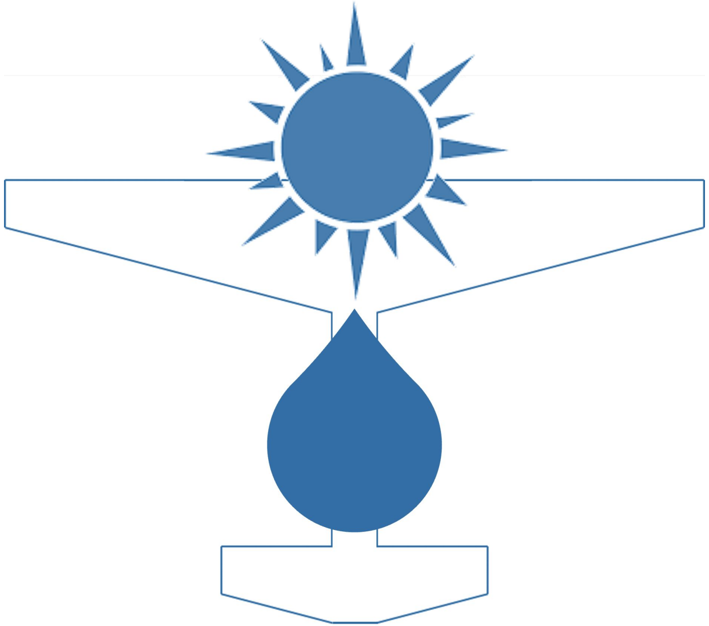


Team Water

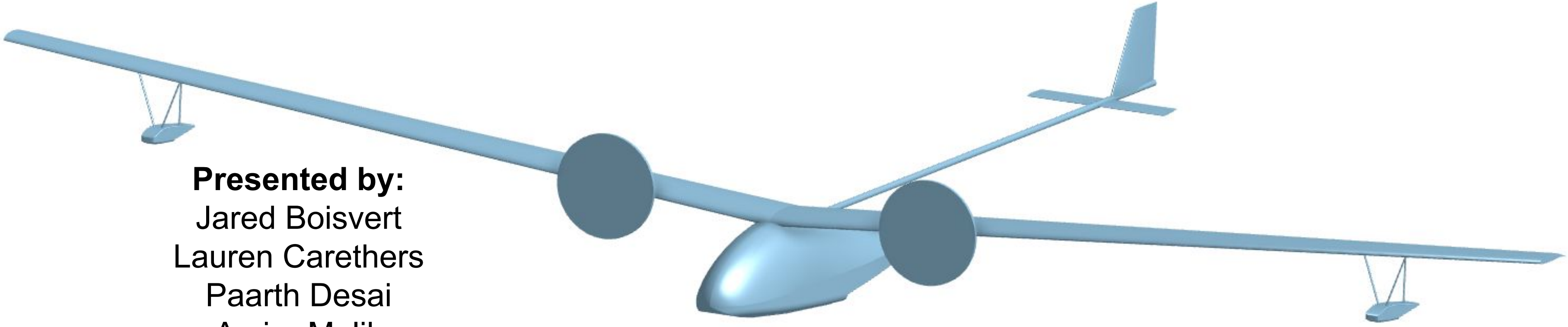
Team Water

Presents:

SEAWAY

Solar Electric Aquatic Winged Air Yacht

"The new way to see new sights"



Presented by:
Jared Boisvert
Lauren Carethers
Paarth Desai
Amira Malik
Josh Malone
Joey Merkel
Jax Rivers
David von Wrangel

Presenter: Josh Malone

Outline

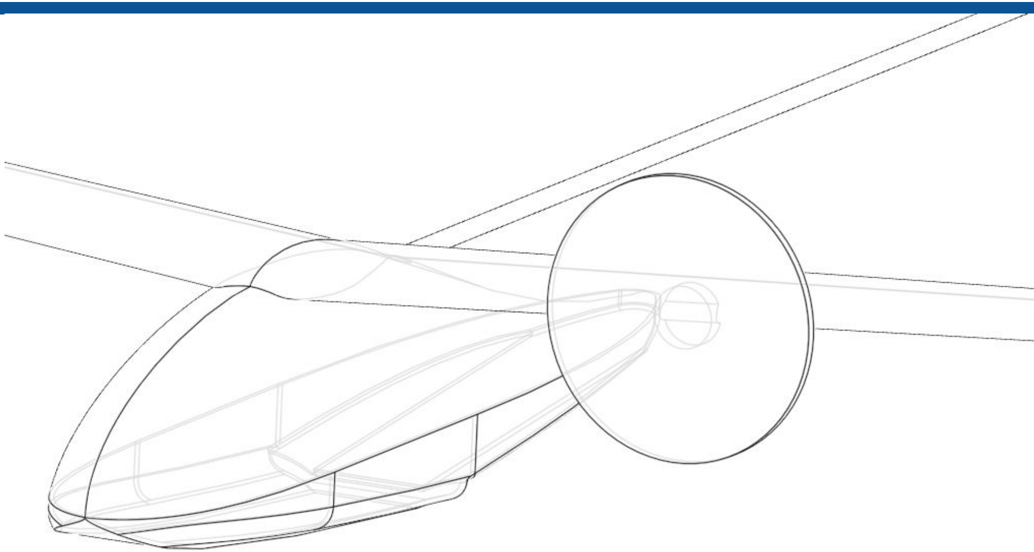
1. **Motivation**
2. General Overview
3. Subsystem Design
4. Risk
5. Conclusion

The Road to Seaway

- Allow people easy entry to the world of aviation
- Go see the great outdoors and be fully immersed in nature
- Do so in an environmentally friendly way

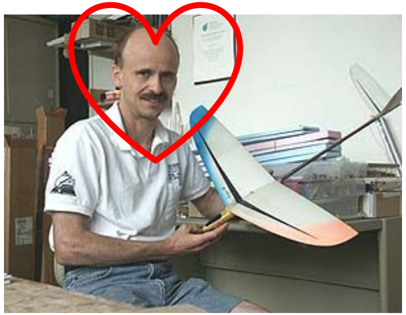
SEAWAY is born

- **Ultralight!**
  - Cheaper to operate and maintain, no pilot's license required
- **Seaplane!**
  - Can land in remote areas w/o a runway
- **Solar Powered!**
  - Completely off the grid for zero emissions



Targeted Audience

- Backpackers
- Wilderness Fishermen
- Aviation Enthusiasts
- Adventurous Professionals



Requirements

	Specification	Requirement
FAA Part 103	Stall Speed (power off)	<24 kts CAS
	Empty Weight	304 lbs (254 regular + 50 as seaplane w/ 2 pylons)
	Max Speed	<55 kts. CAS (full power in level flight)
16.82	In-Flight Emissions	Zero
Self-Imposed	Range	>100 mi
	Max Payload	260 lbs: 1 Passenger (230 lbs.) + cargo (30 lbs)
	Takeoff Distance	<1000 ft
	Runway Terrain	Water (Seaplane)

Outline

1. Motivation
2. **General Overview**
    a. Vehicle Configuration
    b. Mass Breakdown
3. Subsystem Design
4. Risk
5. Conclusion

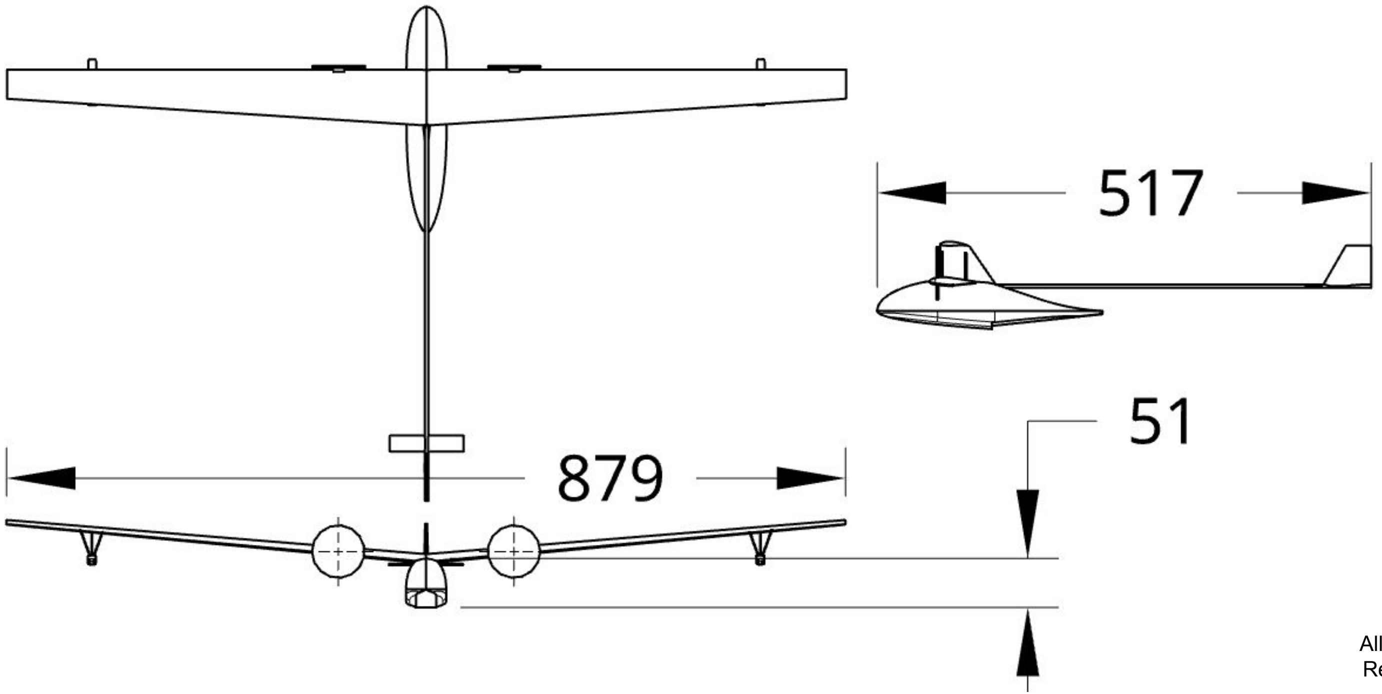
Meet: SEAWAY

Driven By Solar:

- Large Wing Area
- Efficiency-first Wing
- Small Tail Surfaces

Driven By Water:

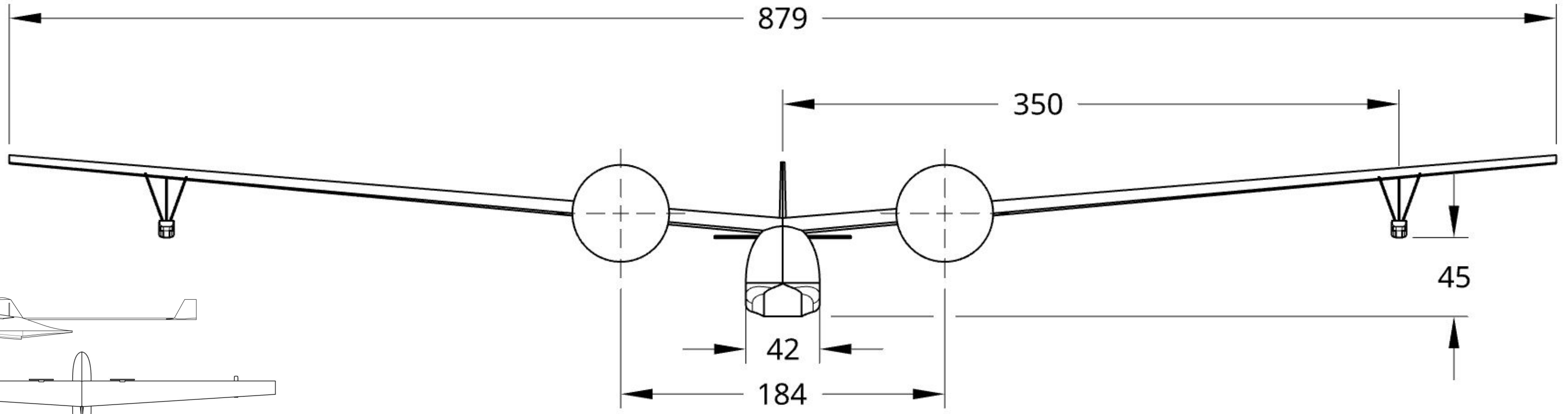
- Planing Hull
- Wing Floats
- Lifted Tail

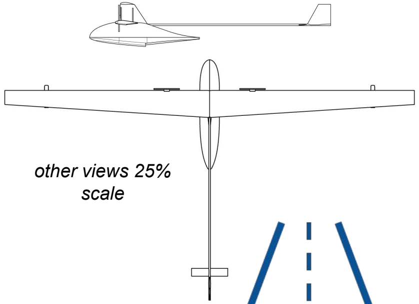


All in inches
Rev. 9 12/8

Presenter: Amira Malik

Meet: SEAWAY, Head-On





other views 25% scale

1000’ Runway

0 Emissions

MTOW
582 lbs

Cruise
33 KCAS

Stall
23 KCAS

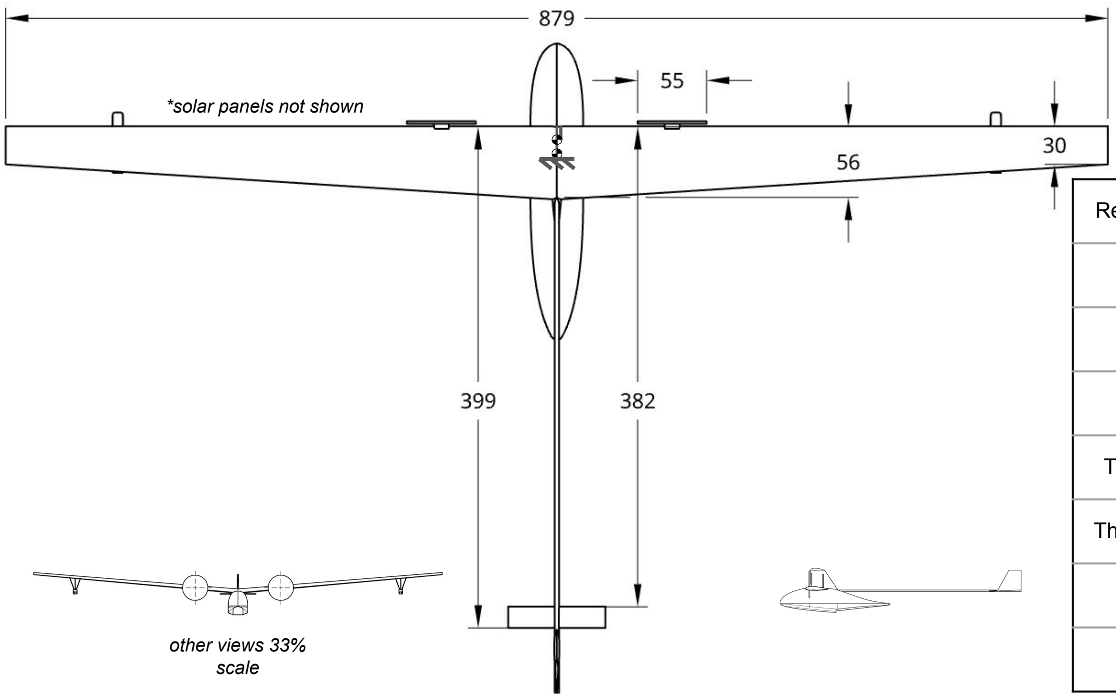
∞ Range*

Max Altitude
3000’

