"D x 20"P at 3500 RPM using FlightStream

9.3.3 Propulsion integration

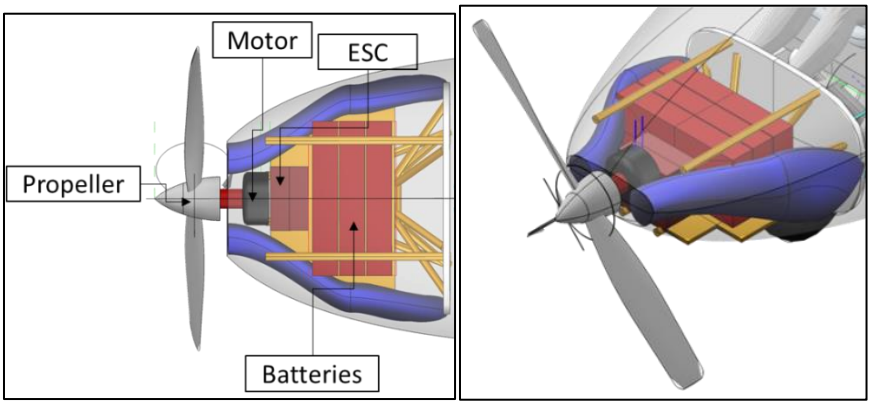


Figure 9.3.3.1: Propulsion Integration with Batteries

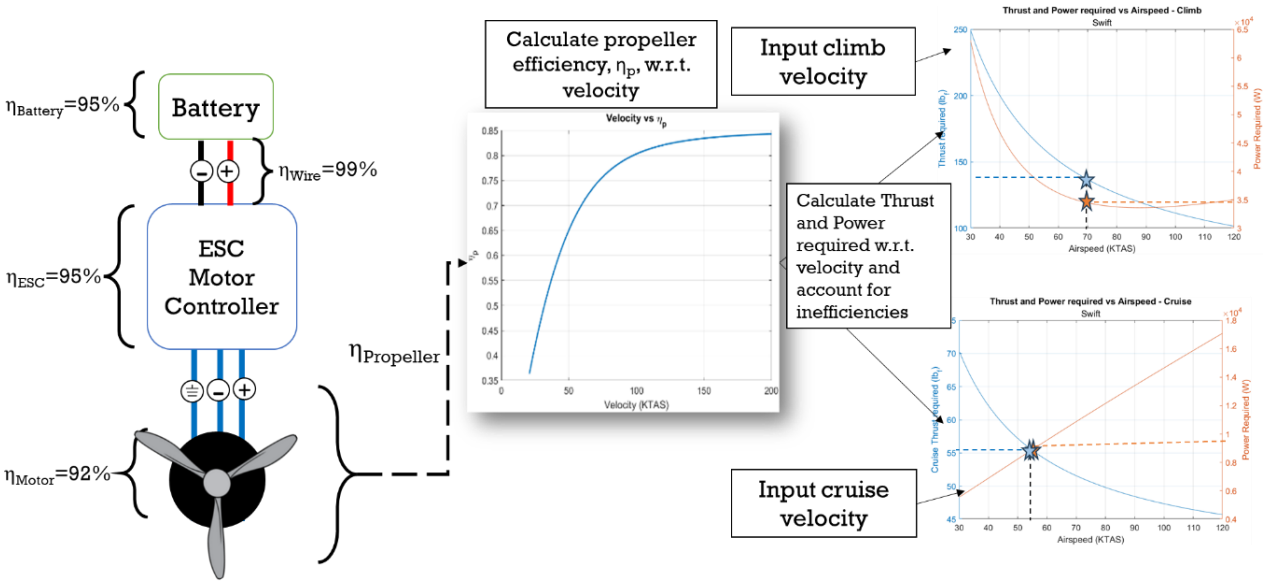


Figure 9.3.3.2: Powertrain Efficiencies and Required Thrust and Power at Different Missions

9.3.4 Battery and Range

The battery selection is crucial to the mission and performance of the aircraft. With the demand for higher energy density batteries rising for electric vehicles such as cars and eVTOLs, technology is rapidly advancing. The team researched historical data and trendlines for Lithium-Ion batteries with a specific energy density and volume of 400 Wh/kg and 500 Wh/L, respectively, for 2029 as RFP required. These estimations are conservative compared to other researched values for specific energy density and volume up to 650 Wh/kg and 1000 W/L, respectively, nearing 2030.

The required battery capacity for all missions is 25 kWh (400V | 62.5 Ahr), weighing 62.5 kg and occupying 50L (1.77 ft^3) of space. During all operations, the battery pack will nominally provide 400V (3.8V/cell), requiring 105 cells in parallel at 378V (3.6V/cell) cutoff voltage. The calculations for range consider speed and power consumption to find the total range covered until the battery reaches 20%. The 20% reserve satisfies CS 22.959 requiring dedication of battery capacity declared as unusable to avoid damaging the energy source. To get the sum of power consumed during the entire mission, velocity and consumed power at each phase are determined and subtracted from battery capacity. The team iterates the time spent during the cruise-climb phase at a specified velocity to find the total range covered until the battery reaches 20% capacity, which indicates the end of powered soaring flight. The 25-kWh battery provides power for three takeoff-climbs during training missions and a range of 176 km during soaring missions on a single charge. Once again, the estimations are conservative in generalizing the number of flights per charge and the range for most conditions.

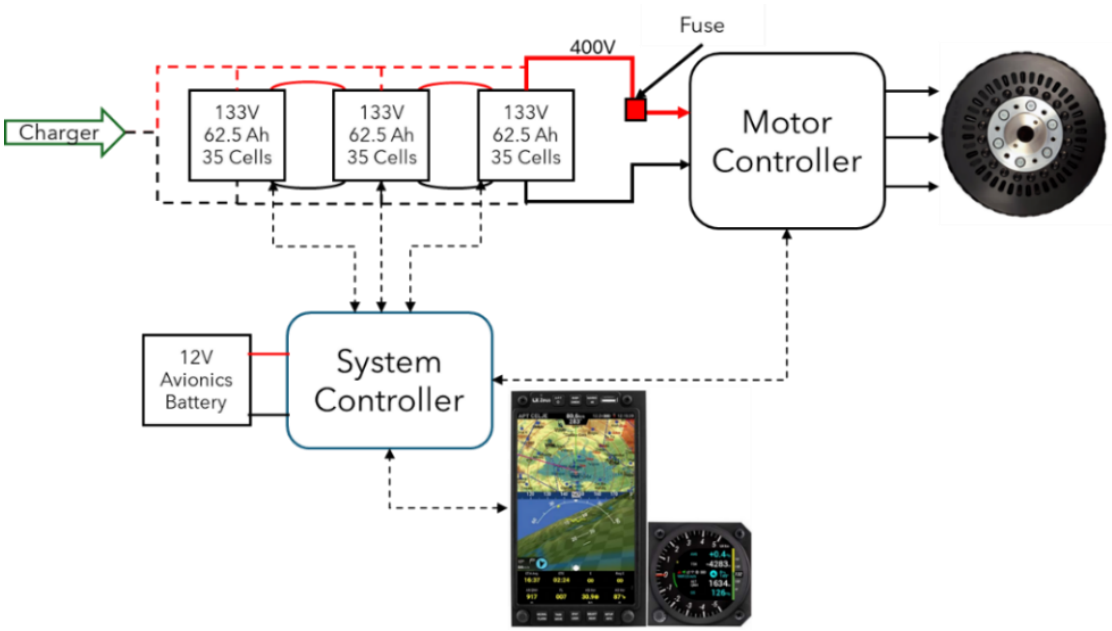


Figure 9.3.4.1: Electrical Schematic

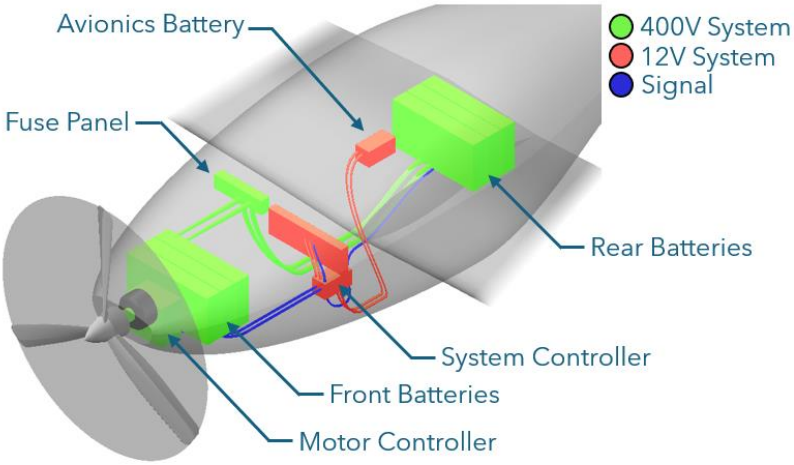


Figure 9.3.4.2: Color Coded Internal Electronic Components

9.3.5 Thermal Management

To ensure electrical components do not overheat, surface temperatures of critical electrical systems were calculated for a self-retrieve mission profile. The motor uses air cooling, so the team made forced convection assumptions. The ESC is cooled through ducts in the nose, where fins will be used in the ducts to provide even more cooling. These ducts Forced convection and conduction assumptions were made in its analysis. The battery is located behind the passengers and is only cooled by natural convection and radiation. Figures 9.3.5.1 and 9.3.5.2 plotted the component temperatures versus time under ISA and ISA +10°C conditions, respectively.

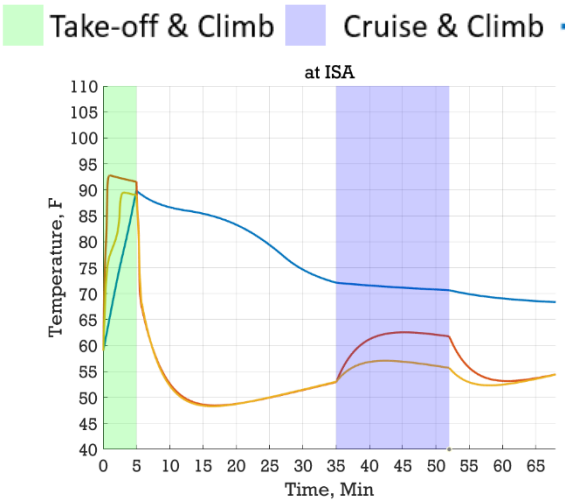


Figure 9.3.5.1: Component Temperatures at ISA

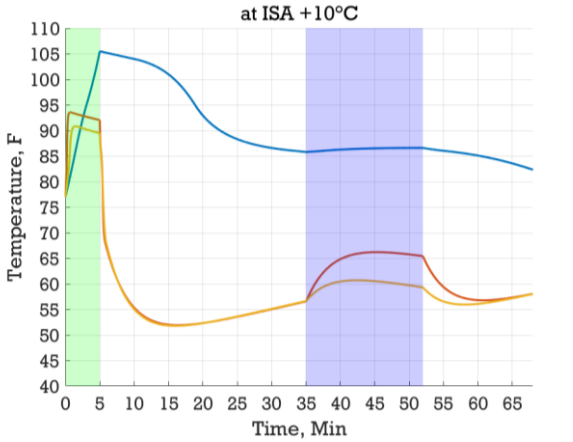


Figure 9.3.5.2: Component Temperatures at ISA +10 °C

9.4 Structures

9.4.1 V-N Diagram

Structural analysis began with developing the V-N Diagram for cruise condition and MTOW configuration. Following 14 CFR Part 23, the V-N Diagram shows both the maneuver and gust speeds with the load factor limits. The positive Maneuver load factors were determined using the following equation[28]:

$$n_{max} = 2.1 + \frac{24{,}000}{MTOW + 10{,}000} \qquad \text{Eqn. 9.4.1.1}$$

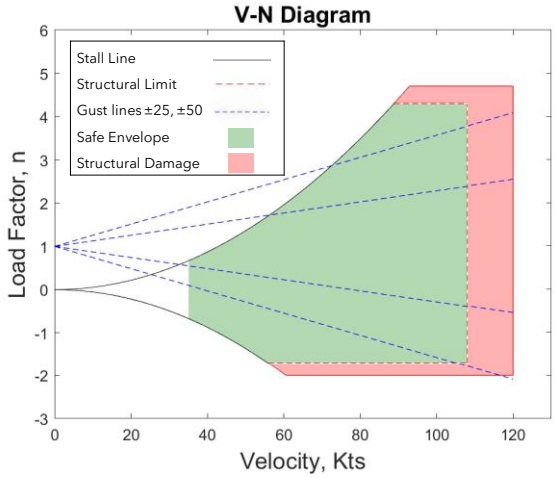


Figure 9.4.1.1: V-N Diagram with Max G of +4.3/-1.7

The negative max load was determined by following 14 CFR 23.337(b)(1) and multiplying the positive load factor by 0.4. Load factors from gust were determined using[28]:

$$n = 1 + \frac{K_g U_{gE} V_E\, a}{498 \frac{W}{S}} \qquad \text{Eqn. 9.4.1.2}$$

In the gust equation K_g is the gust alleviation factor, U_{gE} is equivalent to gust velocity in $\frac{ft}{s}$, V_E is the aircraft's equivalent airspeed in $\frac{ft}{s}$, and a is the slope of the airplane's normal force curve. Figure 9.4.1.1 shows Swift's V-n diagram at 3,500 ft ASL with an MTOW of 977 lbs. in its standard configuration.