All in inches
Rev. 9 12/8

Meet: SEAWAY, From the Top

Distance from LE	
X_{np}	20.6”
Empty Weight	322 lbs
Front X_{cg}	18.4”
Max Weight	582 lbs
Rear X_{cg}	20.5”
Min Weight	478 lbs

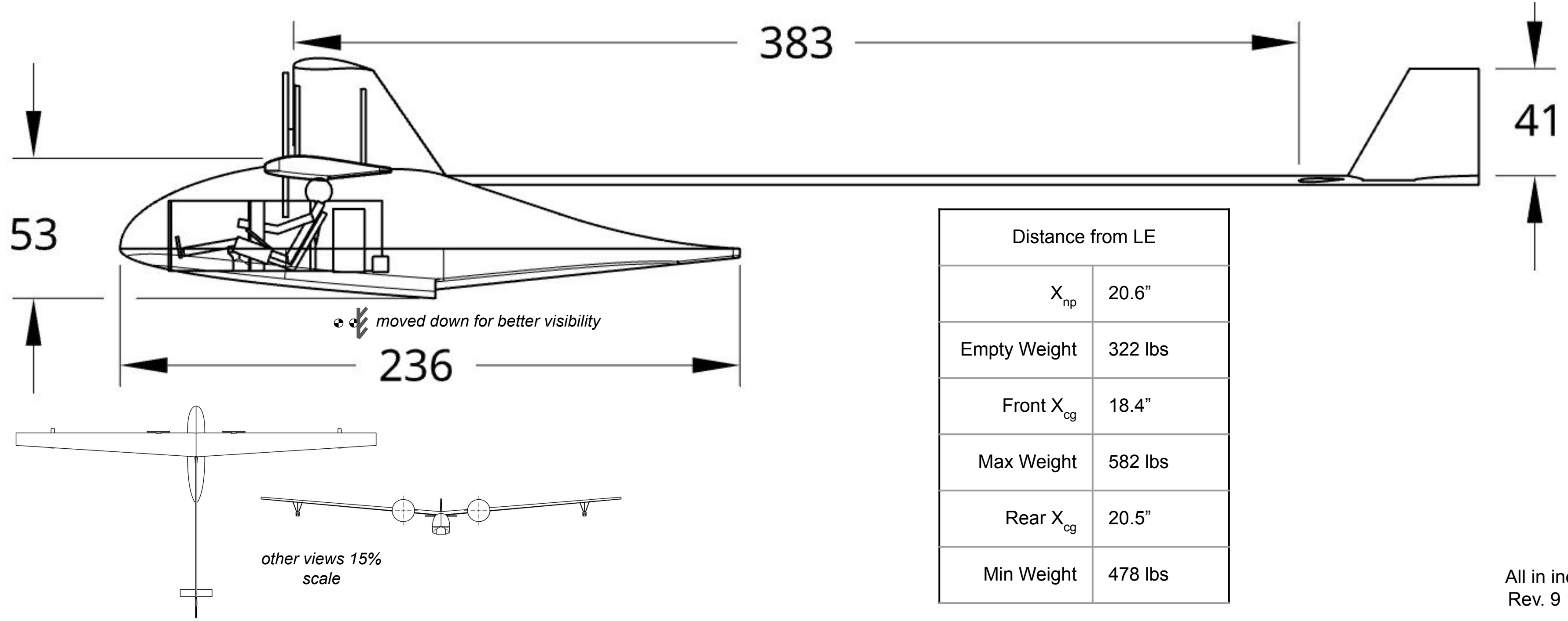


other views 33% scale

Reynolds #	1,300,000
L/D	25.7
AR	19.5
↓ MTOW ↓	
$Thrust_{cruise}$	195 N
$Thrust_{TakeOff}$	275 N
$P_{Required}$	3300 W
$P_{Generated}$	3400 W

All in inches
Rev. 9 12/8

Meet: SEAWAY, Another Aside



Distance from LE	
X_{np}	20.6”
Empty Weight	322 lbs
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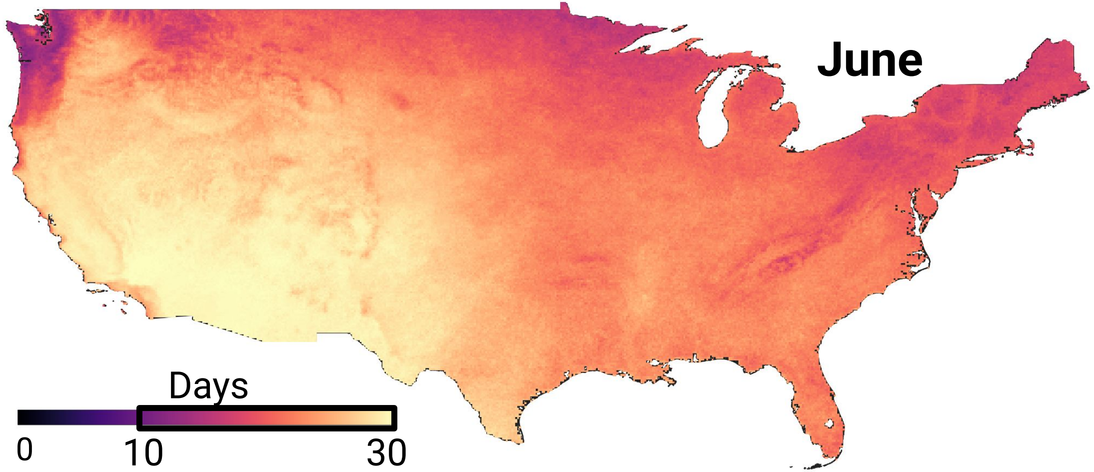
Max Weight	582 lbs
Rear X_{cg}	20.5”
Min Weight	478 lbs

All in inches
Rev. 9 12/8

Solar Powered Cruise Throughout US

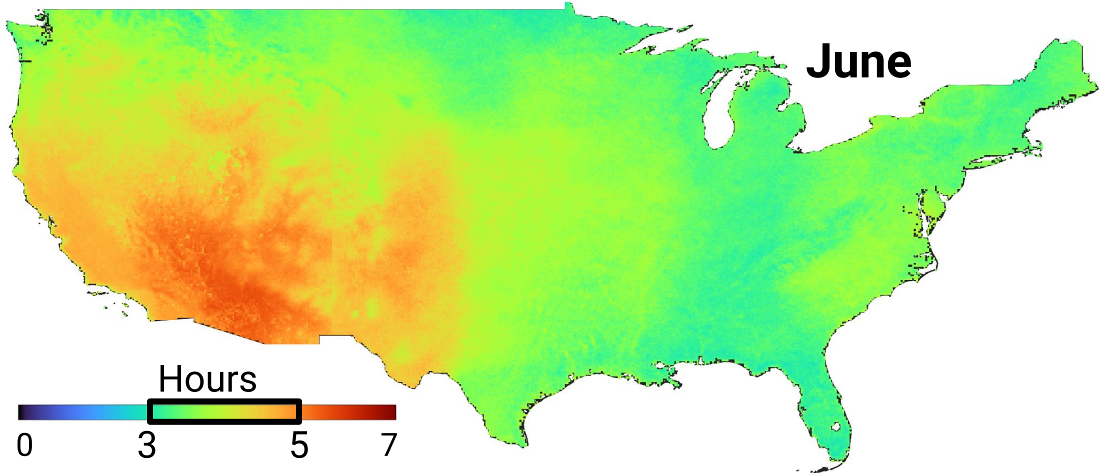
- Designed for use in 5 months with highest solar radiation
    - **April to August**
    - **June** has the highest solar flux - *graph next slide*
    - Rest of year → solar radiation too low for reasonable wing area
- Designed for **800 W/m² solar flux**
    - Tradeoff between usability and mass budget
    - Can operate below 800 W/m², but results in smaller range
- **Coverage throughout US** on clear days



Presenter: Lauren Carethers

Number of “clear” days:

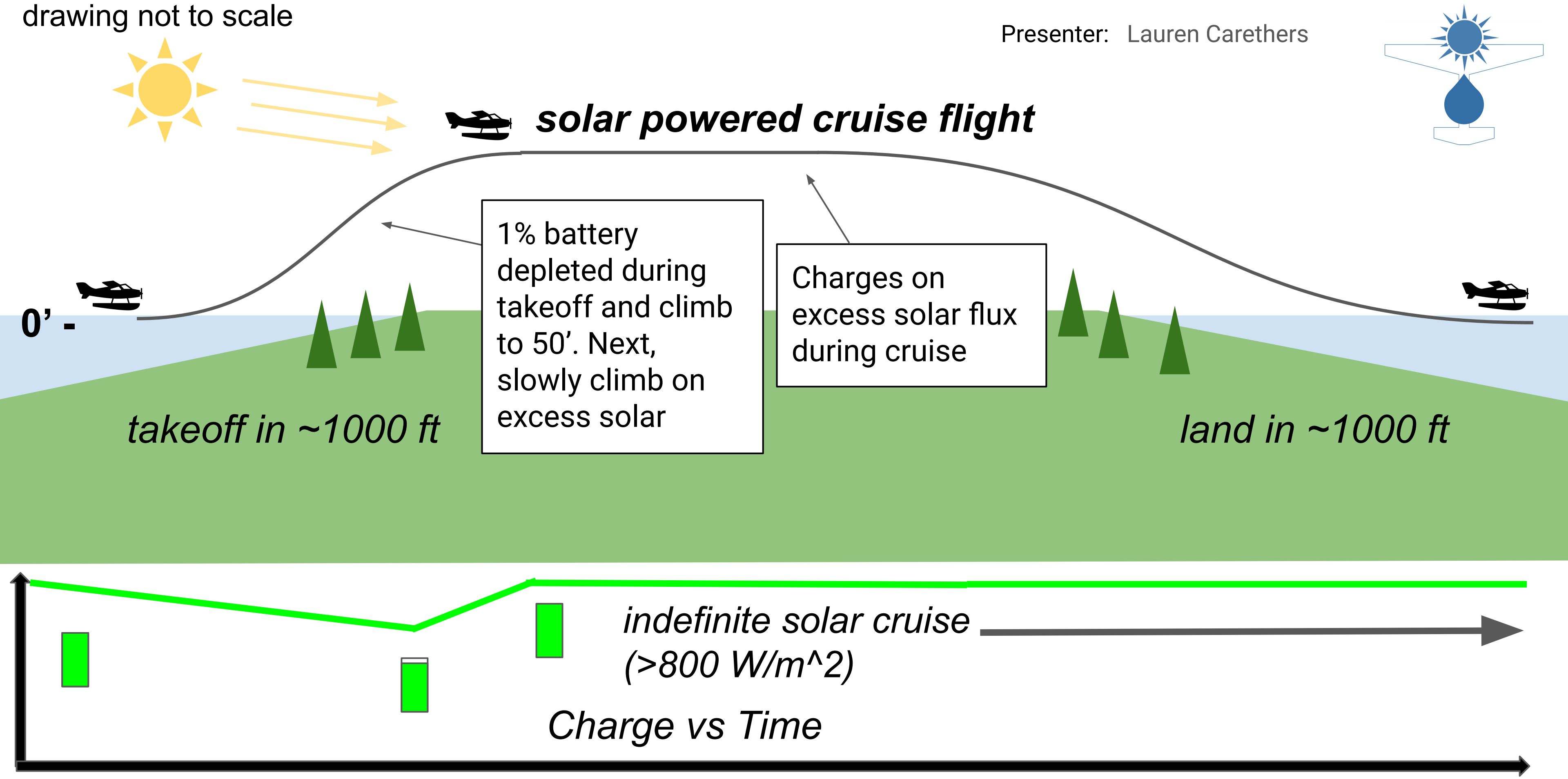
Average **number of days** where solar flux exceeds 800 W/m² for any amount of time during a day

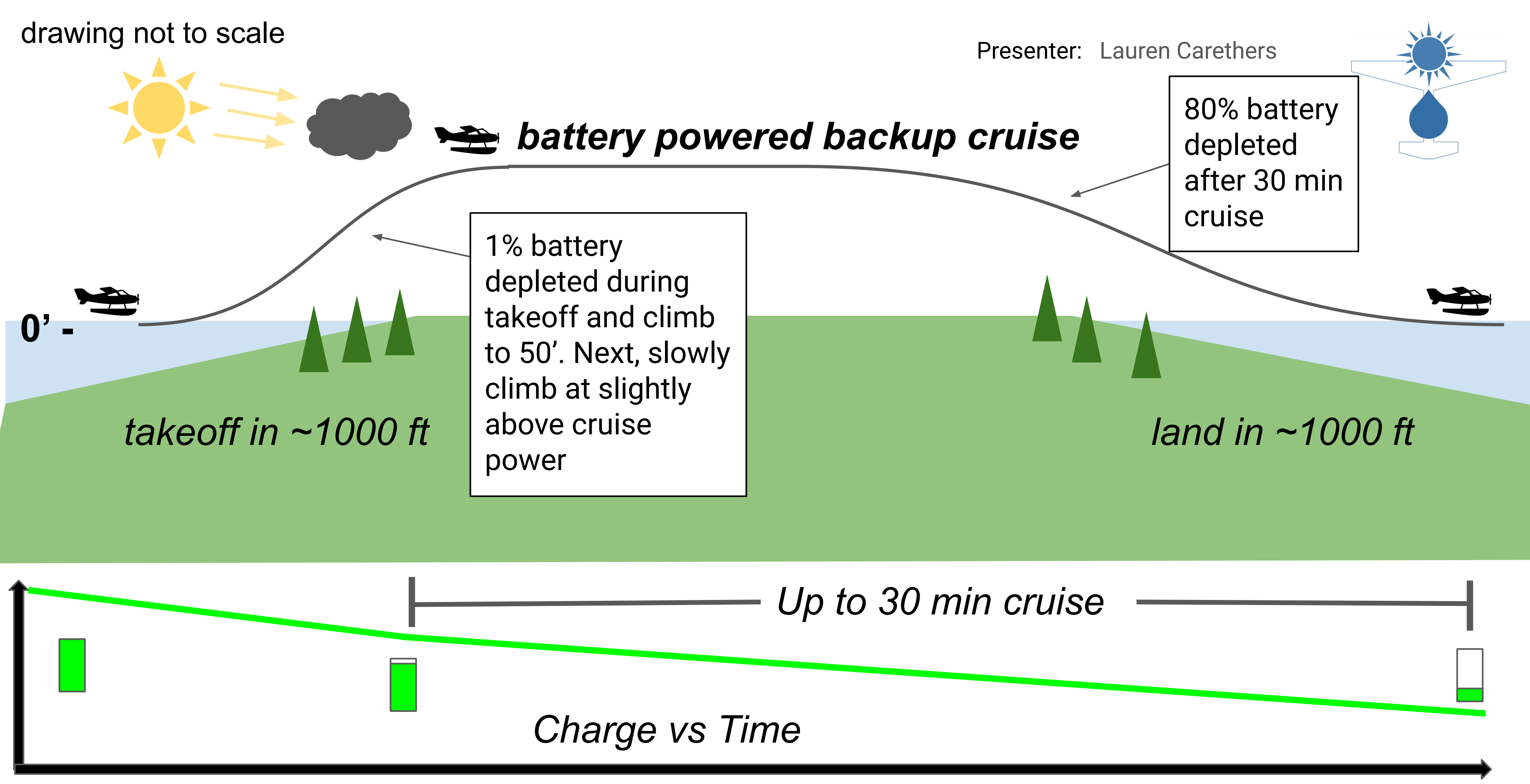


Hours of “solar cruise”:

Average **hours per day** exceeding 800 W/m² on those days

Presenter: Lauren Carethers

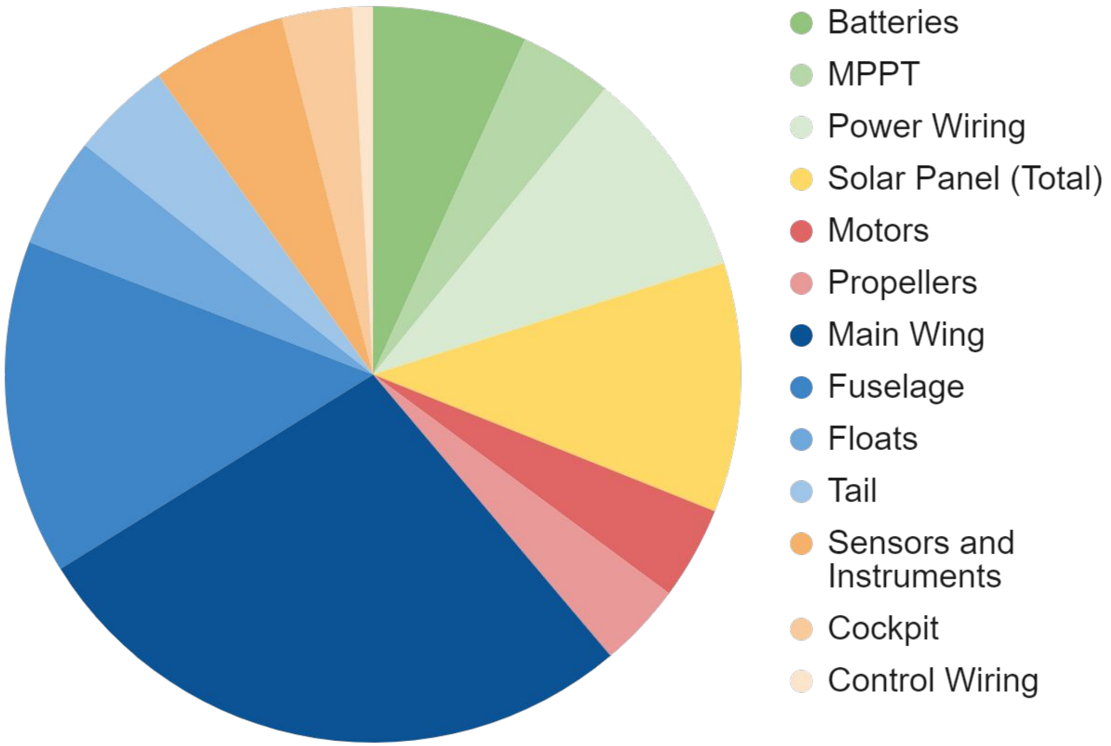



drawing not to scale
Presenter: Lauren Carethers
battery powered backup cruise
80% battery depleted after 30 min cruise
1% battery depleted during takeoff and climb to 50'. Next, slowly climb at slightly above cruise power
0' -
takeoff in ~1000 ft
land in ~1000 ft
Up to 30 min cruise
Charge vs Time

Empty Weight Breakdown

- Current Empty Weight: 322 lbs
- Goal Weight (to be ultralight) 304
    - ❗ Currently 18 lbs overweight

Color Key	
Cockpit and Controls	Electrical
Propulsion	Solar Panels
Key Structures	

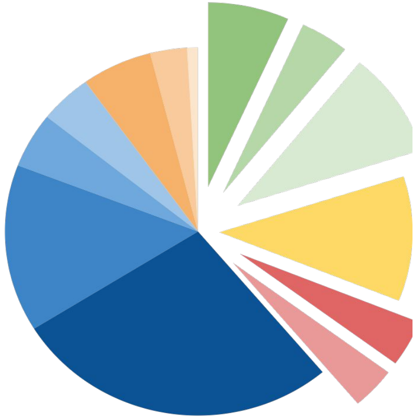


Structural Mass Budget

Part	Weight [lbs]	Sizing Case	
Main Wing	88.6	Bending, torsional stiffness	
Fuselage	47.7	Hydrodynamic drag, buoyancy	
Floats/Pylons	15.7	Water stability at rest	
Tail	14.2	Bending, some torsion	
TOTAL	**166.2**	51.3% of empty weight	

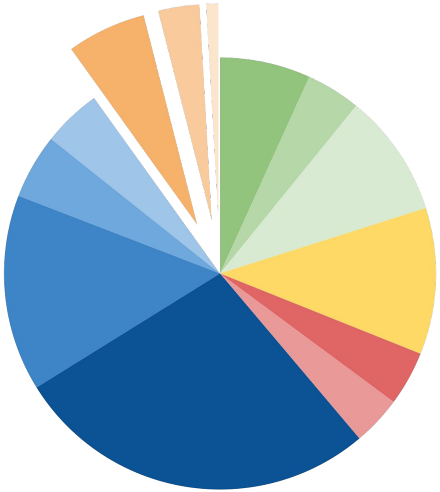
Propulsive and Electrical Mass Budget

Part	Weight [lbs]	Source	
Solar Cells	19.6	Part sourcing	
Solar Protective Coating (Halar® ECTFE)	9.7	Halar® ECTFE density & coating volume	
Adhesive/Glue	6	Estimated glue area and density	
Wiring	30	Est. wire size and length	
MPPT	13.2	Part sourcing	
Battery Packs	22	Part sourcing	
Propellers	12	Size and material considerations	
Motors	13.2	Part sourcing	
TOTAL	**125.7**	38.8% of empty weight	



Other Systems Mass Budget & Margins

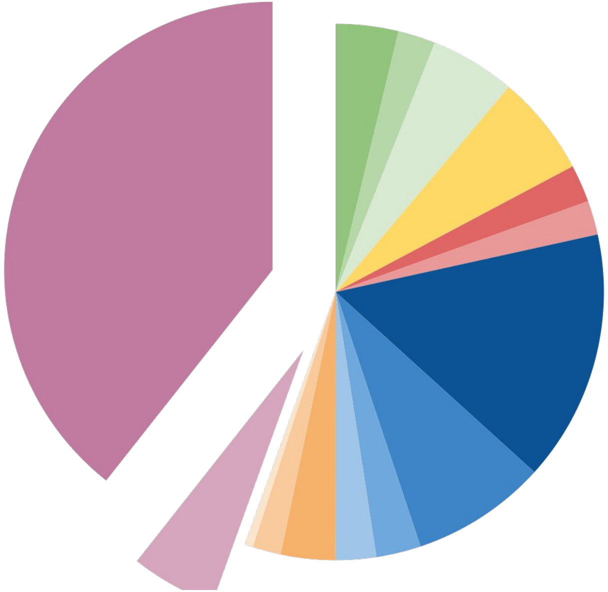
Part	Weight [lbs]	Source	
Sensors	9.7	Avionics Architecture	
Instruments	9.5	Avionics Architecture	
Cockpit	10	Estimate from COTS parts	
Control Cables	1.2	COTS Wires, Pulleys, etc.	
TOTAL	**30.5**	9.9% of empty weight	

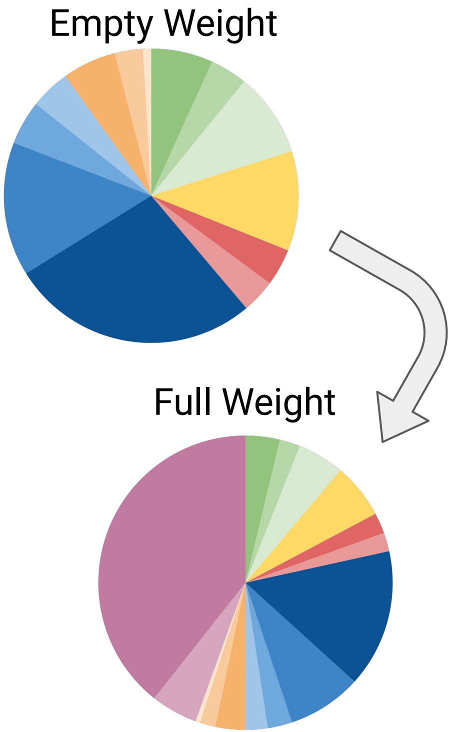


Payload Weight Contribution

Item	Weight [lbs]	
Pilot Max	230	
Baggage Max	30	
TOTAL	**260**	

- Total Weight: 582 lbs
- At max payload, payload contributes 44.5% of weight
- Challenge for stability for different pilot weights





Presenter: Josh Malone

Outline

1. Motivation
2. General Overview
3. **Subsystem Design**
    a. Wing
    b. Fuselage
    c. Stabilizers
    d. Propulsion
    e. Human-Machine Interface
4. Risk
5. Conclusion

Presenter: Amira Malik

Outline

3. Subsystem Design
    a. **Wing**
        i. Aerodynamics
        ii. Solar Cells
        iii. Structural Components
    b. Fuselage
    c. Stabilizers
    d. Propulsion
    e. Human-Machine Interface

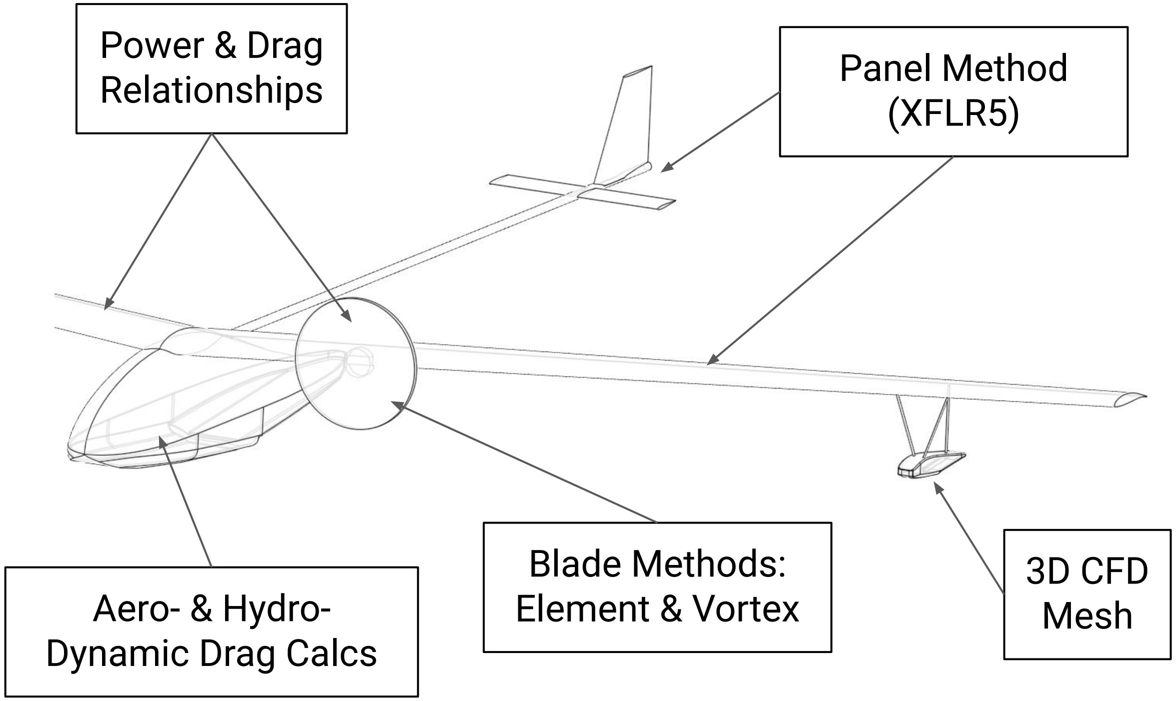
Modeling Overview

Assumptions:

- Viscous flow estimated via panel method within order of magnitude
- Bodies & Aero Surfaces have no interacting effects