Figure 9.4.1.1 shows the Swift will experience maneuver loads of +4.3 and -1.7; these maximum load factors will be evaluated against the material allowables in structural analysis.

9.4.2 Loads

The maximum loads to be experienced by the aircraft were determined by multiplying the max g loading from the V-n diagram by the lift distribution on the wing and running load on the fuselage. Figure 9.4.2.1 shows the distributed aerodynamic, weight, and resultant net loads experienced by the wing, which is idealized as a cantilever beam fixed at the fuselage.

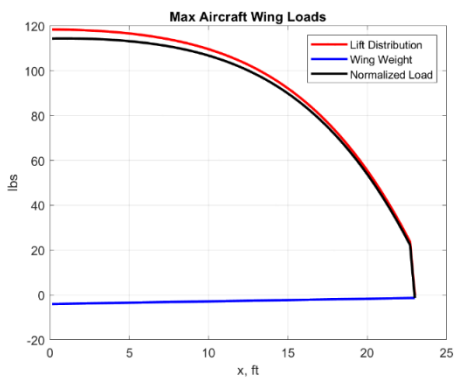


Figure 9.4.2.1: Aircraft Wing Loads

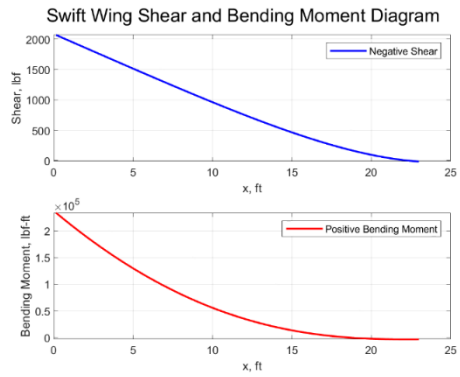


Figure 9.4.2.2: Wing Shear and Bending

The resultant net load was parameterized and treated as a singularity function, which was then integrated to determine the shear distribution; similarly, the shear load was integrated to determine the bending moment distribution across the wing. Figure 9.4.2.2 shows the wing's absolute shear and bending moment distribution under max positive load. The wing was determined to have a max shear force of 2,145 lbs. and a max bending moment of 233,900 $lb\text{-}ft$. These loads will determine the material selection and the resulting deflection.

9.4.3 Load Paths

After determining the loads of the aircraft, the load paths were illustrated on the wing and fuselage using static analysis. Figure 9.4.3.2 shows the wing load paths with shear force at the root, compression on the top, and tension at the bottom.

Figure 9.4.3.1: Aircraft Wing Load Path

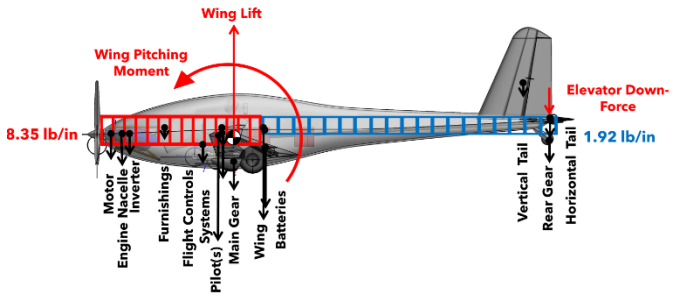


Figure 9.4.3.2: Aircraft Fuselage Running Load

Figure 9.4.3.2 shows the load paths for the fuselage, broken down into running loads for the fuselage weight, point loads for components, and aerodynamic forces.

9.4.4 Material Trade Studies

The next step in the structural analysis was determining the primary materials for the aircraft structure; traditional metals like aluminum and composite materials were evaluated. Composites were selected for a majority of components due to their higher strength-to-weight ratio; however, aluminum was still selected for the stringers. Graphite epoxy composite was selected for the main spar and keel of the aircraft. Fiberglass epoxy was selected for aircraft skin, ribs, and formers. Table 9.4.4.1 shows the mechanical properties of the selected materials[8][20].

Table 9.4.4.1: Mechanical properties of selected composites

Mechanical Properties	Graphite/Epoxy	Fiberglass/Epoxy	Al 6061-T6
Modulus of Elasticity, Longitudinal (MSI)	26.25	5.60	9.9
Modulus of Elasticity, Transverse (MSI)	1.49	1.20	9.9
Shear Modulus (MSI)	1.04	0.60	3.8
Ultimate Tensile Strength, Longitudinal (KSI)	217.56	154.03	41.0
Ultimate Compressive Strength, Longitudinal (KSI)	217.56	88.47	41.0
Ultimate Shear Strength (KSI)	9.863	10.44	28.0
Ultimate Compressive Strength, Longitudinal (KSI)	0.0585	0.0645	0.0975

Classical Lamination Theory (CLT) was used to evaluate the strength and sizing of the composites, as well as the 10% strength rule developed by John Smith of Boeing[16]. In the design of the wing spar, the team varied two independent variables: the spar width and the number of plies. To simplify the analysis, a base ply orientation of [0 45 90 45 0] was kept constant, and so the number of plies would be in intervals of 5. After using CLT to evaluate stresses in each lamina, Hoffman's failure Criterion for plane stress is used to find the margins of safety, following Dr. Coburn's Composite Strength Handbook recommendations[8]. Then, crippling allowables are evaluated using buckling approximations based on an averaged D stiffness matrix. These allowables are conservative as they do not account for clamped conditions. By finding the critical margin of safety for varying spar width and ply number wing spars, the carpet plot in Figure 9.4.5.1 can be generated. This can be used to optimize the spar's weight versus the minimum safety margin. A lack of mounting space for fasteners or lap joints constrains the spar width greater than 2.4 inches. Therefore, the team chose a design point of 0.25-inch thickness and 3-inch width spar.

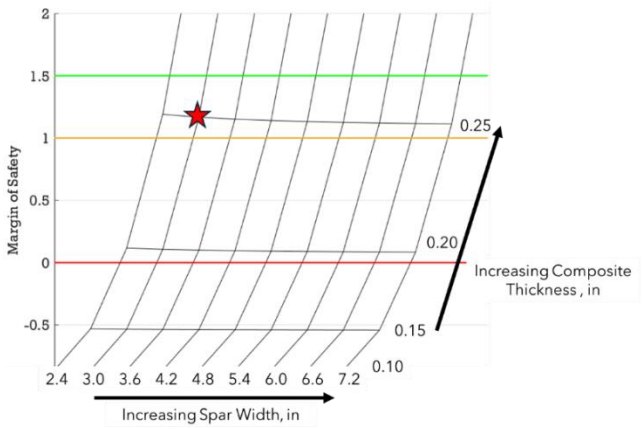
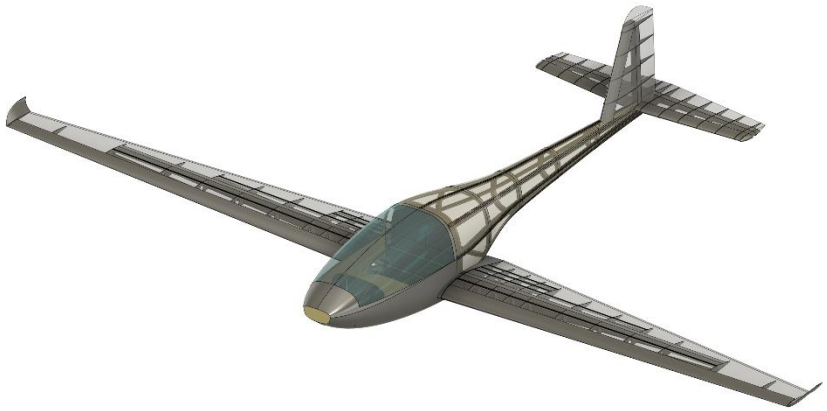


Figure 9.4.5.1: Composite Flange Optimization with Design Point of 1.15 Margin of Safety

9.4.5 Structural Layout



9.4.5.1 Wing Structure

The wing structure comprises two C-channel spares spaced equally from the aerodynamic center to carry the load, with C-hat stringers around the perimeter with dimensions as seen in Figure 9.4.5.1.1. In the wing, there will be 12 ribs spaced initially at 1.0 ft near the root, then 2.0 ft towards the tip. The wing skin will have a thickness of 0.1 in.

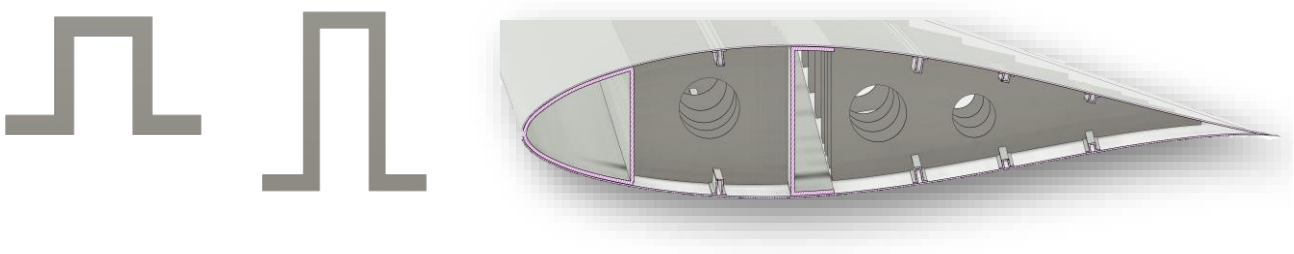


Figure 9.4.5.1.1: Wing Root Structure and Stringer Cross Section

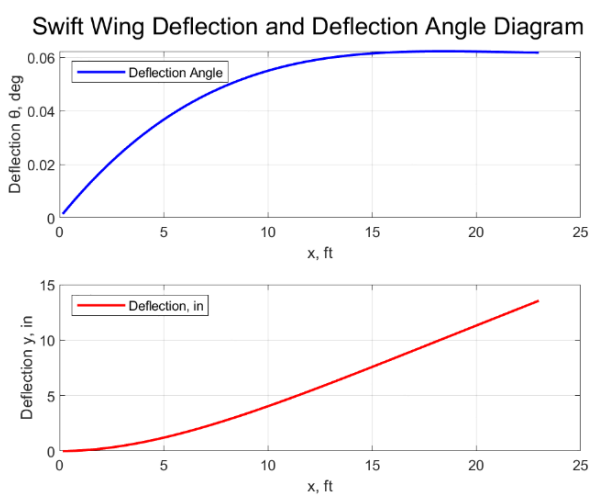


Figure 9.4.5.1.2: Aircraft Wing Deflection

Using the mechanical properties of the selected composite materials and the substitution of $EI = Db$, where E is the modulus of elasticity, I is the moment of inertia, D is the average bending stiffness from the D matrix in *CLT*, the deflection angle and deflection of the wing was determined by integrating upon the bending moment as shown in Figure 9.4.5.1.2.

The wing is expected to experience its max stresses on the top of the wing in compression and shear at the root and have minimum margins of safety listed below in Table 9.4.5.1.1 determined by Hoffman's ultimate failure criterion.

Table 9.4.5.1.1: Wing Stresses and Margins of Safety

Max Axial Stress (KSI)	Max Shear Stress (KSI)	Min. Axial MS	Min. Shear MS	Min. Buckling MS	Min. Crippling MS
-19.60	5.00	10.12	4.40	1.90	1.1667

Figure 9.4.5.3: Fuselage and Internal Wing Structure

9.4.5.2 Fuselage Structure

The fuselage structure is comprised of formers spaced at every 3.0 $ft.$, with C-hat stringers around the perimeter and a keel along the bottom with dimensions as seen in Figure 9.4.5.2.1. The fuselage skin will have a thickness of 0.25 in. The forward firewall is angled back 30 degrees to improve survivability in the event of a gear-up landing, complying with CS 22.1353.

9.4.5.3 Shear Pin Analysis

The shear stress at the root was used to evaluate the spar pin connection to the fuselage. Pins with 1.25 $in.$ diameter in a horizontal pair pattern per spar was selected as shown in Figure 9.4.4.3.

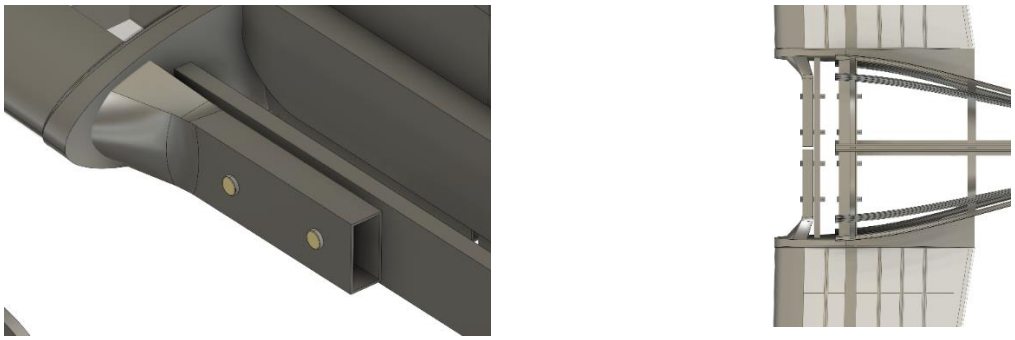


Figure 9.4.5.3.1: Wing Fuselage Pin Connection

10.0 Performance

The Swift features all-electric self-launch capabilities with a high rate of climb of 600 $\frac{ft}{min}$, maximum range of 167 miles, and sink rate of 192.6 $\frac{ft}{min}$ in a 250 ft radius turn at +10 °C. These allow it to take off without usage of winches and towplanes from fields ranging from 520 ft to 800 ft, while also providing increased performance in turns to stay within thermals. The Swift accomplishes this with its 33.7 lbs. EMRAX 208 electric motor, providing peak power of 86kW and continuous power of 56kW, giving the Swift 600 $\frac{ft}{min}$

climb at 70 knots. These features allow room for error which enhances trainee experience by giving them more controllability.

10.1 Take-Off

The Swift is designed to operate in grassy fields. The assumed ground friction coefficient for take-off is 0.2 while braking and 0.08 with brakes off, values for wet grass from Gudmundsson[30][30]. The motor is assumed to be throttled to a continuous power mode of 56kW.

10.1.1 Balanced Field Length

The balanced field length shows the braking distance required at a given velocity graphed over take-off velocities at a runway length. If there is an engine malfunction or configuration error, the intersection point gives the abort velocity and runway distance. In its max configuration with 977 lbs. and ISA +10°C the Swift's balance field length is 745 ft at 54.8 knots, as seen in figure 10.1.1. The balanced field length is calculated using Raymer's[25] [25][25] and Schaufele's[28][28] design textbook methods, yielding results differing by about 1%. Since the Swift is a single-engine aircraft, typical one-engine inoperable conditions were not analyzed.

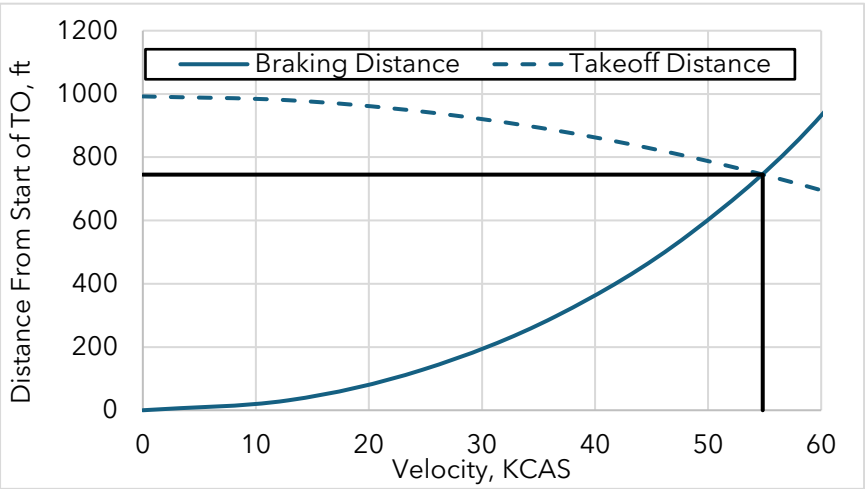


Figure 10.1.1: Balanced Field Length

10.1.2 Take-Off Run

For analysis accuracy, Gudmundsson's design textbook[30][30] recommends an iterative approach to a typical take-off run. Using thrust produced as a function of airspeed, provided in section 9.3.1, the aircraft's acceleration, velocity, dynamic pressure, lift, and drag can be calculated in that order. The equation to find the aircraft acceleration when lift, drag, thrust and airspeed are found is given by equation 10.1.2.1, where gravity (g) is 32.2 $\frac{ft}{s^2}$ and weight (w) is 997.1 lbs. This is then put into kinematic equations to find iterative velocity (V_i)

and distance (S). With the recommended time step of 0.25 seconds, the process is repeated until V_i reaches rotation velocity (V_{LOF}), estimated to be 1.1 times the stall speed (V_{Stall}), given by equation 10.1.2.2. Rotation distance (S_{LOF}) is found as part of kinematic equations.

$$a_i = \frac{g}{W} * [T(v_{i-1}) - D_i - \mu * (W - L_i)] \qquad \text{eq. 10.1.2.1}$$

$$V_{Stall} = \sqrt{\frac{2 * W}{\rho * S_w * C_{L\,max}}} \qquad \text{eq. 10.1.2.2}$$

After V_{LOF}, the aircraft enters a transition period to rotate to 6° rotation conditions. The climb angle γ_{climb} can be calculated using equation 10.1.2.3, and after estimating radius through equation 10.1.2.4, transition runway distance (S_{TR}) and height can be calculated using trigonometric relations in 10.1.2.5. After subtracting the obstacle height from the transition height, the remaining distance can be calculated using trigonometric relations to clear the 50 ft obstacle in equation 10.1.2.6. Summing the S_{LOF}, S_{TR}, and S_{Climb} gives the total take-off runway distance required to clear $h_{obstacle}$ of 50 ft obstacle.

$$\gamma_{climb} = \sin^{-1}\frac{T}{W} - \frac{D}{L} \qquad \text{eq. 10.1.2.3}$$

$$R \approx 0.2156 * {V_{Stall}}^2 \qquad \text{eq. 10.1.2.4}$$

$$S_{TR} = R * \sin\gamma_{climb} \quad , \quad h_{TR} = R * (1 - \cos\gamma_{climb}) \qquad \text{eq. 10.1.2.5}$$

$$S_{Climb} = \frac{h_{obstacle} - h_{TR}}{\tan\gamma_{climb}} \qquad \text{eq. 10.1.2.6}$$

This method allowed the team to account for three flight conditions that can be seen in figure 10.1.2.1: three wheels on the ground at 11° α, two wheels on the ground at 0° α, and rotation condition at 6° α. The figure has a left y-axis of airspeed in knots, right y-axis of altitude, and x-axis in runway distance, both in feet. The lift and drag coefficients were gathered using the same methods from section 9.1.4, including take-off flaps and ground effects.

In Figure 10.1.2.1, the Swift weighs 997.1 $lbs.$ and is at 1,000 ft MSL at +10 °C from T 0.0-32. In this configuration, the minimum runway length needed to clear a 50 ft obstacle at the end of the runway is 785 ft.

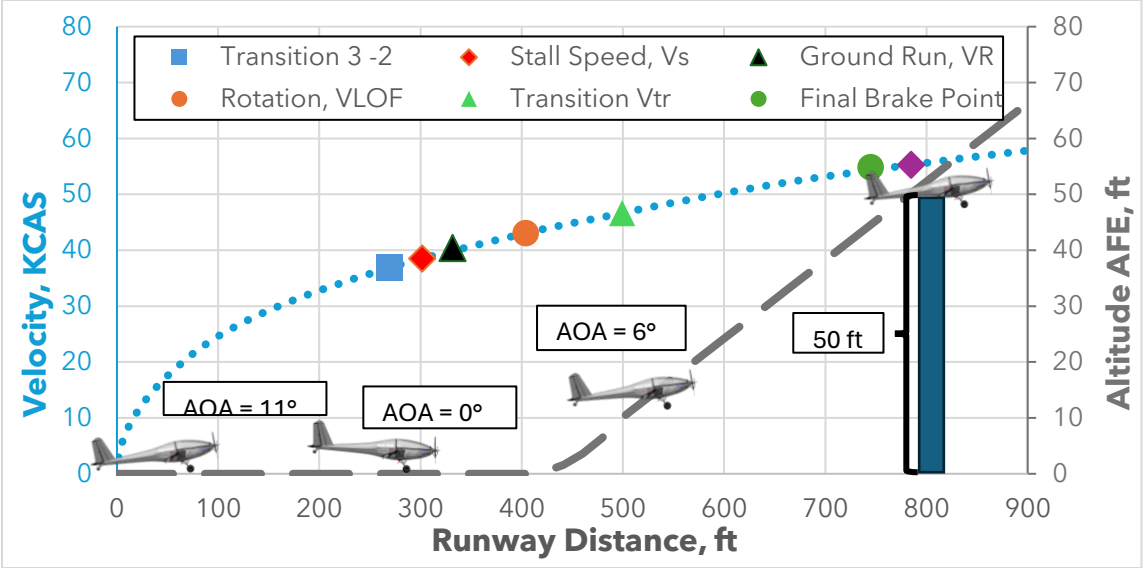


Figure 10.1.2.1: Take-Off Diagram

These results indicate that the balanced field length critical speed happens right before climb velocity (V_2) meaning that the aircraft is already 43 ft into the air. In the event of an engine failure prior to this final brake point and with a 50-ft obstacle in the flight path, the pilot is advised to fully activate spoilers and attempt to return to the ground, as without engine power safely, the aircraft cannot clear the obstacle.

10.1.3 Take-Off Sensitivity

Large variations in take-off configurations due to weight and weather conditions impact the take-off capability of the Swift. Using Gudmundsson's recommendations[30][30], the methods used in section 10.1.2 can be repeated using MATLAB to generate tables of required take-off distances at varying altitudes, weights, and ISA temperature differences to demonstrate the aircraft's capabilities in different conditions. As seen in Figure 10.1.3.2, at 1,000 ft altitude msl and maximum crew weight of 400 lbs., the Swift can take off at 875 ft or longer runways. Within the operational weight range of 687 lbs. and 1065.8 lbs., the runway distance required to take-off ranges from 520 ft to 900 ft, as seen in Figure 10.1.3.1.