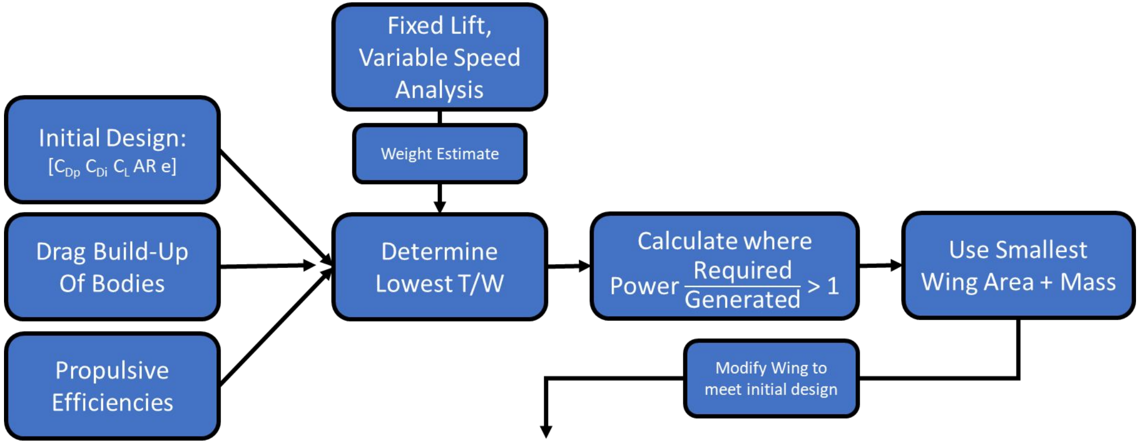
Compensations:

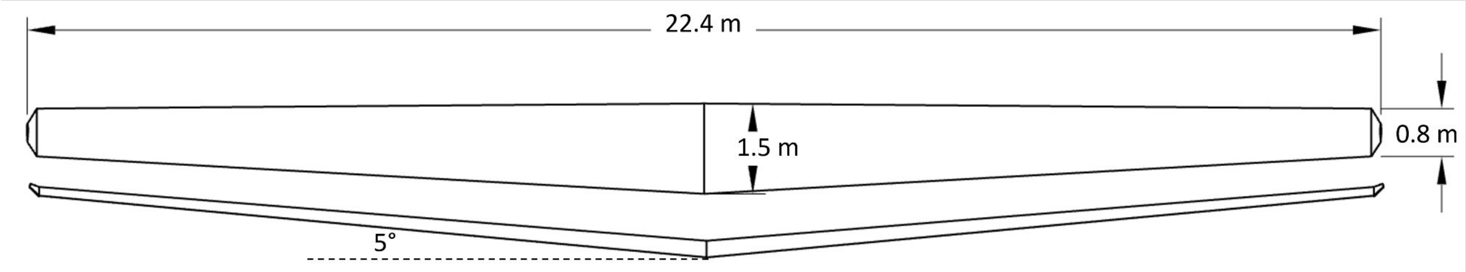
- 5% drag margin
- Meaningful analysis limited to small angles



Presenter: Amira Malik

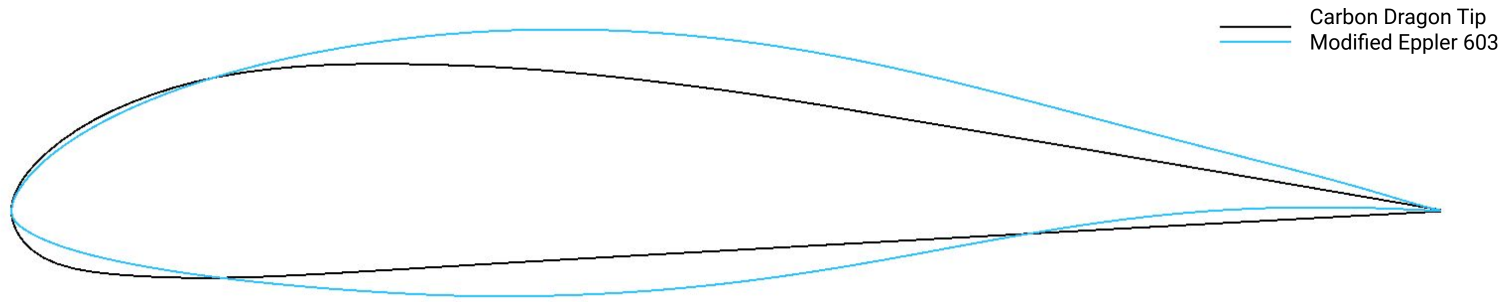
Wing Powered by the Sun

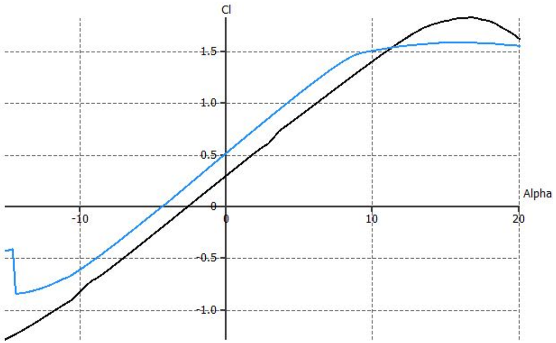




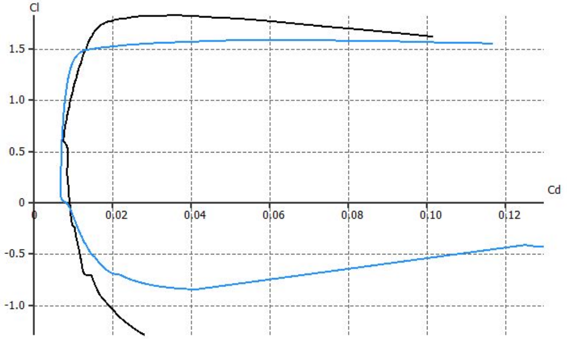
Reynolds #	1,300,000
L/D	25.7
AR	19.5
e	.8
Wing Loading	97 Pa
$Thrust_{cruise}$	195 N
$P_{Required}$	3300 W
$P_{Generated}$	3400 W

2D Aerodynamic Performance



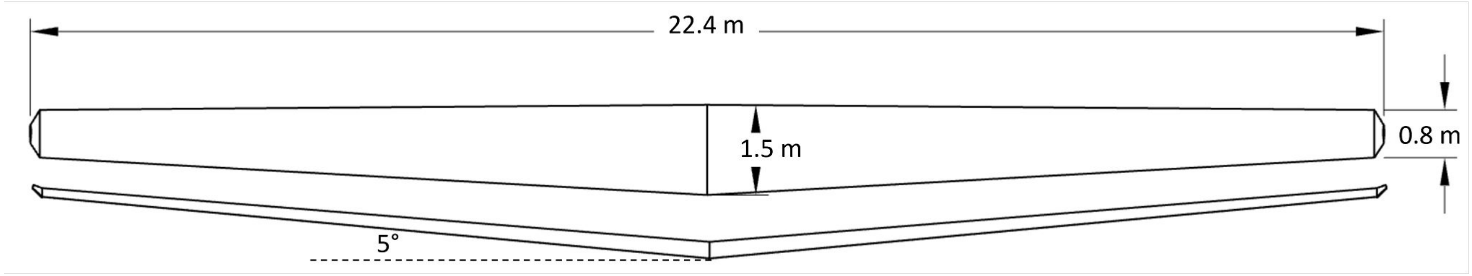


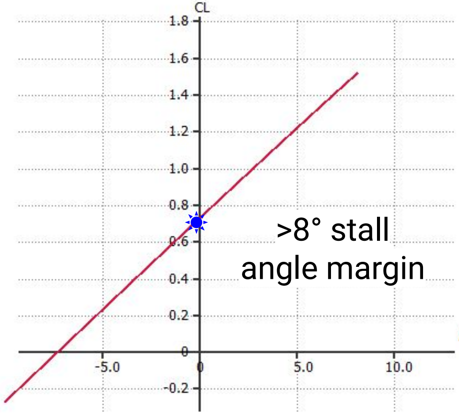
- Modified Eppler 603 at Root
- Carbon Dragon Tip Airfoil at Tip
  - Linear Interpolation
- Allows Aerodynamic Washout
  - No Twist
    - Easier solar panel mounting
    - Easier structures planning
- Adequate Low Reynolds # Performance

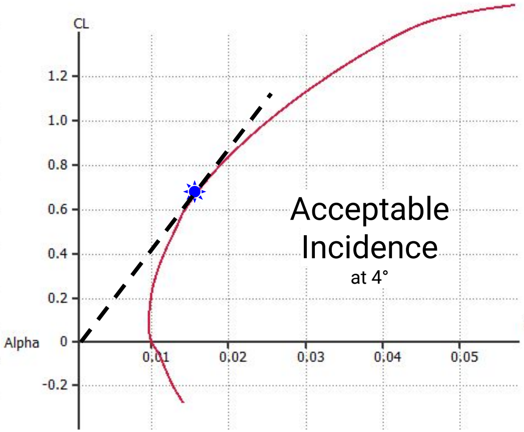


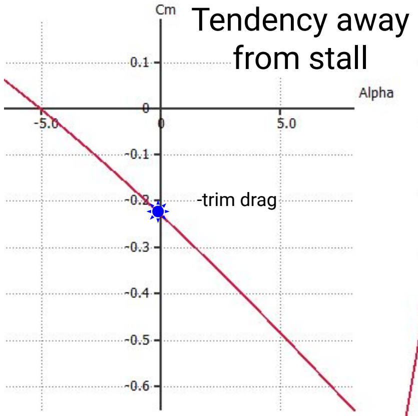
Presenter: Amira Malik

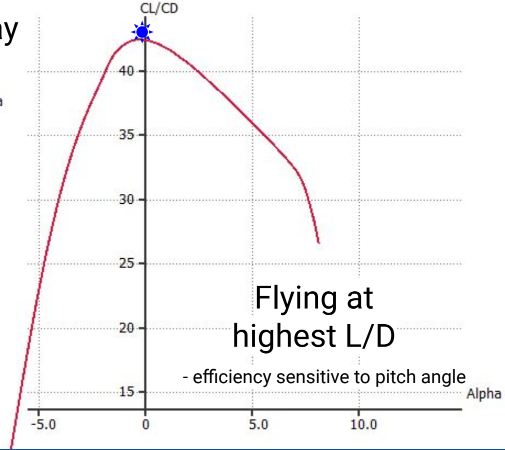
3D Aerodynamic Performance







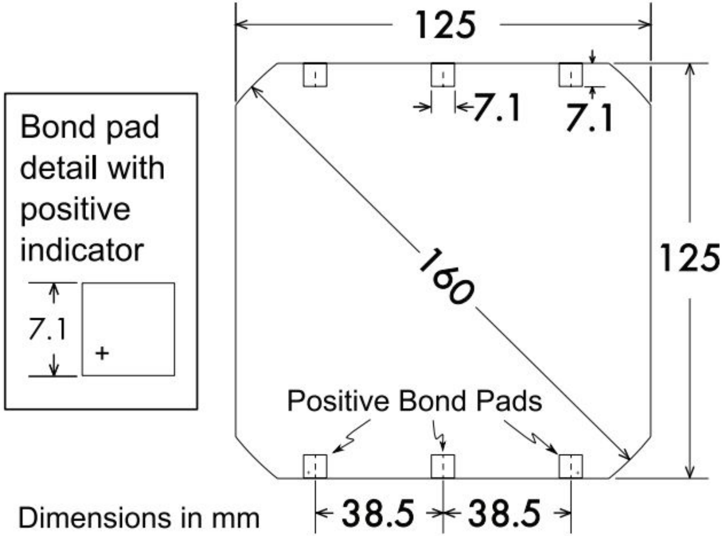




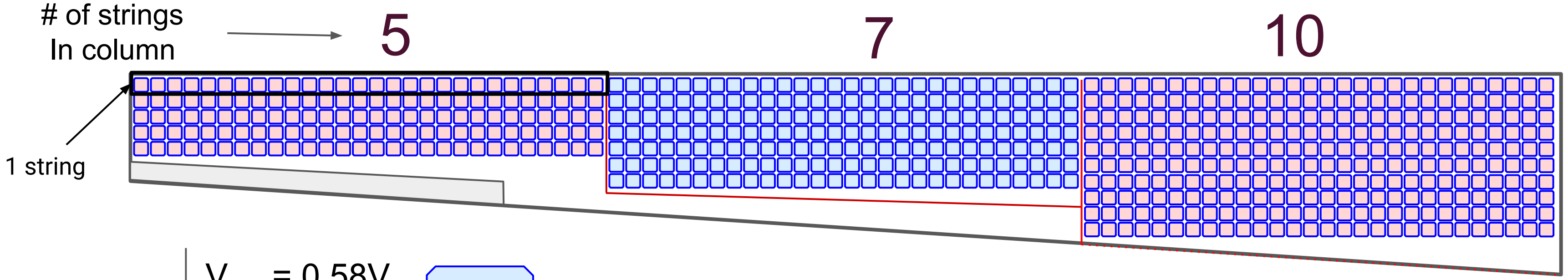
Solar Cell Selection

- SunPower C60 Solar Cell
- Commonly used in solar aviation
- Mono Crystalline Silicon
- Can be place anywhere on wing

Efficiency	22.5
Weight [lbs/cell]	0.014
Max Bend Angle	30°
Cost [$/cell]	3.4



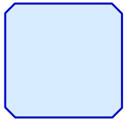
Solar Cell Layout



1 Cell*

V_{mpp}= 0.58V

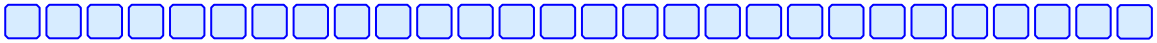
I_{mpp}= 5.93A



Total Area of Solar Cells = 19.25 m^2 → 75% of wing area
1232 cells on 1 wing → 2464 cells in total

1 String
28 Cells*

V_{mpp}= 16.27V
I_{mpp}= 5.93A



1 Wing
44 Strings**

$P_{total, wings}$ = 3400W > 3300W Cruise Requirement

* Electrical specifications tested at 1000W/m2 flux
** 800W/m2 flux

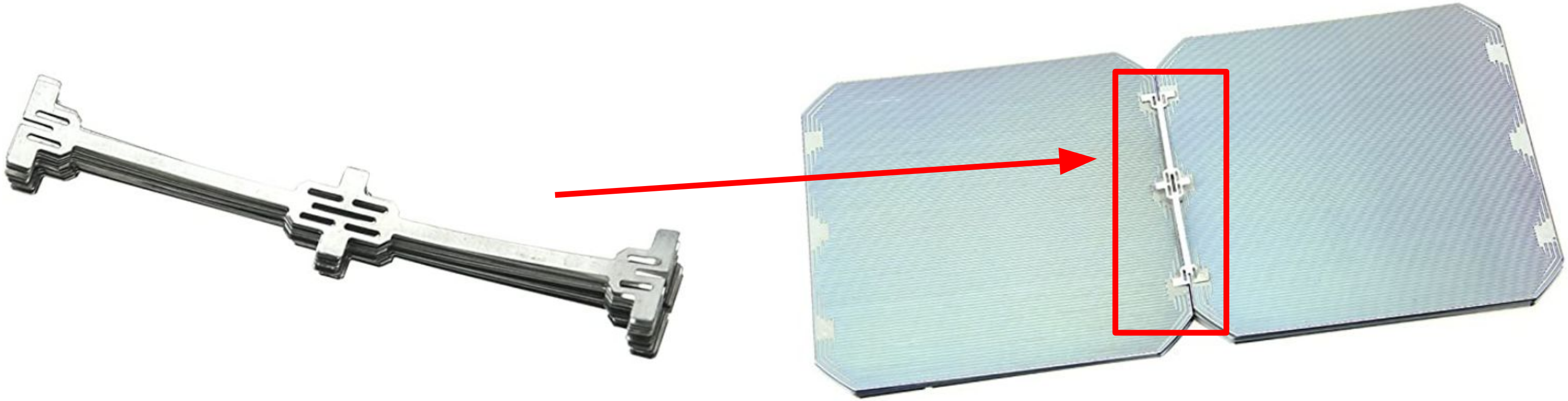
Solar Cell Protection

- Cover cells in a single layer of Halar® ECTFE
  - Semi-crystalline fluoropolymer
  - Used on Solar Impulse 2
  - Strong, smooth and transparent
  - Abrasion and chemical resistant
  - Excellent weathering properties
  - Low permeability → protects against various liquids and gases