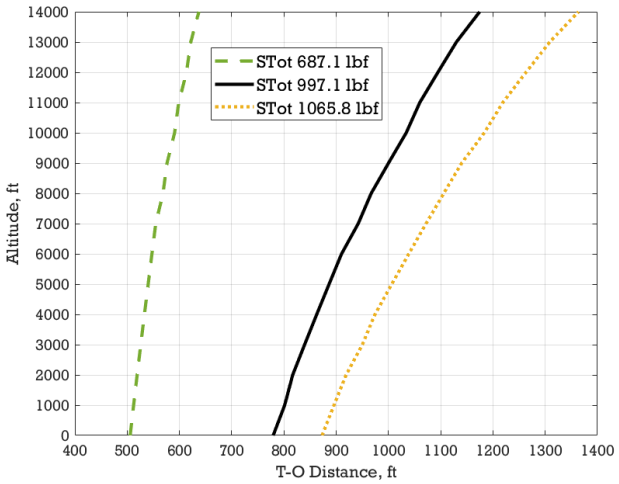


Figure 10.1.3.1: Weight Effects on Take-Off Distance

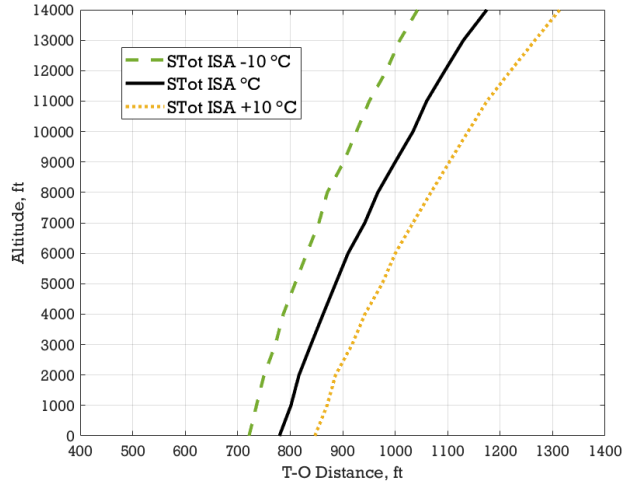


Figure 10.1.3.2: Temperature Effects on Take-Off Distance

10.2 Climb

The Swift's rate of climb is required to be greater than 600 $\frac{\text{ft}}{\text{min}}$ and airspeed to be between 1.3 times stall speed and 80 knots during the first segment of both missions from requirement T 0.0-34. Figures 10.2.1 and 10.2.2 show the effects of altitude and ISA +10°C. The equations and approach are introduced in Gudmundsson's[30] text[30]. In both ISA conditions, the Swift reaches the desired rate of climb at specified airspeed ranges. To conserve battery endurance for subsequent missions, the minimum rate of climb was chosen at 600$\frac{\text{ft}}{\text{min}}$, at around 70 knots for the mission profiles.

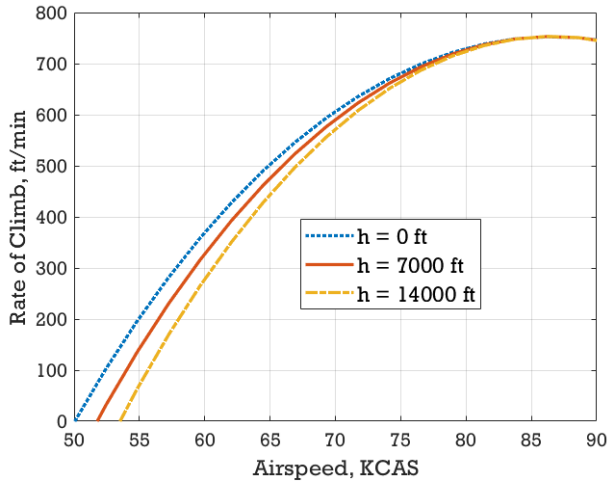


Figure 10.2.1: Height Effects on Rate of Climb

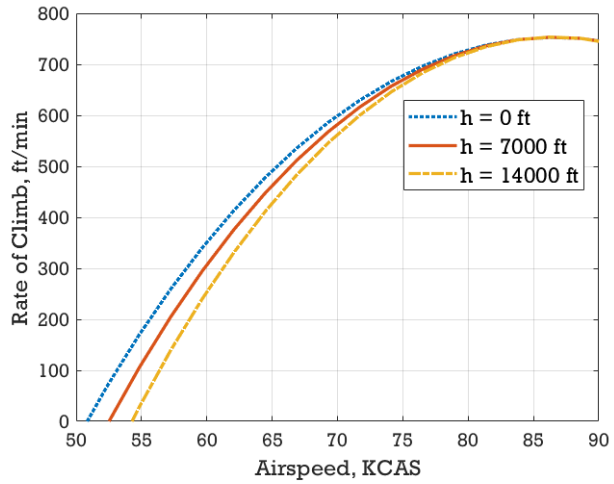


Figure 10.2.2: Temperature Effects on Rate of Climb

10.3 Descent

In the unpowered descent of a sailplane, there are two important considerations: turning and gliding. Turning is required when the pilot tries to stay within a thermal column of rising air that gives energy to an sailplane;

therefore, the sink rate in a sustained turn is important to analyze. Within the RFPs listed, KPPs include a requirement for the aircraft to have a sink rate no greater than 250 $\frac{\text{ft}}{\text{min}}$, while the objective to meet is 150 $\frac{\text{ft}}{\text{min}}$.

In level flight gliding, there are two velocities to calculate: the best sink rate airspeed (V_{BA}) and the best glide ratio airspeed (V_{BG}). The first maximizes endurance and can be derived from a glide polar plot by minimizing sink rate. The second maximizes range, trading a higher sink rate for greater airspeed, and is the velocity with the highest L/D ratio. Using a glide polar to find the sink rates at those airspeeds allows the calculation of glide angle (γ_{Glide}). The airspeed for best endurance is used in the descent segment of the instructional flight mission to extend the time to 10 minutes, and in the soaring flight segment of the self-retrieval flight mission to extend the time to 30 minutes with the assistance of thermals. The best glide airspeed is used in the climb-cruise and descent segments of the self-retrieve mission to reach the 31-mile threshold and 124-mile objective KPP.

10.3.1 Turn

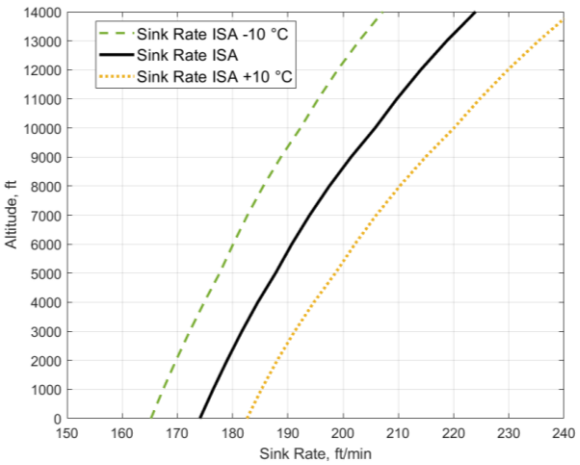


Figure 10.3.1.1: Temperature Effects on Sink Rate at a Constant 250 ft Radius Turn

Using equation 10.3.1.1 from Gudmundsson's text[30], with the given radius of 250 ft, the corresponding velocity to a given bank angle (ϕ) can be found from eq. 10.3.1.1. Using bank angle and airspeed, the lift and drag coefficients can be found and plugged into equation 10.3.1.2, the sink rate (V_{SC}) can be found at that bank angle and airspeed.

$$\phi = \tan^{-1}\left(\frac{v^2}{R * g}\right) \qquad \text{eq. 10.3.1.1}$$

$$V_{SC} = \frac{C_D}{C_L^{\frac{3}{2}}} * \sqrt{\frac{2}{\rho} * \left(\frac{W}{S}\right)} * \frac{1}{\left[1-\left(\frac{2}{\rho} * \frac{w}{s} * \frac{1}{r * g * C_L}\right)\right]^{\frac{3}{4}}} * 60 \qquad \text{eq. 10.3.1.2}$$

The aircraft weight used was 997.1 lbs. , the heaviest default configuration. Using MATLAB, a sweep of ϕ from 10° to 60° was evaluated, taking the minimum sink rate. This process is repeated over a range of 0 to 14000 altitude, the service ceiling dictated by RFP, and between ISA ±10°C conditions. The Swift satisfies the threshold value of the KPP at 192.6 $\frac{ft}{min}$.

10.3.2 Glide Polar

The glide polar from Figure 10.3.1.1 has three black lines plotted. The 4.7 $\frac{lb}{sf}$ wing loading allows only the solo pilot to weigh 90 lbs. The default aircraft's 6.8 $\frac{lb}{sf}$ configuration is the heaviest, and the 7.3 $\frac{lb}{sf}$ configuration with the optional 50% battery in the nose is the heaviest.

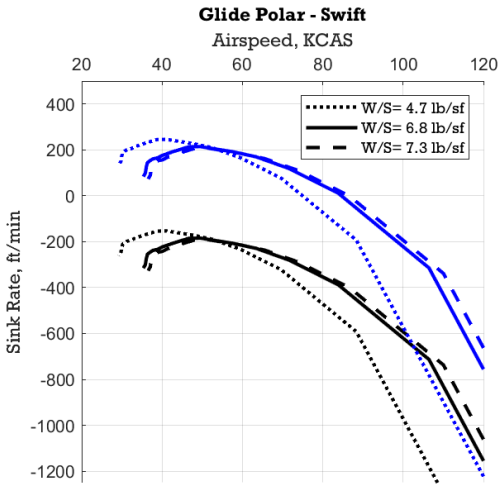


Figure 10.3.2.1: Glide Polar With 3 Wing Loadings

The blue lines represent possible thermals using the power-law velocity profile from Gudmundsson's text[30][30] in equation 10.3.2.1, where n=2, V_{TO} is the maximum updraft in the center of the thermal, V_T is the aircraft's current updraft, R is the total radius of the thermal, and r is the aircraft's current radius. From the text's recommendations, R is assumed to be 1000 ft, and V_{TO} to be 4.2 knots. Coupled with the RFP requirement of 250 ft radius, the updraft is found to be 398.8 $\frac{ft}{min}$, which is added to the sink rate to simulate thermal performance.

$$\frac{V_T}{V_{TO}} = 1 - \left(\frac{r}{R}\right)^n \qquad \text{eq. 10.3.2.1}$$

From section 9.1.1, the best glide radio airspeed V_{BG} was found to be 70 knots. The sink rate is 243 $\frac{\text{ft}}{\text{min}}$, used in section 9.3.2.2 to calculate the maximum range during self-retrieve flight. The minimum sink rate airspeed is 48 knots, as shown in Figure 10.3.2.1. With a sink rate of 194 $\frac{\text{ft}}{\text{min}}$, this was used to calculate a time of 12.9 minutes to descend 2,500 ft, satisfying the instructional mission requirement of 10 minutes.

10.4 Landing

The team calculated Swift's landing performance using Gudmundsson's[30] approach[30], beginning with estimating the unpowered descent angle ($\gamma_{Descent}$) through equation 10.4.1. The radius of rotation to touchdown is found in equation 10.4.2 and is used to find the flare height in equation 10.4.3. This is subtracted from the 50 ft required obstacle height and used to find approach distance (S_A). Flare distance (S_F) is calculated based on radius and descent angle in 10.4.4, while the free roll distance (S_{FR}), where the aircraft has touched down, but the brakes have not been activated yet, is assumed to last one second, and therefore is equal to the airspeed, the braking distance (S_{BR}) is calculated using equation 10.4.7. The assumptions for braking friction

coefficients remain the same from section 10.1 take off. The four distances are then summed up to a total landing distance in equation 10.4.8.

$$\gamma_{Descent} = \tan^{-1}\left(\frac{D}{L}\right) \quad \text{eq. 10.4.1}$$

$$R = 0.1512 * V_{Stall}{}^2 \quad \text{eq. 10.4.2}$$

$$h_f = \mathrm{R} * (1 - \cos(\gamma_{Descent})) \quad \text{eq. 10.4.3}$$

$$S_A = \frac{(h_{obstacle} - h_f)}{\tan(\gamma_{Descent})} \quad \text{eq. 10.4.4}$$

$$S_F = R * \sin(\gamma_{Descent}) \quad \text{eq. 10.4.5}$$

$$S_{FR} = V_{FR} \quad \text{eq. 10.4.6}$$

$$S_{BR} = \frac{V_{BR}{}^2 * W}{2 * g * [T - D_{landing} - \mu * (W - L_{landing})]} \quad \text{eq. 10.4.7}$$

$$S_{TOT} = S_A + S_F + S_{FR} + S_{BR} \quad \text{eq. 10.4.8}$$

The landing analysis of the 997.1 $lbs.$ default configuration at ISA +10 °C can be found in figure 10.5.1 where airspeed is plotted against runway distance. The wings are designed to reach L/D_{MAX} of 30, so piloting the plane to descend can be difficult. With partial spoilers, the L/D can be brought down to 5, leading to a glide angle of 10°.

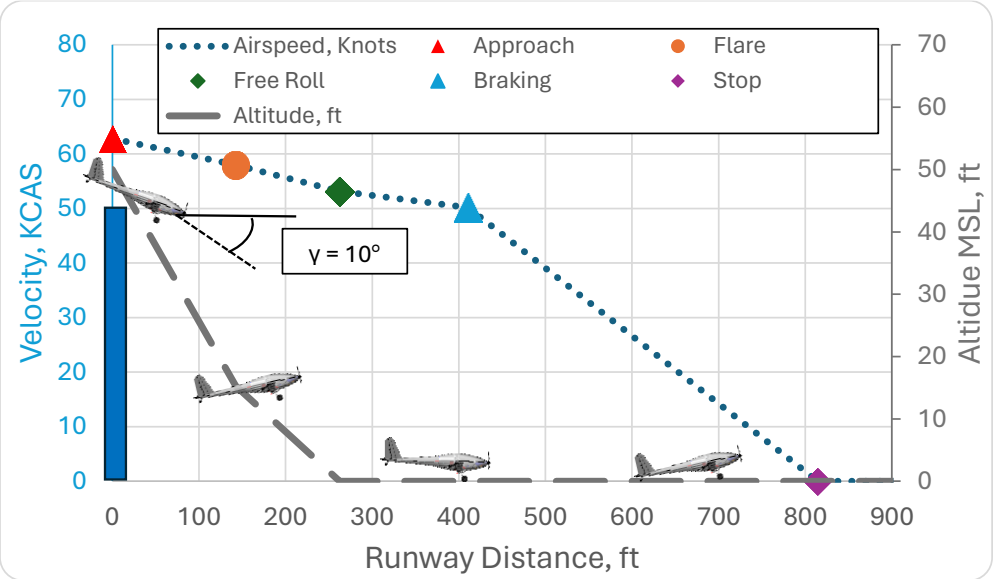


Figure 10.4.1: Landing Diagram

The iterative process is once again repeated to find landing sensitivity to temperature and weight in figures 10.4.2 and 10.4.3. The Swift can land at a typical glider port runway length of 1,000 ft anywhere below 8,000 ft MSL at all ISA temperature conditions, and below 11,000 ft MSL for all weight configurations.

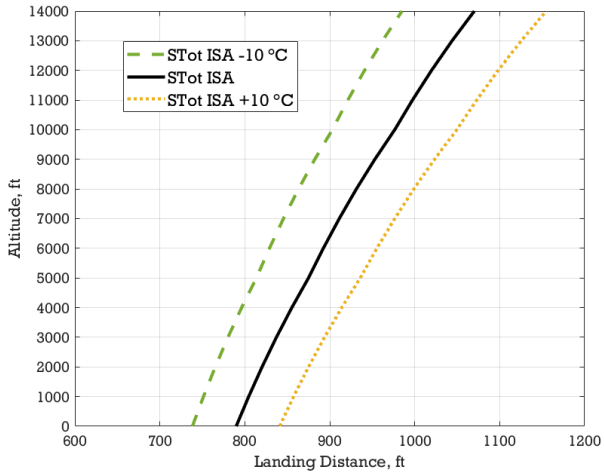


Figure 10.4.2: Temperature Effects on Landing Distance

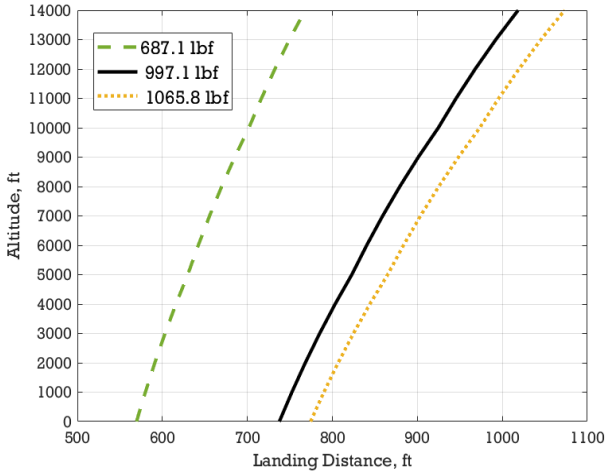


Figure 10.4.3: Weight Effects Landing Distance

10.5 Range

Using the method discussed in section 9.3.2.2, 5 ranges were calculated and shown in figure 10.5.1. The percentage of each number represents the percent battery installed onto the aircraft. The payload is assumed to be the second pilot.

In the default configuration, the Swift reaches 104 miles (167 km), meeting the KPP threshold of 31 miles (50 km) but not the objective of 124 miles (200 km). With the optional 50% battery installed into the nose at number 5, the range reaches 166.5 miles (268 km), satisfying the KPP objective.

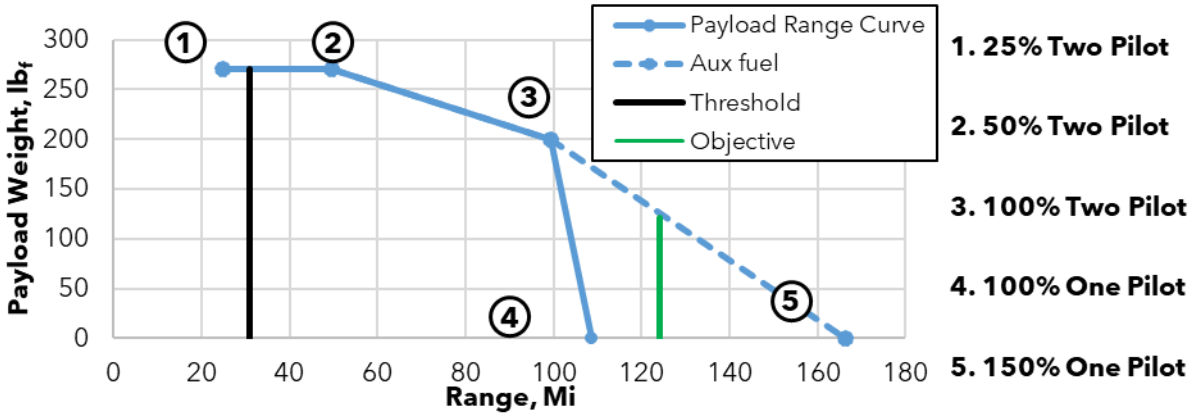


Figure 10.5.1: Payload-Range Curve

11.0 Operations and Support

The primary focus of the Swift aircraft is to enable rapid turnaround so that the operators can maximize the number of training flights in a 6-hour period as specified in the KPP. The Swift can be stored in 35

feet x 6 feet x 6 feet trailer (T 0.0-11) and assembled by two individuals in 17 minutes satisfying T 0.0-8. The sailplane also features self-aligned connections for control surfaces attached during the assembly process. The Swift can complete three instructional missions on one charge with a turnaround in 12 minutes, after a 20-minute flight. If battery, along with the instructor need to swap, the turnaround is completed in 22 minutes (Figure 11.3.1), all the while costing only $21/hr. for the operator (Sec 13.3).

11.1 Trailer Storage and Removal

The Swift sailplane is designed with a detachable wing, propeller, and horizontal stabilizer so that it fits into a 35'x6'x6' trailer as required in T0.0-11, as shown in Figure 11.1.1. It can easily be stored and transported to any field for training and recreational missions.

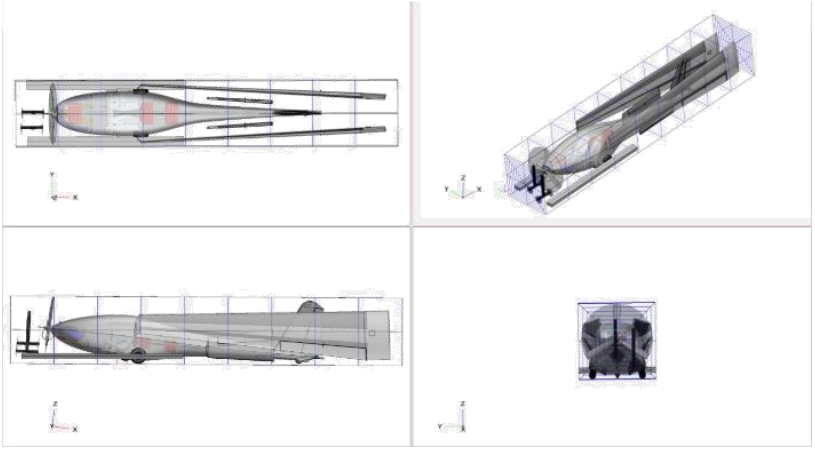


Figure 11.1.1: Swift Sailplane Disassembled and Stored in 35'x6'x6' Trailer

11.2 Field Assembly and Disassembly

The trailer can be driven to any field, and the Swift can be easily assembled in 17 minutes by two individuals. The trailer contains tools such as wing assists to ease the assembly process. Figure 11.2.1 provides the assembly process, showing the detailed approach to ensure the correct order is followed.

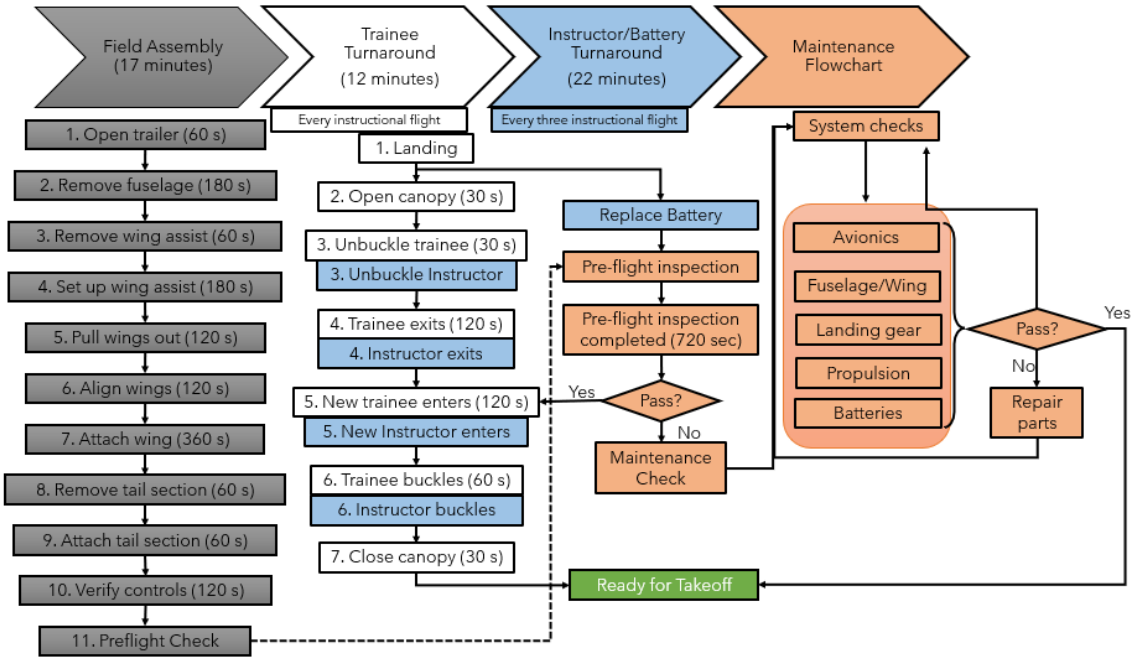


Figure 11.2.1: Assembly, Trainee, Instructor/Battery, and Maintenance Turnaround Flowchart

- Begin by assessing the overall condition of the fiberglass or fabric.
- Be alert for signs of damage or excessive wear.
- Ensure that the canopy is clean and free from damage.
- Verify the interior wing and control connections are safe and secure.
- If a battery is used, ensure that it is charged and safely fastened in the proper spot.
- Ensure that seat harnesses are free from excessive wear.
- Buckle and tighten any harness that will not be used to prevent it from inadvertently interfering with controls.
- Test the tow hook to ensure it is operating correctly.
- Inspect top, bottom, and leading edge of wings, ensuring they are free from excess dirt, bugs, and damage.
- Inspect spoilers/dive brakes for mechanical damage. They should be clear of obstructions.
- Inspect the wingtip and wingtip skid or wheel for general condition.
- Inspect ailerons for freedom of movement, the condition of hinges and connections, and the condition of the gap seal.
- Check the condition of flaps for freedom from damage and for appropriate range of motion.
- Inspect the general condition of the empennage.
- Check static ports, pitot tube, and total energy probe to ensure they are free from obstruction.
- Check top, bottom, and leading edge of tailplane for of bugs, dirt, and damage.
- Check the landing gear for signs of damage or excessive wear. The brake pads should be checked if they are visible; otherwise, the brakes can be checked by pulling the glider forward and applying the brakes. Note that the landing gear is frequently a problem area for gliders used in training.
- Check elevator and trim tab for condition of connections, freedom of movement, and condition of gap seal.
- Check rudder freedom of movement and condition of connections.