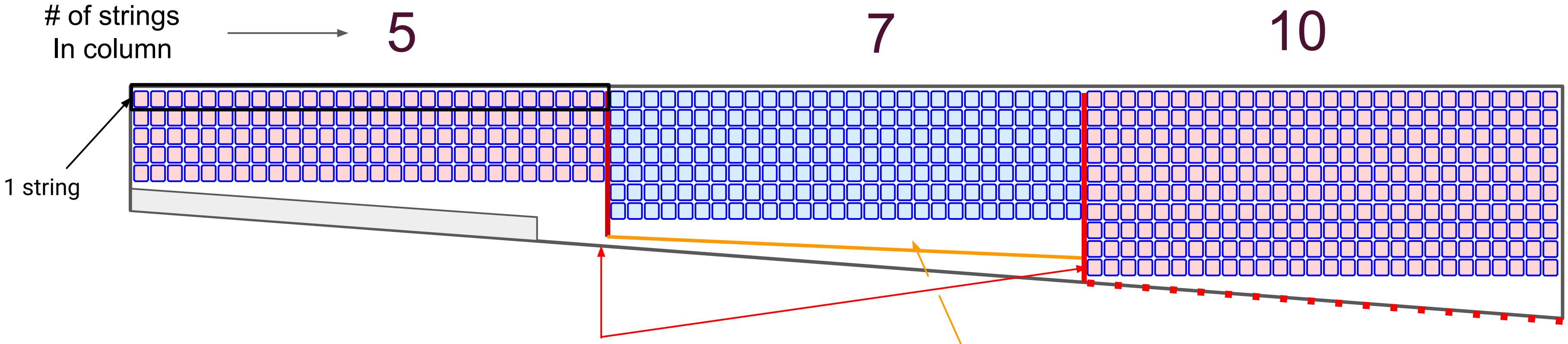
- Smooth finish reduces drag across panels

Solar Cell Attachment

- Flexible solar cells attach to the wing fabric with Sikaflex®-221 glue
- Solar cells connected **in series** via SunPower C60 Dog Bone Tabbing Wire Connector



Solar Cell Attachment



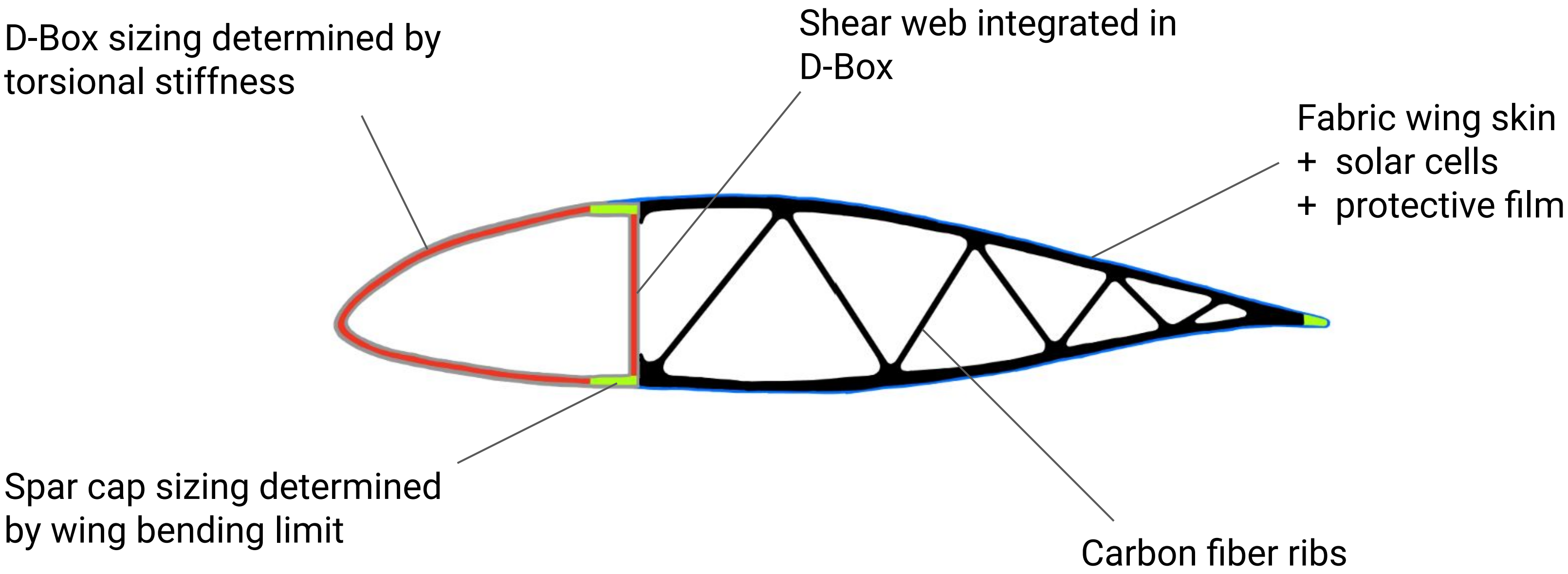
Connections that unite strings **in parallel**

- 2 connectors per wing, 1 on fuselage

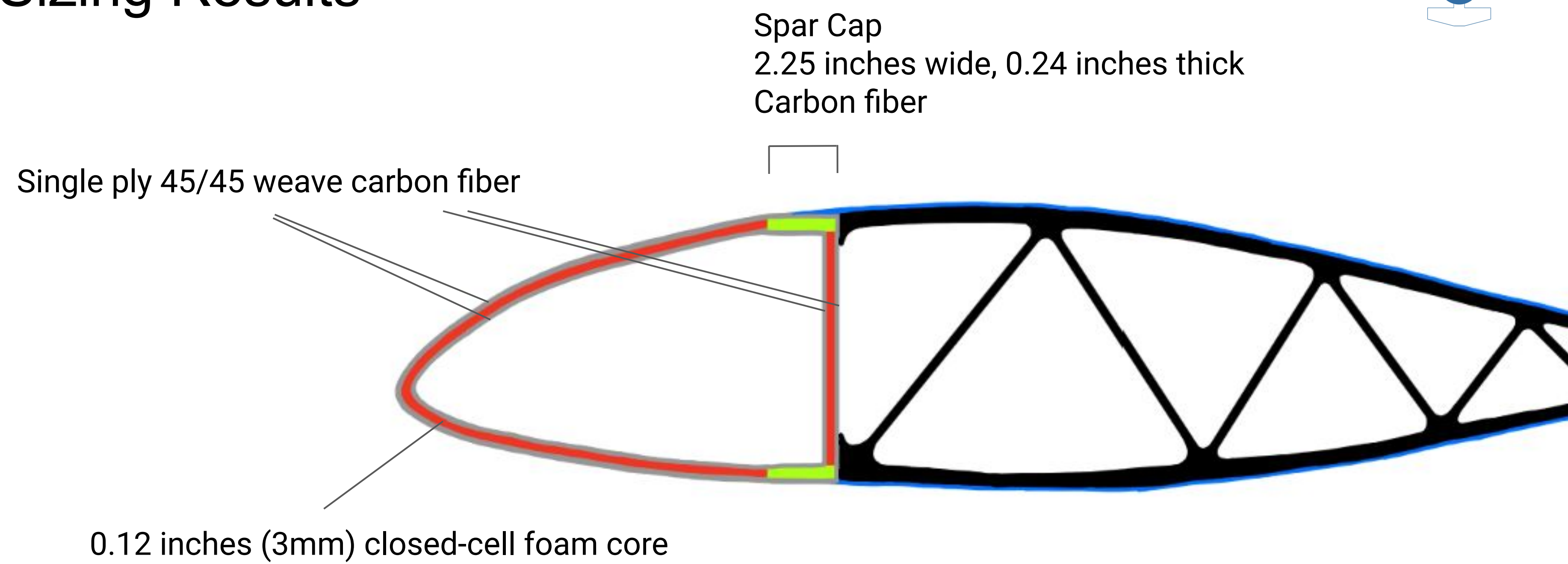
Connection between 2 connectors

Connection runs under trailing edge to MPPT

Structural Components of the Main Wing



Sizing Results



* thicknesses not to scale

Sizing Requirements Dominated by Stiffness

D-Box sized for torsional loads

Sizing case: Max aileron deflection, tip twist limit of 2 degrees

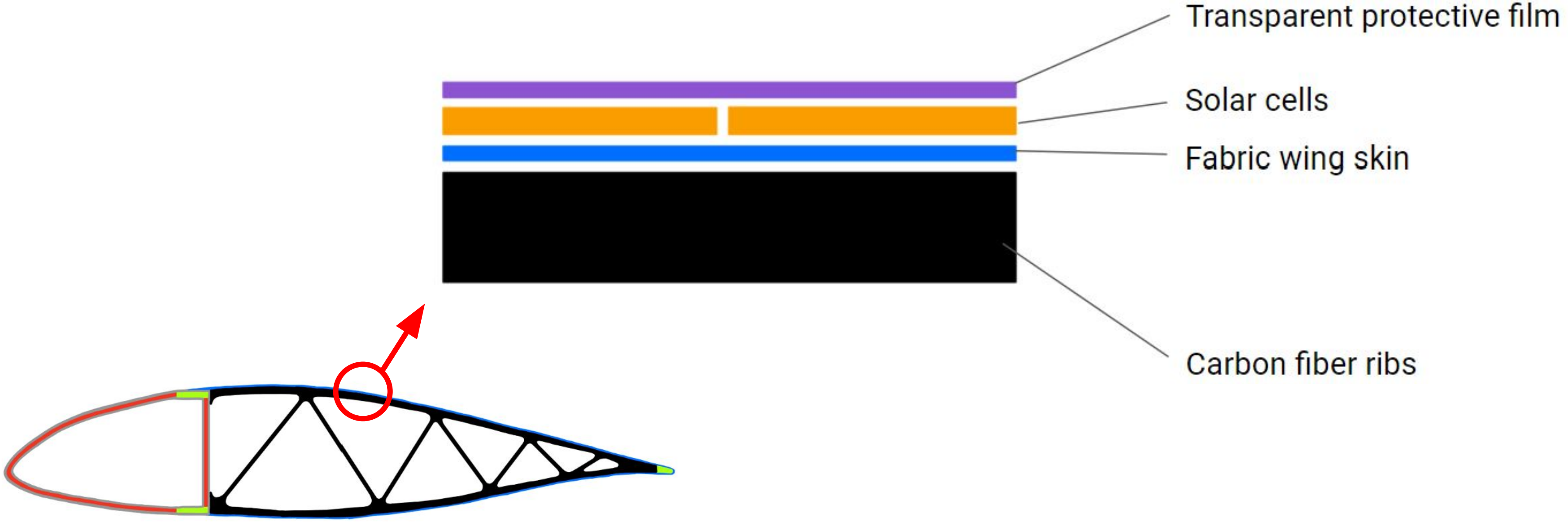
Sized for both strength and stiffness → stiffness dominates sizing requirement

Result: **Gauge limited**

Spar caps sized to limit tip deflection to 6 degrees at a load factor of 4

Shear web is also gauge limited, therefore shear requirement is satisfied by the vertical side of the D-Box

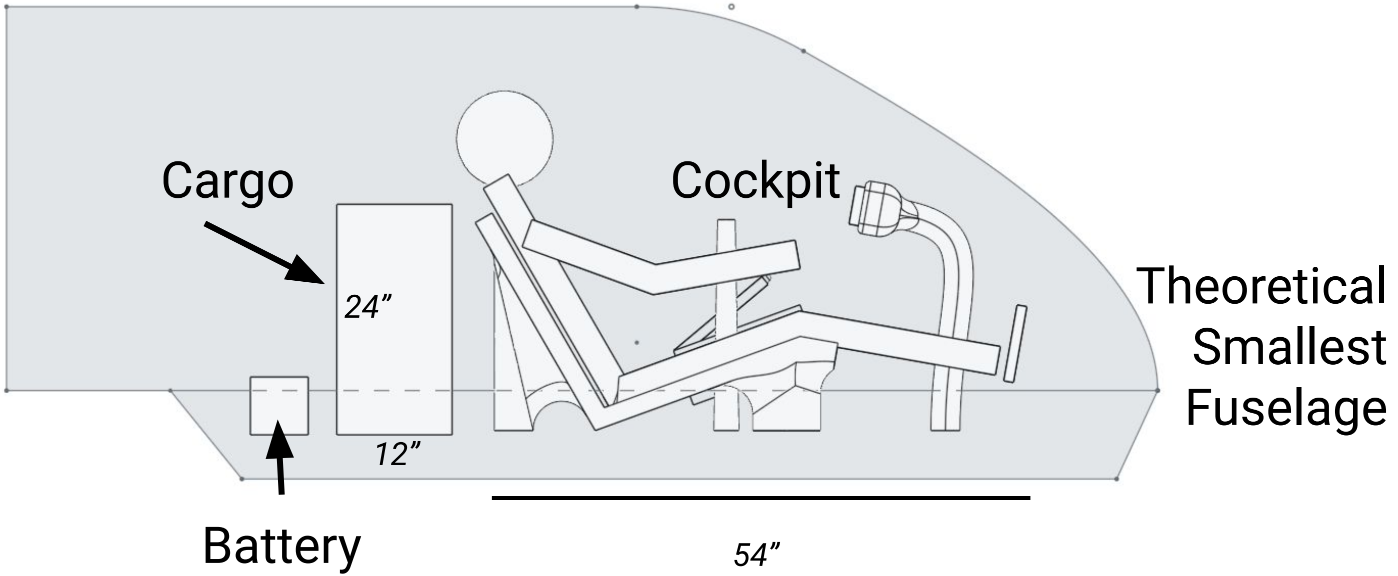
Solar Cells Sandwiched in Wing Skin



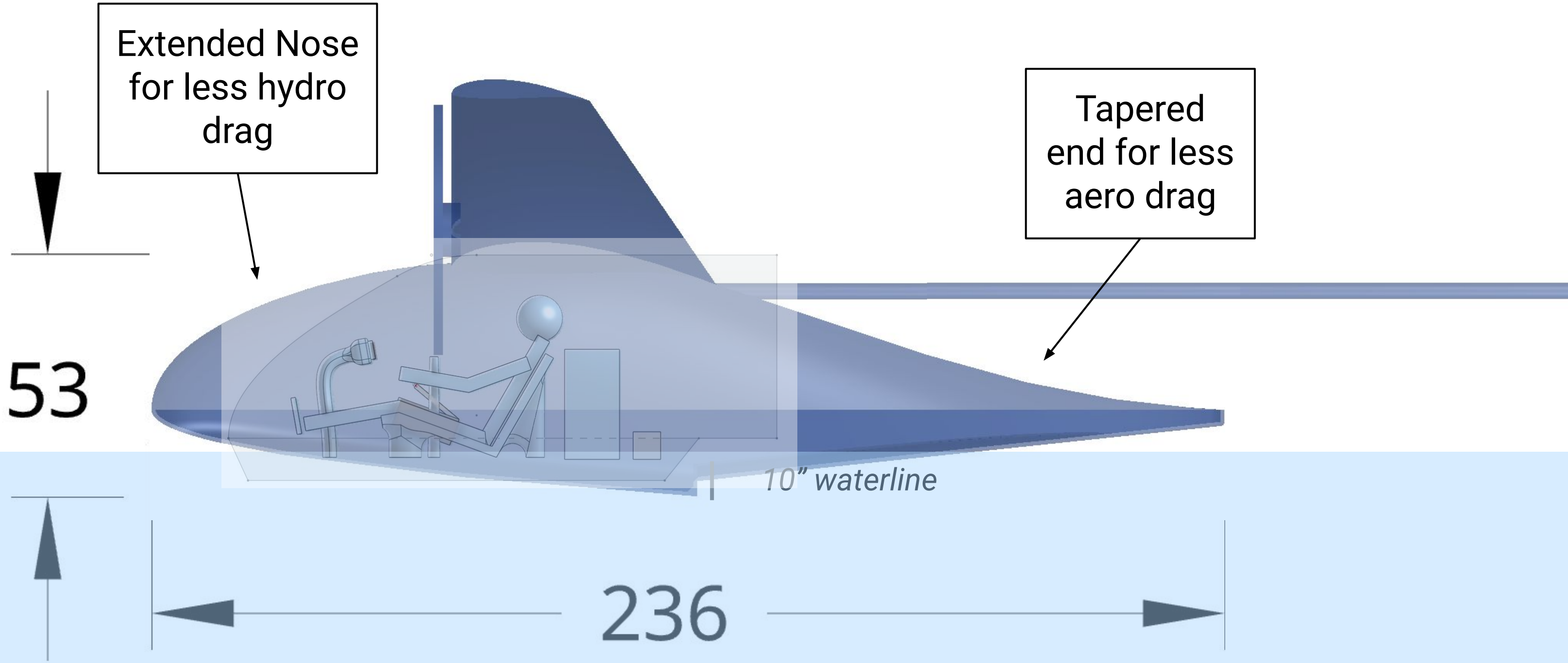
Outline

3. Subsystem Design
    a. Wing
    b. Fuselage
        i. Shape & Design
        ii. Structural Components
    c. Stabilizers
    d. Propulsion
    e. Human-Machine Interface

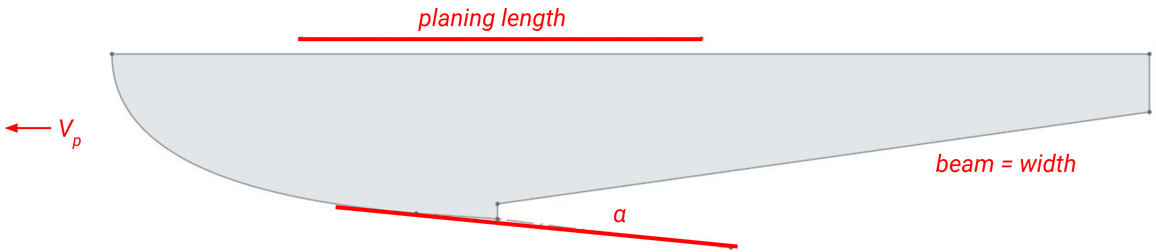
Fuselage Sized by Payloads

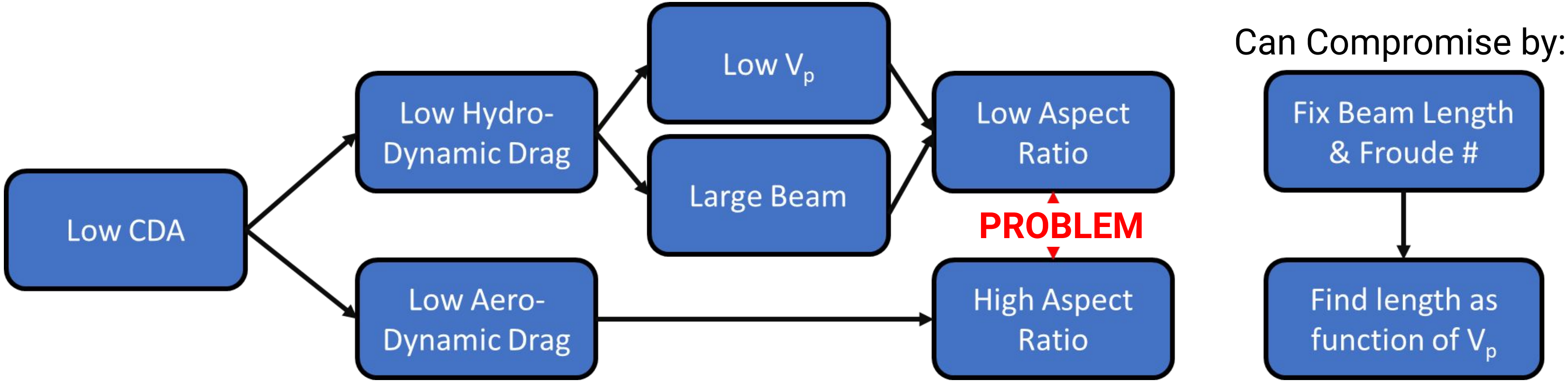


Meet the Fuselage



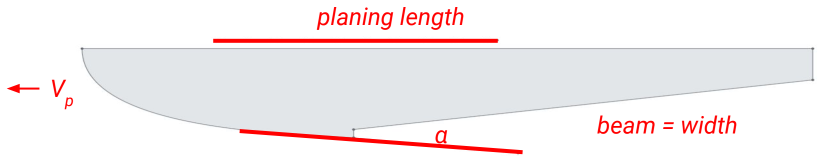
Hull: How to Compromise on Drag



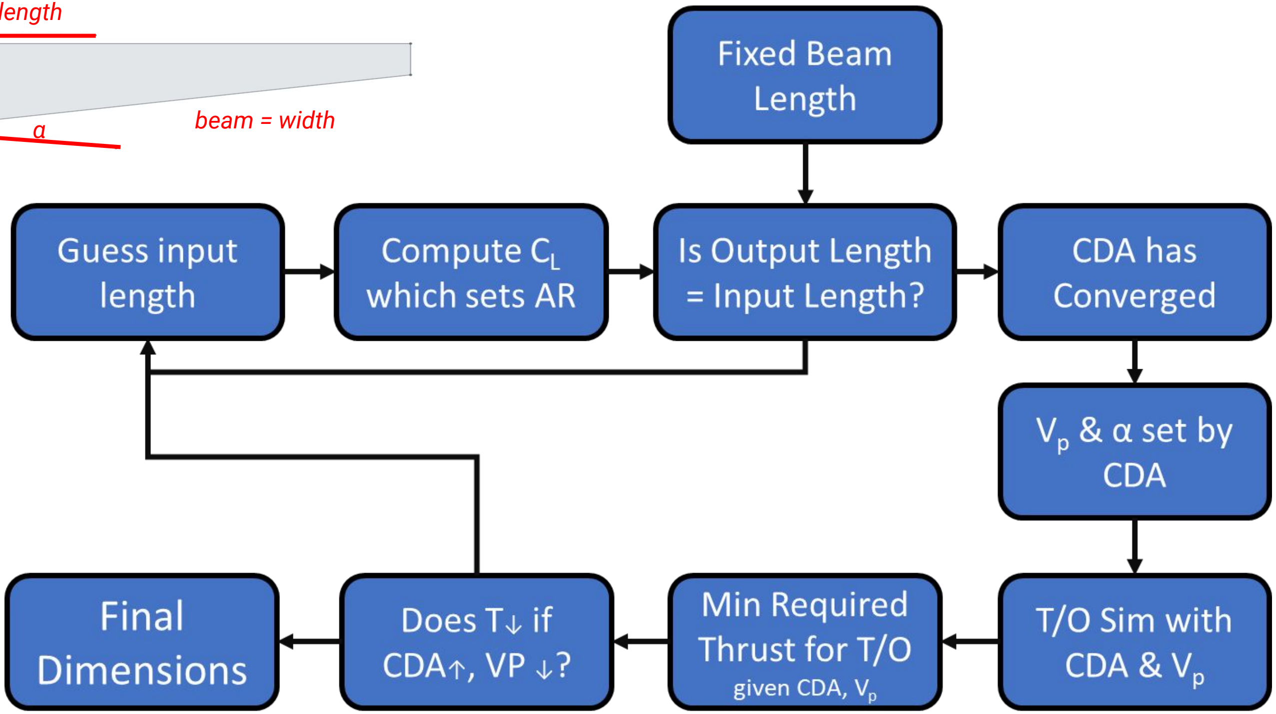


Presenter: Amira Malik

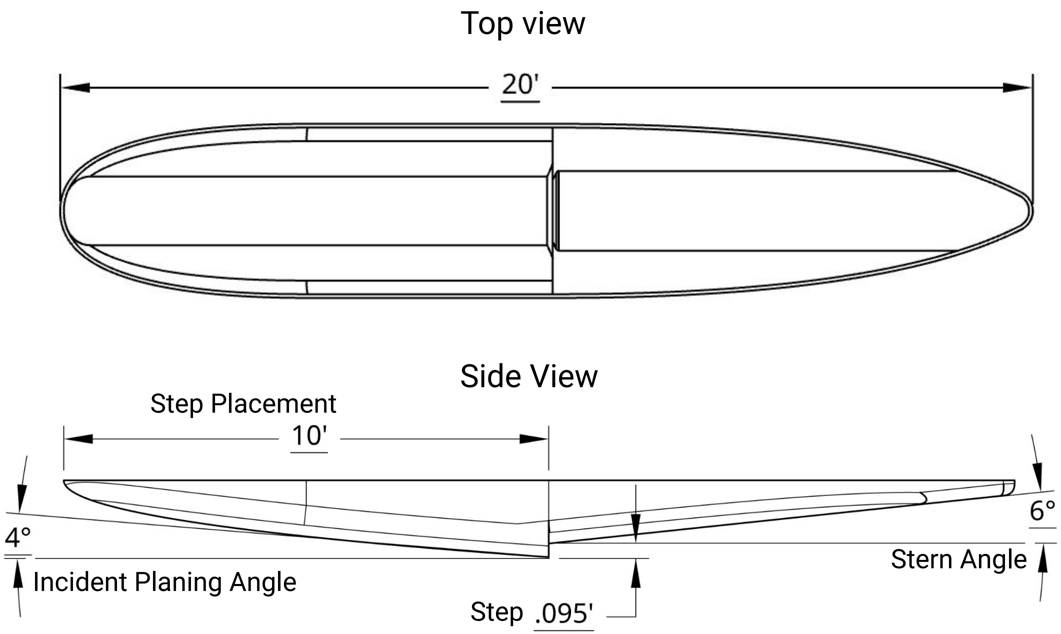
Hull: The Drag Loop

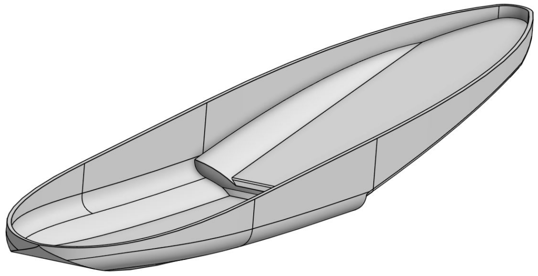


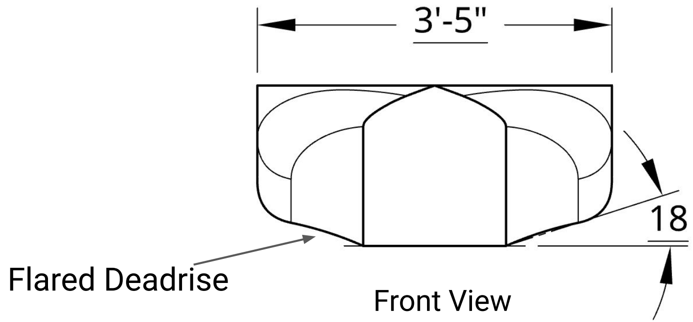
Converged Dimensions	
Trim angle, α	4 degrees
Planing Length	10’
Beam Length	3.5’
Fr_{min}	1.5
$V_{planing}$	16 knots
$CDA_{planing}$	0.006 m^2