Figure 11.2.2: Sailplane Preflight Inspection – Provided by the FAA[4]

11.3 Turnaround Times

The Swift can fly three instructional flights on one charge, with 20% reserve after the third flight to prolong battery health. The standard configuration consists of 25 kWhr batteries split amongst three battery packs. With six battery packs, the sailplane can continuously fly with three batteries for 6 hours per day while the other three packs charge. Figure 11.2.1 shows the trainee and instructor/battery turnaround flowchart where trainee missions are broken into three flights, back-to-back each, and trainee turnaround between each flight. After every third flight, the instructor and batteries are swapped, following the instructor/battery turnaround flowchart.

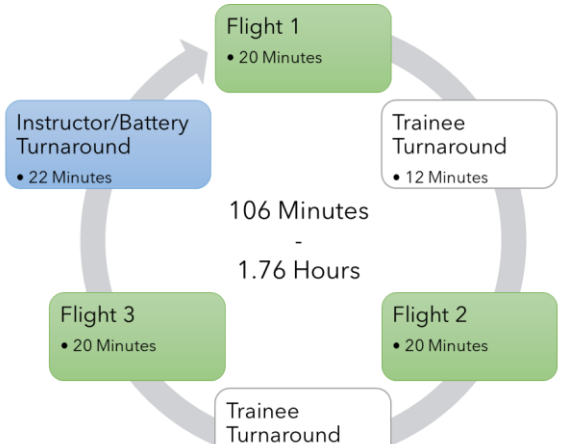


Figure 11.3.1: Instructional Turnaround Concept

As shown in Figure 11.3.1, a 20-minute training flight is followed by a 12-minute trainee turnaround and a 22-minute instructor/battery turnaround after every third and each segment taking 1.76 hours. The Swift can achieve a maximum of 10 instructional flights every six hours with standard battery configuration. The optional upgrade will allow five training missions with a maximum of 11 instructional flights every six hours.

11.4 Maintenance

The instructor and trainee will visually inspect as shown in Figure 11.2.2 the Swift before every flight, with the path shown in Figure 11.4.1. Any electrical, avionics, structural, or other major visual damage must be addressed, leading to aborting the flight, fixing the issue(s), and reinspection. The aircraft structure will be visually inspected before each flight and maintenance will be completed upon finding an issue and recertification will be required as per Part 23. Appendix A to Part 43 will be used for instructions and information for preventative maintenance, major repairs, and major alterations.

12.0 Manufacturing Approach

The Glydetek Swift employs fiberglass composite manufacturing, enabling the creation of the entire fuselage, vertical stabilizer, wings, horizontal stabilizers, and spars with a small number of clamshell molds.

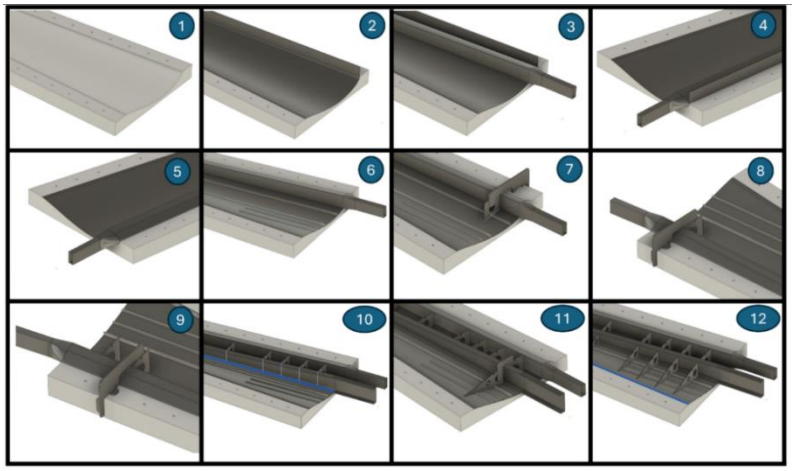


Figure 12.0.1: Internal Wing Structure Manufacturing Process

Table 12.0.1: Wing Manufacturing Process

Step	Description
1	Start with empty top skin mold.
2	Layup fiberglass into top skin with excess to wrap around leading edge.
3	Insert D spar and align with leading edge.
4	Lay excess skin over D spar.
5	Cut excess skin over D spar for leading edge joint, vacuum bag and let cure.
6	Sand and bond in aluminum stringers.
7	Use sheet metal tool to align front portion of ribs
8	Front view of how tool is bolted and aligned to mold
9	The sheet metal tool can be moved and re-bolted to locate all ribs
10	Use ribs to locate aft spar. Apply adhesive in highlighted areas
11	Clamp U-shaped sheet metal tool to front rib to locate aft ribs.
12	Sand trailing edge flat and prep for bonding wing together.

Using two-part clamshell molds for the fuselage and vertical stabilizer, along with similar molds for the wings, horizontal stabilizers, and spars, significantly reduce part count and process elimination. With a total of eight major molds, the manufacturing process achieves consistency, precision, reduced complexity, and part count. This results in shorter lead times, lower labor costs, and higher-quality finished products.

Figure 12.0.2 Wing Manufacturing Process

Table 12.0.2: Wing Manufacturing Process

Step	Description
1	Start with empty bottom skin mold.
2	Scribe mold to locate bottom skin cut.
3	Cut and remove excess bottom skin, vacuum bag, and let cure.
4	Sand and bond in aluminum stringers.
5+6	Attach crane to hard points on the side of the mold.
7+8	Lift and move mold away from table.
9	Attach crane to hard points near CG of mold.
10	Detach crane from hard points on the side of the mold.
11	Locate bottom skin over top skin, add adhesive to blue locations.
12	Lower and locate molds with pin holes, bolt together and let adhesive cure

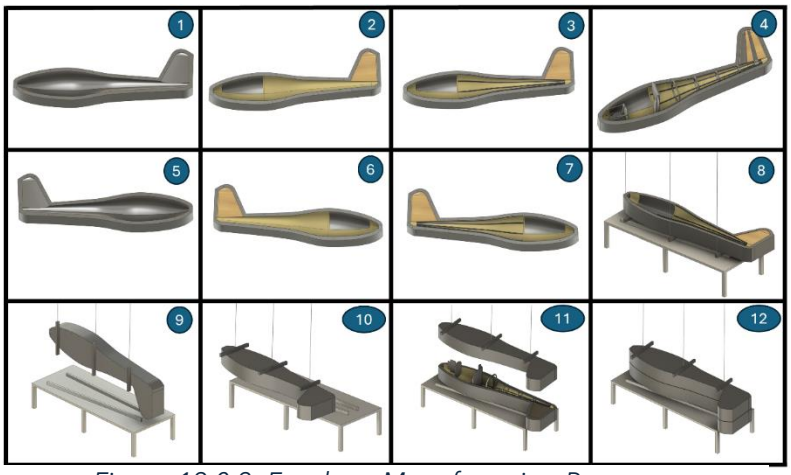


Figure 12.0.3: Fuselage Manufacturing Process

Table 12.0.3 Fuselage Manufacturing

Step	Description
1	Start with right hand side of fuselage mold.
2	Layup and trim fiberglass in mold.
3	Sand and bond in aluminum stringers.
4	Insert bulkheads, engine structure, firewall, and v-stab spars.
5	Start with left hand side of fuselage mold.
6	Layup and trim fiberglass in mold.
7	Sand and bond in aluminum stringers.
8	Attach crane to hard points on the side of the mold.
9	Lift and move mold away from table.
10	Attach crane to hard points near CG of mold.
11	Locate mold, apply adhesive to structure and attach with lap joint.
12	Bolt fuselage halves together and let cure.

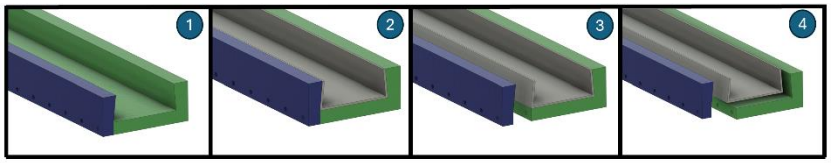


Figure 12.0.4: C-Spar Manufacturing Process

Table 12.0.4: C-Spar Manufacturing Process

Step	Description
1	Bolt together two-part C-channel spar mold.
2	Layup fiberglass plies and trim plies to length, then vacuum bag.
3	Demold spar by unbolting blue portion of mold.
4	Detach green portion of mold.

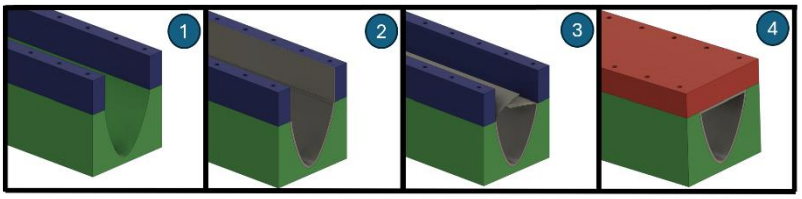


Figure 12.0.5: D-Spar Manufacturing Process

Table 12.0.5: D-Spar Manufacturing Process

Step	Description
1	Bolt blue portion of mold to green portion.
2	Layup fiberglass plies and cut to length.
3	Interleave fiberglass plies and lay on top of bladder.
4	Bolt red portion of mold, inflate bladder and let cure.

13.0 Business Case

The business case aims to provide an estimate of the costs for producing, maintaining, and operating the Swift aircraft. Additionally, it will prove its financial viability and determine the time at which the program reaches 15% profit. The Glydetek Swift is a low-cost option for sailplane training schools and private

aviators alike. This allows Swift considerable benefit versus the current market competitors which are nearly double the cost and offer less performance. The Swift's ability to market to the Electric Self-Launching Sailplane, General Aviation, and Light Sport Aircraft markets, allows it a large consumer base to lower the acquisition cost of the aircraft. In addition, the electric propulsion system's simple mechanics minimize maintenance and overhaul costs. Variable production rates, realistic distribution of labor throughout the program lifespan, and consideration of the cost of money over the 15-year production run allow for the accurate use of net present value methods to determine the business viability of the Glydetek Swift program (Sec 13.3) .

13.1 Production Rate

As initially mentioned in Section 3.0 Market analysis, four different market cases have been considered when calculating the acquisition cost of the Glydetek Swift. A detailed breakdown of each market case can be found in Figure 3.2.1 Market Case vs Unit Cost. As shown in Figure 13.1.2, a production rate was set for each market capture percentage to allow the program to ramp up and down from full scale production over its 15-year-long lifespan.