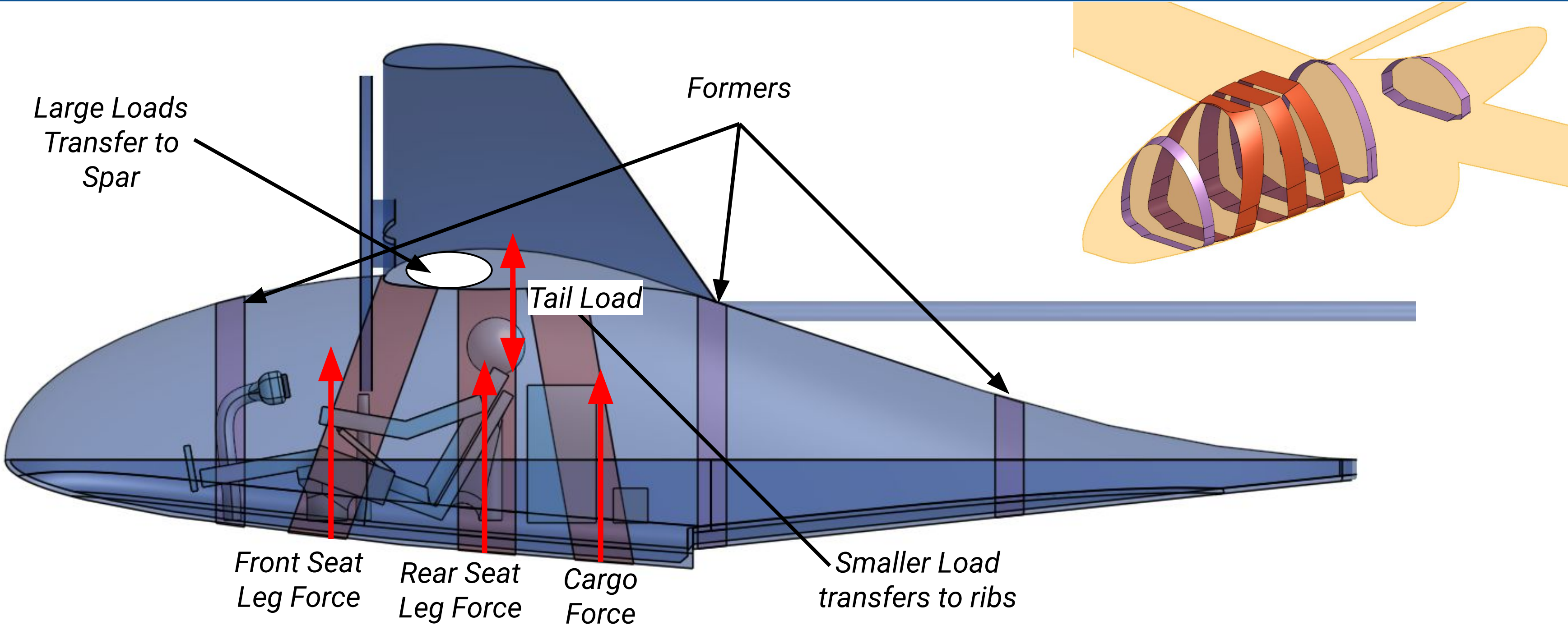
Determined Planing Hull Geometry



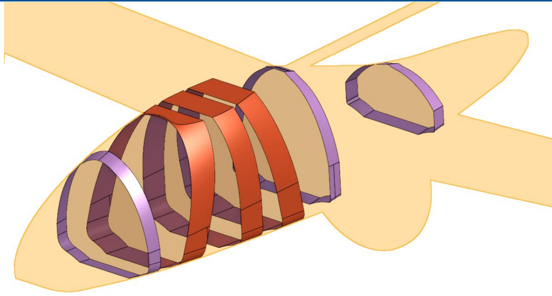




Bulkheads Positioned by Load Pathing



Fuselage Structure Sized by Landing

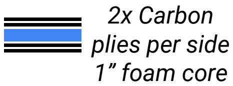


- Recommended sizing from 14 CFR 25.527
  - Solving gives us 1.61x load factor
  - Minimum from same regulation is 2.33x
- Going with 2.5x gives us >1.5x safety factor

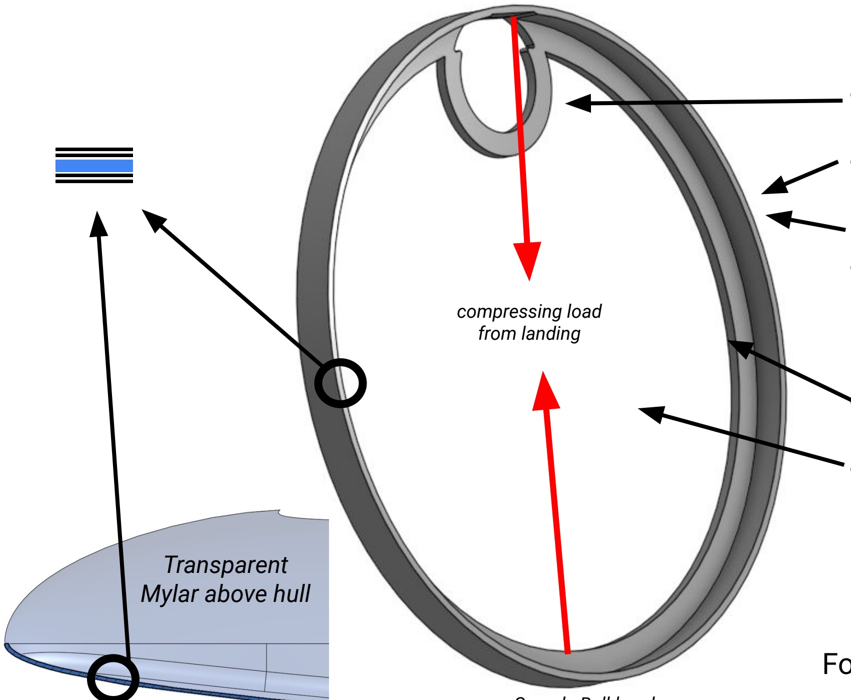
$$n_w = \frac{C_1 V_{SO^2}}{\left(\mathrm{Tan}^{\frac{2}{3}} \beta\right) W^{\frac{1}{3}}}$$

2.5G = 2550 N Load

- Each bulkhead takes 191 lbs of weight
  - Most pilots can step on bulkheads as they step in
    - Preliminary: structures made of same cross-section as spar ^



Hull & Bulkhead Cross-Section

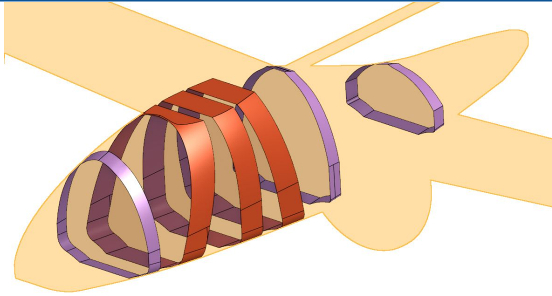


Sample Bulkhead

- Mates around tail boom
- Large flange for epoxy

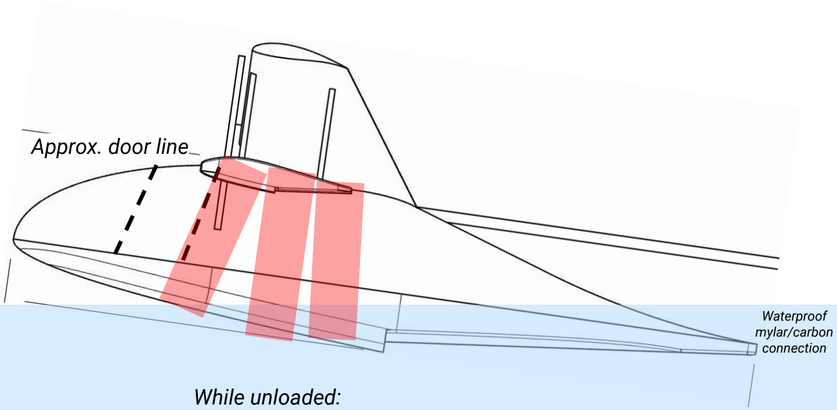
  10” bulkhead, 5” former
- Flange mates with IML for perfect fit
- Inner circle acts as hat-section
- Large hole for payload volume
  - Minimal Stiffness effect

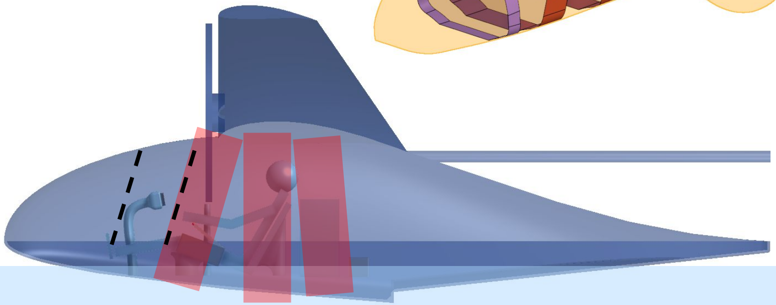
Formers are same concept, but less stiff

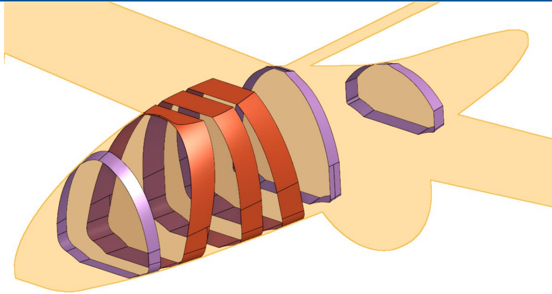


Estimated Weights (lbs)	
3x Bulkheads	10
3x Formers	5
Hull	15
Mylar Covering	3
total	33

Stepping into the Fuselage







While unloaded:

- *Plane rests on tail (8°)*
- *Door doesn't interfere with bulkheads*
- *Pilot steps on front bulkhead **slowly***
- *Enough room for pilot to pivot around, sit, and extend legs to pedals*

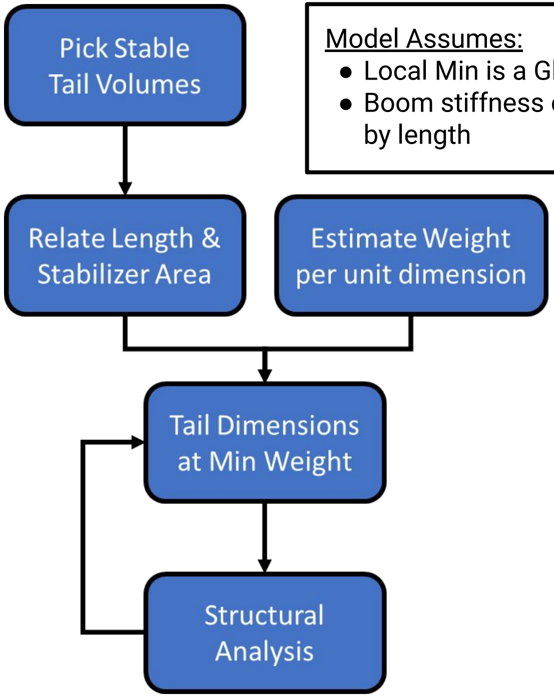
While loaded:

- *Plane rests on hull (0°)*
- *Mylar door is closed (zipped or velcro'd)*
- *If cargo, pilot set inside before stepping in*
- *To leave: pilot steps on bulkhead, **slowly** steps out, letting plane rest on tail*

Outline

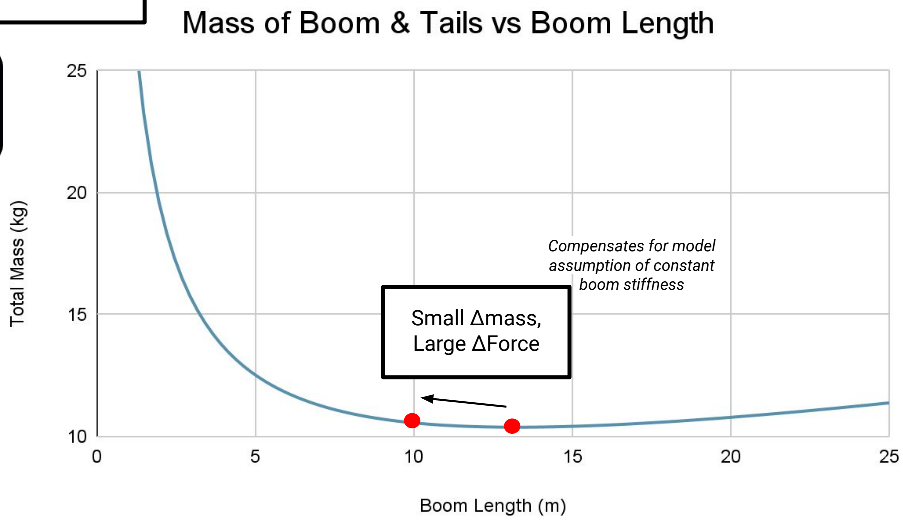
3. Subsystem Design
    a. Wing
    b. Fuselage
    c. **Stabilizers**
        i. Empennage
        ii. Ailerons
        iii. Elevator
        iv. Rudder
        v. Pylons
    d. Propulsion
    e. Human-Machine Interface

Tail Size Dominated by Minimizing Weight



Model Assumes:

- Local Min is a Global Min
- Boom stiffness constant by length

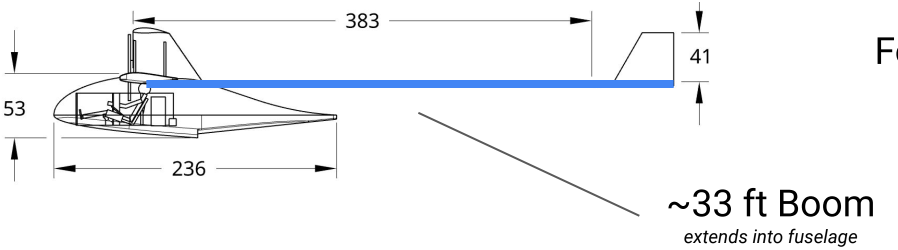


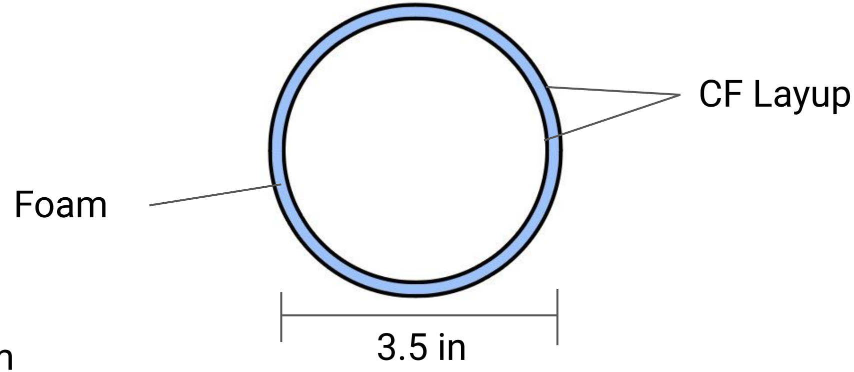
Final Dimensions

Boom Length	10 m
H-Stab Area	0.82 m^2
H-Stab Mass	4.66 kg
V-Stab Area	1.05 m^2
V-Stab Mass	3.9 kg