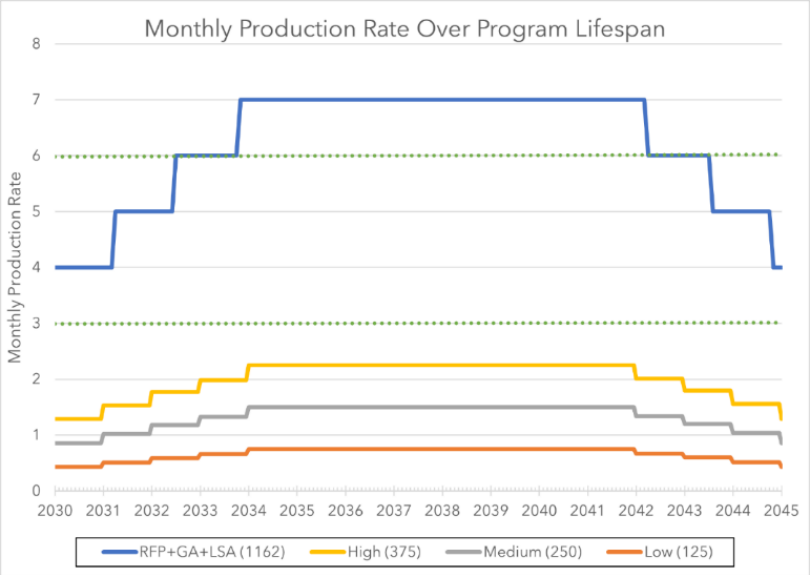


Figure 13.1.1: Monthly Production Rate to Meet Market Demand

Table 13.1.1: Recap of Market Cases

Case	Market Size
RFP Low	125
RFP Medium	250
RFP High	375
RFP (Low) + GA + LSA	1162

13.2 Costing

The costing method used in this proposal analysis was developed by Professor Emeritus Charles Eastlake of Embry Riddle Aeronautical University[30]. The method is his modification of a cost estimating relationship (CER) derived by the RAND Corporation, called DAPCA-IV[5], which was originally formed around US Military aircraft.

His modifications allow for the method to accurately predict the cost of general aviation propeller aircraft. The process followed was provided in detail in *General Aviation Aircraft Design* by Snorri Gudmundsson[30][30]. Additionally, this costing method has been adapted to our sailplane platforms and unconventional propulsion systems by applying fudge factors that consider the design and operational differences of piston propeller aircraft and electric self-launching sailplanes. The costs provided within this section are in 2024 USD.

The following characteristics of the Swift aircraft were used in our costing process.

Table 13.2.1: Swift Costing Characteristics

Skeleton Weight	321.9 lbs
Max Airspeed	91 knots
Certification Class	14 CFR Part 23
Flap System	Simple
Composite Fraction	95%
Cabin Pressurization	Unpressurized
Taper	Tapered Wing
Prototypes	2 Units

13.2.1 Workforce Hours

The engineering and tooling workforce hours are fixed for a given program and distributed between the years of 2026 to 2030 for design, test, and analysis. However, a small percentage of the hours were spread amongst the program lifespan to provide ongoing support.

Engineering Workhours

$$H_{ENGR} = 0.03696 * W_{airframe}^{0.791} * V_H^{1.526} * N^{0.183} * F_{CERT_1} * F_{CF_1} * F_{COMP_1} * F_{PRESS_1} \quad \text{eq 13.2.1.1}$$

Hours necessary to research and develop the design and test and evaluate the performance and safety.

Tooling Workhours

$$H_{TOOL} = 1.0032 * W_{airframe}^{0.764} * V_H^{1.526} * N^{0.178} * Q_m^{0.066} * F_{CF_2} * F_{COMP_2} * F_{PRESS_2} * F_{TAPER_2} \quad \text{eq. 13.2.1.2}$$

Number of hours necessary to design and build the tools necessary to build the aircraft production line.

Table 13.2.1.1: Fixed Swift Man-Hours

	Hours
Engineering	21,922
Tooling	30,989

The manufacturing workforce hours are variable with consideration of the number of aircraft produced.

Manufacturing Labor Workhours

$$H_{MFG} = 9.6613 * W_{airframe}^{0.74} * V_H^{0.543} * N^{0.524} * F_{CERT_3} * F_{CF_3} * F_{COMP_3}$$ eq. 13.2.1.3

Number of hours necessary to build the aircraft.

Table 13.2.1.2: Variable Swift Man-Hours

	Hours			
	RFP Low (175)	RFP Mid (250)	RFP High (375)	RFP+GA+LSA (1162)
Manufacturing	127,002	181,866	224606	401,071

13.2.2 Fixed Costs

The costs that are independent of the number of units produced are described as fixed costs. Fixed costs consist of engineering, development support, and tooling salaries as well as the costs associated with flight testing. The hourly rates used have been suggested by S. Gudmundsson[30].

Table 13.2.2.1: Labor Rates Suggested by S. Gudmundsson

	Hourly Rate (2012 USD)
Engineering Rate	$92/hr
Tooling Rate	$61/hr

Total Cost of Engineering $$C_{ENGR} = H_{ENGR} * R_{ENGR} * CPI_{2012}$$ Eq 13.2.2.1

Cost of engineering salaries to develop the aircraft.

Total Cost of Development Support $$C_{DEV} = 0.06456 * W_{airframe}^{0.873} * V_H^{1.89} * N^{1.89} * CPI_{2012} * F_{CERT_5} * F_{CF_5} * F_{COMP_5} * F_{PRESS_5}$$ Eq 13.2.2.2

Cost of overhead, admin, logistics, etc. to support the development effort.

Total Cost of Flight Test Operations $$C_{FT} = 0.009646 * W_{airframe}^{1.16} * V_H^{1.281} * N^{1.281} * CPI_{2012} * F_{CERT_6}$$ Eq 13.2.2.3

Cost of completing development and certification flight-test program. 2 prototypes were assumed.

Total Cost of Tooling $$C_{TOOL} = H_{TOOL} * R_{TOOL} * CPI_{2012}$$ Eq 13.2.2.4

Total cost of designing, fabricating, and maintaining tools. ie manufacturing engineers and technicians.

The fixed cost of the program can be described as the sum of the forementioned costs.

Fixed Cost $$C_{fix} = C_{ENGR} + D_{DEV} + C_{FT} + C_{TOOL}$$ Eq 13.2.2.5

Table 13.2.1.1: Swift Fixed Costs

	Cost (2024 USD)
Engineering	$2,775,890
Developmental Support	$58,887
Flight Test	$63,854
Tooling	$2,608,311
Fixed Cost (Total)	**$5,506,941**

13.2.3 Variable Costs

Total Cost of Manufacturing $$C_{MFG} = H_{MFG} * R_{MFG} * CPI_{2012}$$ eq. 13.2.3.1

Costs associated with aircraft construction. A manufacturing rate of $52 (2012 USD) per hour was assumed.

Total Cost of Quality Control $$C_{QC} = 0.13 * C_{MFC} * F_{CERT_9} * F_{COMP_9}$$ eq. 13.2.3.2

Costs associated with assuring the aircraft adheres to the engineering drawing design specifications.

Total Cost of Materials $$C_{MAT} = 24.896 * W_{airframe}^{0.689} * V_H^{0.624} * N^{0.792} * CPI_{2012} * F_{CERT_{10}} * F_{CF_{10}} * F_{PRESS_{10}}$$ eq. 13.2.3.3

Cost associated with purchasing materials to construct the aircraft.

Table 13.2.3.1: Vendor Supplied Items

	Cost (2024 USD)
Avionics	$6,428
Battery	$6,348
Motor	$5,520
Propeller	$4,340

The avionics, battery, motor, and propeller will be supplied by vendors. Gudmundsson[30] provides a suggestion on how to account for bulk order discount by applying a quantity discount factor to the item price.

Quantity Discount Factor $$ODF = (F_{EXP})^{1.4427 * \ln N}$$ eq. 13.2.3.4

As suggested by Gudmundsson for a start-up business, an insurance rate of 17% (C_{INS}) was applied.

Variable Cost eq. 13.2.3.5

$$C_{var} = \frac{C_{MFG} + C_{QC} + C_{MAT}}{N} + C_{VSC} + C_{INS}$$

Table 13.2.3.2: Swift Variable Costs

	Cost (2024 USD)			
	RFP Low	**RFP Mid**	**RFP High**	**RFP+GA+LSA**
Manufacturing	$15,814,825	$23,160,598	$28,832,024	$52,723,289

Quality Control		$1,516,246	$2,220,522	$2,764,270	$5,054,845
Materials		$1,918,083	$3,301,699	$4,541,340	$11,083,251
Vendor Controlled Items		$2,187,120	$4,188,228	$6,136,326	$17,878,398
Insurance	$4,210,220	$6,247,854	$7,906,930	$15,663,988	
Variable Cost (Total)		**$25,646,493**	**$39,118,901**	**$50,180,890**	**$102,403,772**
Unit Fly Away Cost		**$201,941**	**$155,234**	**$133,106**	**$87,976**

The minimum selling price of the aircraft is equivalent to the fly away cost plus the fixed cost distributed amongst the sales. This was found by dividing the Swift program fixed cost of $5,506,941 by the units sold.

Table 13.2.3.3 Swift Minimum Selling Price

	RFP Low	RFP Mid	RFP High	RFP+GA+LSA
Unit Fly Away Cost	$201,941	$155,234	$133,106	$87,976
Fixed Cost per Unit	$44,056	$22,028	$14,685	$4,739
Minimum Selling Price	**$245,997**	**$177,262**	**$147,791**	**$92,715**

13.3 Operational Costs

The operational cost of an aircraft is dependent on usage of the aircraft. For the following costing calculations, the primary customer of the aircraft shall be considered, flight schools. The operational cost per hour of the aircraft consists of maintenance, storage, insurance, electricity rate, and annual inspection costs.

"A primary trainer operated 4 h, 5 days a week, flies 4 x 5 x 52 = 1040 h per year" - Gudmundsson[30][30]

Table 13.3.1 shows the assumptions to calculate the operational cost for a flight school operating the Swift.

Table 13.3.1: Operational Cost Assumptions

A&P mechanic used	14 CRF Part 23 Certification
Easy access engine	$0.1287/kWh
VFR Equipped	$300 per month storage

Annual Maintenance Cost $$C_{AP} = F_{MF} * R_{AP} * Q_{FLGT} * 0.6$$ Eq 13.3.1

Gudmundsson's method[30] considers maintenance costs for a piston engine. Due to the much simpler system of an electric motor, a fudge factor has been applied to account for Swift's alternative propulsion system. Data from the growing electric vehicle industry was used to approximate 40% less maintenance cost than traditional piston engines[13]. The maintenance cost per flight hour is **$11.52 / hr**.

Annual Storage Cost $$C_{STOR} = 12 * (\$300\ per\ month)$$ Eq 13.3.2

Annual Insurance Cost $$C_{INS} = (500 + 0.015 * C_{AC}) * 1.50$$ Eq 13.3.3

The annual insurance cost for Swift (C_{INS}) assumed the insured value of the aircraft (C_{AC}) to the purchase price. An additional 50% insurance cost has been added to account for the additional risk of instructional flights.

Annual Inspection Cost $$C_{INS} = \$500$$ Eq 13.3.4

Engine Overhaul Fund $$C_{OVER} = 5 * N_{ENG} * Q_{FLGT} * 0.2$$ Eq 13.3.5

Bye Aerospace expects aviation electric motor overhaul requirements to be about 10,000 hours[9]. Thus, a one-fifth factor has been applied to adapt the typical 2,000-hour requirement for electric population.

Annual Consumables Cost

The tires, brakes, and battery of the aircraft will need regular replacing to keep the aircraft within Part 23 airworthiness standards[34]. Harsh treatment of the aircraft from trainees was considered.

Table 13.3.2: Consumable Replacements

	Cost (2024 USD)	Time to Replacement	Annual Cost
Tires	$559 x 2 = $1,118	Every year	$1,118
Brake Lining	$20 x 2 = $40	Every year	$40
Brake Disks	$200 x 2 = $400	Every year	$400
Battery	$6,348	Every 3.5 years	$1813
Air Filter	$80	Every 3 years	$27
Total			**$3,398**

When factoring an annual operational time of 1040 hours, **$3.27** must be set aside per flight hour to replace the aircraft consumables.

Table 13.3.3: Annual Operations Cost

	Cost (2024 USD)
Annual Maintenance Cost	$11,981
Annual Storage Cost	$3,600
Annual Insurance Cost	$2,955
Annual Inspection Cost	$500
Engine Overhaul Fund	$1,040
Annual Consumables Cost	$3,398
Annual Operational Cost	**$23,474**

Considering 600 instructional flights per year, the annual ownership cost increases by $347.49. With 10 self-retrieves per year, $11.58.

Cost per Flight Hour $$C_{HR} = \frac{C_{YEAR}}{Q_{FLGT}}$$ Eq 13.3.6

With 1040 hours of flight per year, the hourly operational cost, not including electricity, is **$22.57 / hr.**

Electricity Cost per Instructional Flight (20 minutes) $$C_{ELEC} = ((PC_{TAXI} * T_{TAXI}) + (PC_{CLIMB} + T_{CLIMB})) * R_{ELEC}$$ Eq 13.3.7

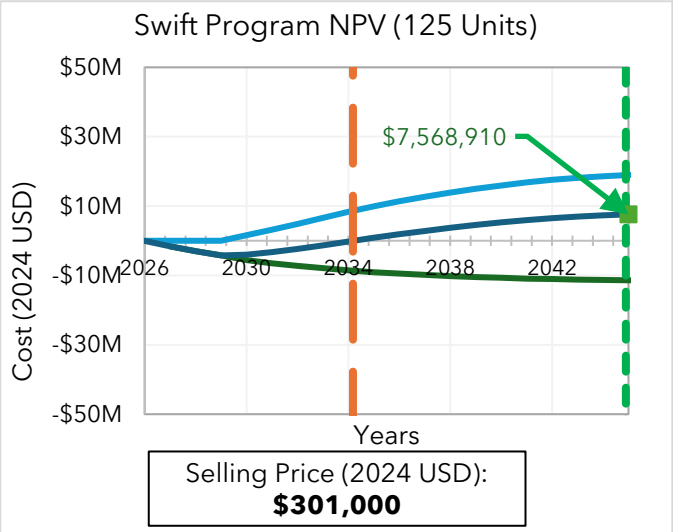
The electricity cost per instructional flight (C_{ELEC}) was calculated by first finding the kW hours used in an instructional flight. The power consumption of taxi and climb (PC_{TAXI} & PC_{CLIMB}) were multiplied by the hours spent in each stage of the flight (T_{TAXI} & T_{CLIMB}). The total kW hours of the flight were multiplied by the RFP specified electricity rate (R_{ELEC}) of $0.1287/kWh.

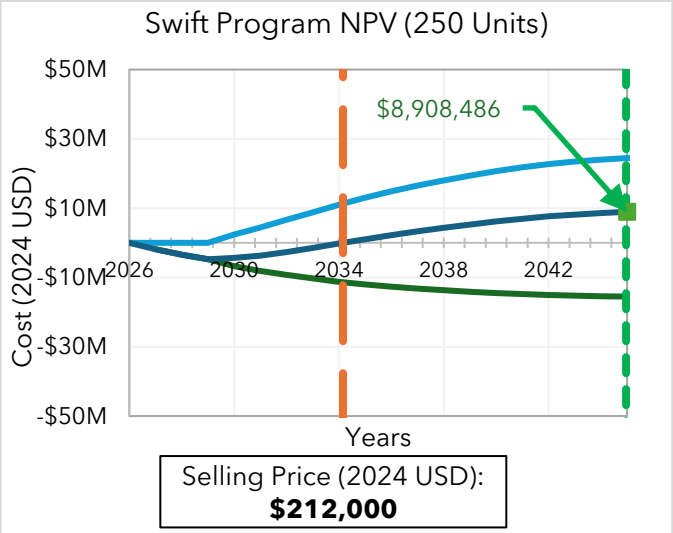
Cost per Instructional Flight $$C_{INS_FLT} = \frac{C_{HR}}{3} + C_{ELEC}$$ Eq 13.3.8

The 20-minute instructional flight consists of 1/3 of the hourly flight cost (C_{HR}) and the electricity needed for the flight (C_{ELEC}). This results in a cost of **$8.10** per instructional flight.

13.4 Net Present Value / Program Profit

The selling price of the Glydetek Swift was determined using net present value (NPV). Net present value is a method used to consider the profitability of a program involving large initial investments and overtime program costs. The NPV method allowed the Swift program to set the 15% program profit date at the end of its lifetime to determine the optimal selling price in 2024 USD. A discount rate of 12% was assumed.





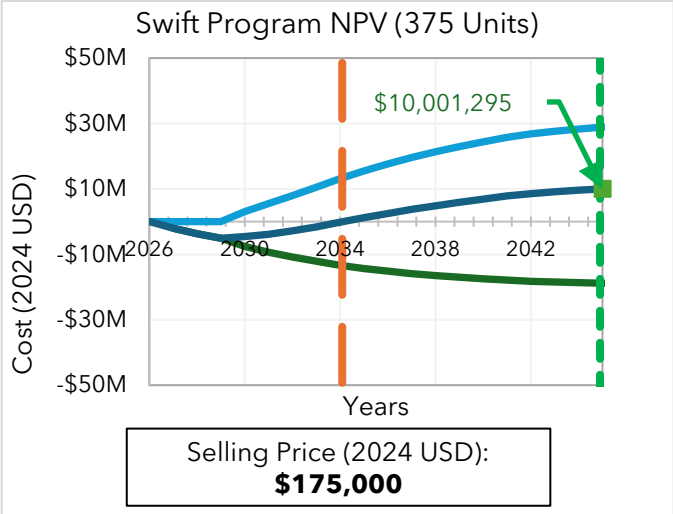


Figure 13.4.3 Swift NPV – 375 Units

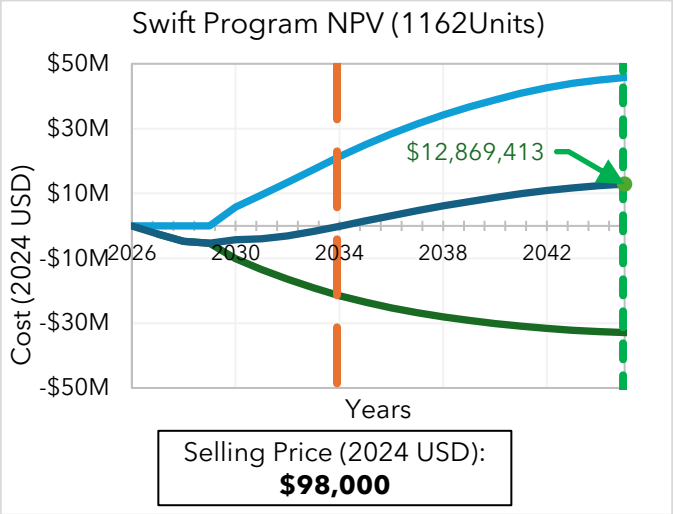


Figure 13.4.4 Swift NPV – 1162 Units LSA Market

Figure 13.4.5 Swift NPV Legend

Table 13.4.1 Swift Net Present Value

	RFP Low	RFP Mid	RFP High	RFP+GA+LSA
Program NPV	$7,569,910	$8.908,486	$10,001,295	$12,869,413
Selling Price	**$301,000**	**$212,000**	**$175,000**	**$98,000**

The Swift additionally will three additional optional add-ons. As pictured in Figure 8.3.4: Battery Locations and Storage Compartment, a 1.5 range extension can be added for an additional $10,000 acquisition cost.

13.5 Final Comparison to Alternatives

Table 13.5.1 KPP Values Compared to Alternatives

KPP	Threshold	Objective	Swift	Taurus	Elektra Trainer
Operational Cost Per Instructional Flight	<$50/flight	$20/flight	**$8.10/flight**	$25/flight	$34/flight
Unit Cost	**$300,000**	**$100,000**	**$98,000**	**$200,000**	**$225,000**
Flights Per 6 Hours	6	18	**10**	-	-
Sink Rate @ 250 ft Turn	250 ft/min	175 ft/min	**193 ft/min**	138 ft/min	~140 ft/min
Airspeed @ L/D = 25	45 kts	70 kts	**50 kts**	82 kt	65 kts

Annual Total Ownership Cost (600 Flights)	-	-	**$23,821**	$14,000	$21,000
Climb Altitude On One Charge	2,500 ft	10,000 ft	**16,000 ft**	- ft	- ft
Self-Retrieve Range	50 km	200 km	**176 km (268 with optional battery)**	- km	300 km

14.0 Appendix A

Table A: Design and Performance Summary Table

Parameter	SI Units	Imperial Units
Aircraft Design	Swift by Glydetek	
Wingspan (assembled)	14 m	46 ft
Storage Wingspan (wingtips removed if applicable)	14 m	46 ft
Length	7.86 m	25.8 ft
Height	3 m	10 ft
Reference Wing Area	13.28 m^2	143 ft^2
Wing Aspect Ratio	14.47	
Maximum Takeoff Weight	452 kg	997 lbm
Operating Empty Weight	270 kg	597 lbm
Minimum Individual Crew Weight	40.8 kg	90 lbm
Maximum Individual Crew Weight	122.5 kg	270 lbm
Propulsion		
Propulsor Type/Number/Location	EMRAX 208/1/Front	
Motor Peak Power Duration Specific Power Efficiency	86 kW 60-120 sec 14 kW/kg 92%	115 hp 60-120 sec 8.5 hp/lbm 92%
Motor Max Continuous Power Specific Power Efficiency	56 kW 10 kW/kg 96%	75 hp 6.1 hp/lbm 96%
Total Max Thrust	1334.5 N	~300 lbf
Battery Chemistry	Lithium - Ion	
Installed Energy at 1C Discharge	25,000 W.h	33.52 hp.h
Battery Energy Density at 1C Discharge	0.4 kW.h/kg	0.24 hp.h/lbm
Battery Peak Power	75 kW	100.6 hp
Number of Instructional Flights Between Re-Charge	3	
General Performance/Operations		
Minimum/Maximum Ambient Operating Temperature	-17 / 55 °C	1.4 / 131 °F
Service Ceiling	4,876.8 m	16,000 ft

Altitude Lost During Transition Between Gliding and Powered Flight	5 m	16 .2 ft
Stall Speed and Flap Setting, MTOW, ISA, SL (CAS)	m/s	36 kts
Maximum L/D (clean – propulsor off/retracted) @ speed	28.2:1 @ 25.7m/s	28.2:1 @ 50 kts
Maximum L/D (dirty – propulsor off/extended if applicable) @ speed	21.5:1 @ 25.7m/s	21.5:1 @ 50 kts
Takeoff Ground Roll, 400 lb crew, 1000 ft MSL, ISA+10C, Cut Grass	123.2 m	404.3 ft
Takeoff Distance Over 50' Obstacle, 400 lb crew, 1000 ft MSL, ISA+10C, Cut Grass	239 m	785 ft
Landing Ground Roll, 400 lb crew, 1000 ft MSL, ISA+10C, Cut Grass	168.3 m	552 ft
Landing Distance Over 50' Obstacle, 400 lb crew, 1000 ft MSL, ISA+10C, Cut Grass	248 m	814.4 ft
KPPs		
Operating cost per design reference instructional flight	$8.10 USD	
Aircraft unit acquisition cost	$98,000 USD	
Number of instructional flights which can be performed in 6 hours	10	
Minimum sink rate in a turn with radius of 250 feet (3000 feet MSL ISA+10C)	0.98 m/s	1.91 kts 193 ft/min
Indicated airspeed at which a lift-to-drag ratio of 25 is achieved	33.4 m/s	65 kts
Total cost of ownership per year (600 flights).	$23,821 USD	
Climb altitude on one charge	3,657.6 m	12,000 ft
Self-retrieve range	176 km	95 nm

Table for Design reference instructional flight: Please see ***2.2 Instructional Flight***

Table for Design reference self-retrieve flight: Please see ***2.3 Soaring/Cross-Country Self-Retrieve***

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