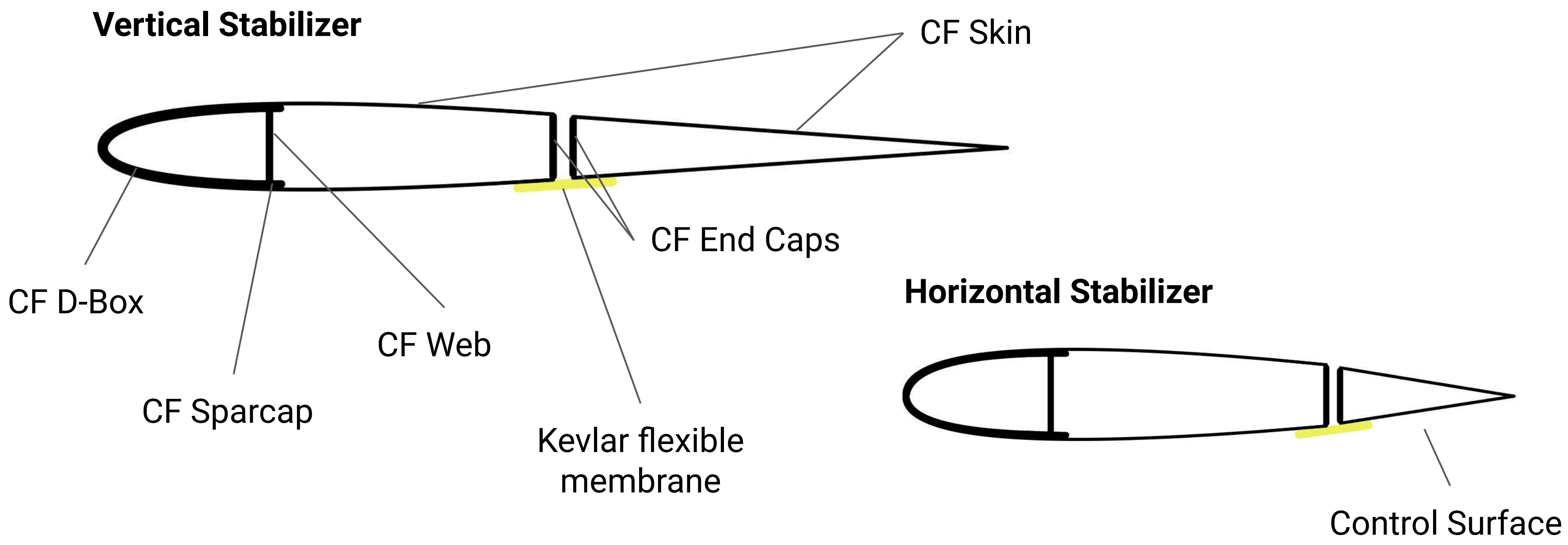
Boom Is **C**arbon **F**iber Composite Sandwich Tube

- Tube chosen for its good bending and torsional resistance
  - Bending deflection in z-axis is primary sizing case (lift and weight)
  - Torsion considered for rough landing
- 1 layer CF + thin layer of foam + 1 layer CF
  - Prevent ovalization or denting
  - Relatively lightweight

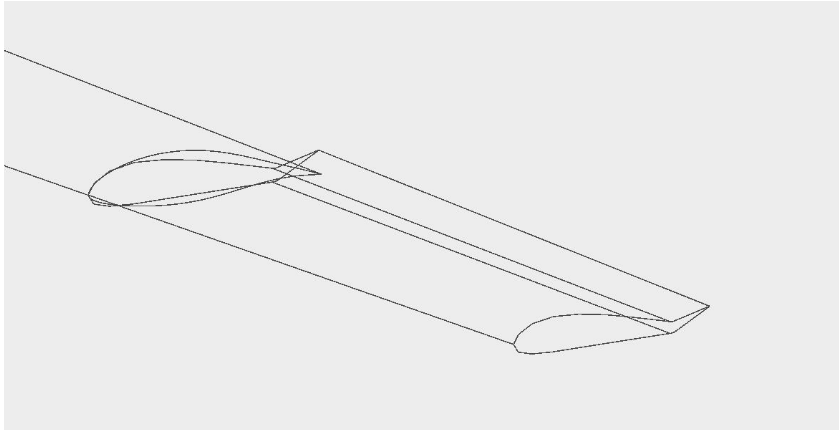


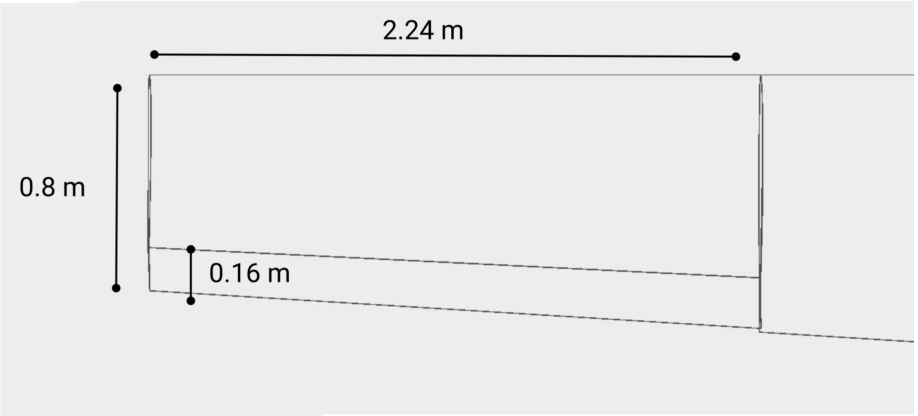


Structure of Stabilizers is **C**arbon **F**iber Shell



Aileron - Geometry

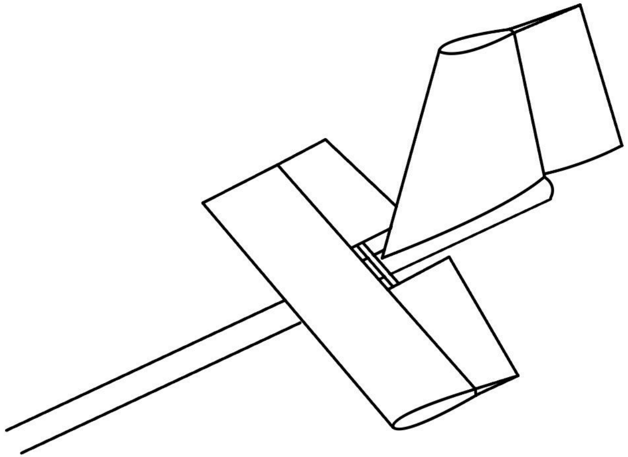


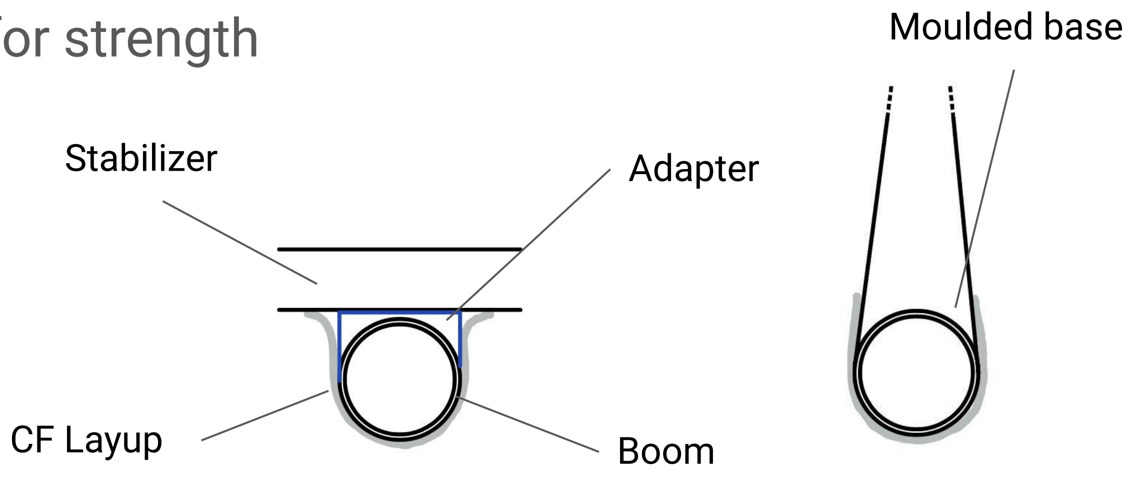


20% root chord, 20% semispan from tip, max deflection 25°

Stabilizer Mounting Configuration

- Saves overall weight, is structural and constructable
- Foam adapters interface stabilizer with boom tube
- Unidirectional CF layup for strength



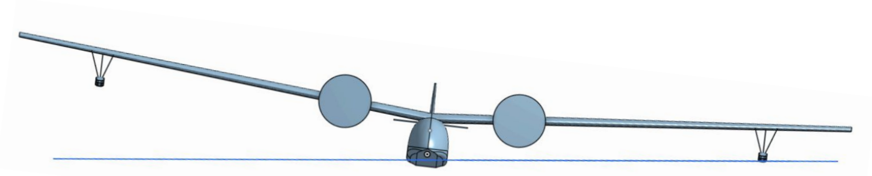


Horizontal Stabilizer **Vertical Stabilizer**

Pylon + Floats

- Float placement constraints
  - Propeller clearance from waves at rest (>18in)
  - Float clearance during landing (>18in)
- Floats attached to wing with pylon structures made from symmetric airfoil shaped carbon fiber tubes
- Ultimate constraint for placement of floats is maximizing distance from waterline on landing

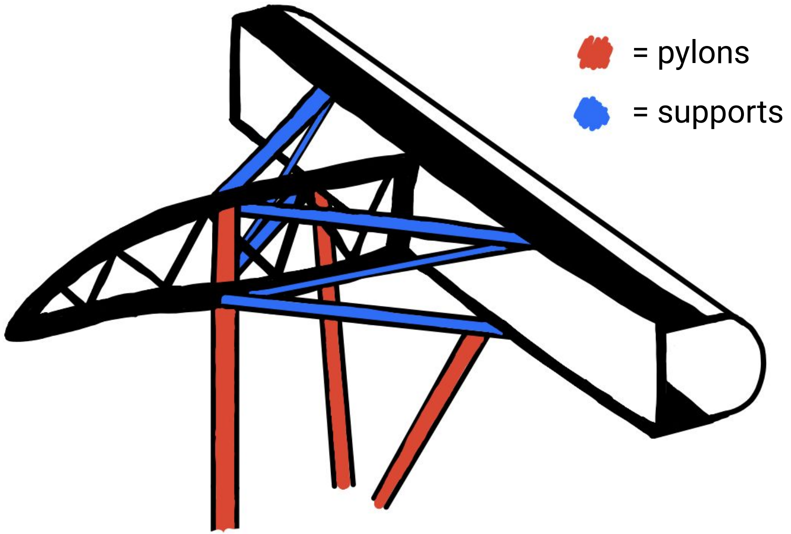
Configuration when flat in water/airborne



Configuration when resting on floats

Pylon Connection

- Two front pylons are connected to the spar
- Back pylon connects to a reinforced CF rib
  - Rib is reinforced and attached to the spar with supports so the float assembly can withstand hard landings
- Molded inverted-wingtip design not possible due to wing structure

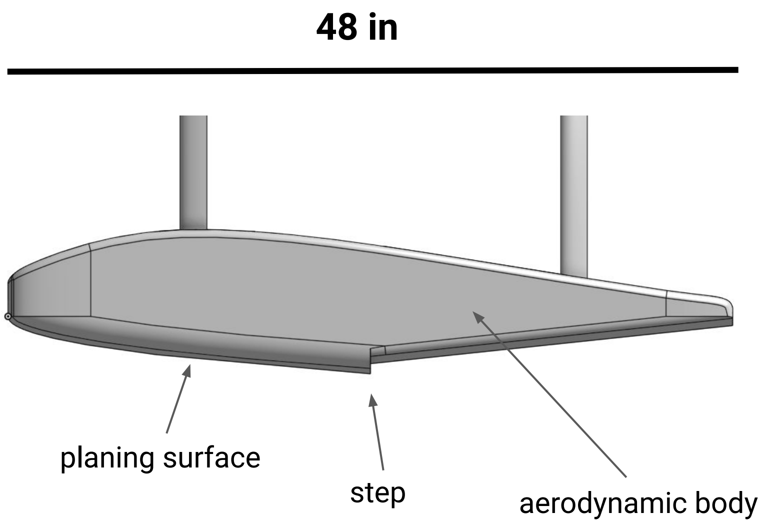


Float Sizing and Shaping

- Floats were sized to correct for 15 mph winds when at rest and support the weight of the wing
  - Provide roll-axis stability in water
  - Designed to provide 1.5x needed moment for safety margin

- **Required Volume (per float) > 2.35 ft^3**

- Floats have a planing surface and step to reduce hydrodynamic drag and encourage separation from the water



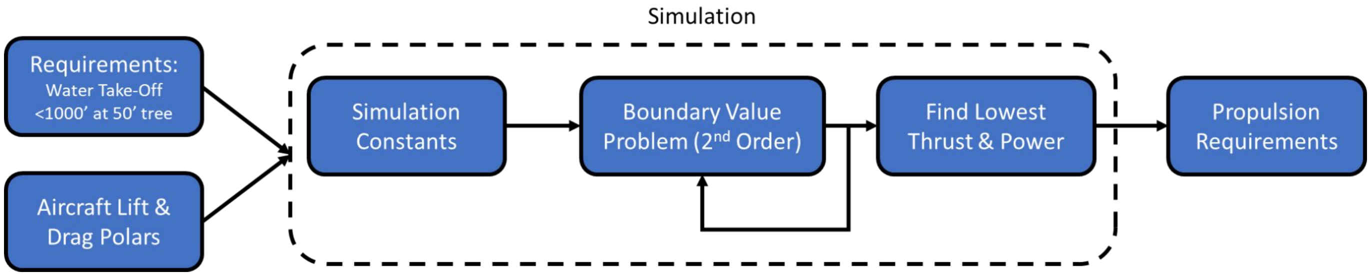
Outline

3. Subsystem Design
    a. Wing
    b. Fuselage
    c. Stabilizers
    d. **Propulsion**
        i. Propulsion Requirements
        ii. Propeller
        iii. Motor
        iv. Battery
        v. MPPT
    e. Human-Machine Interface

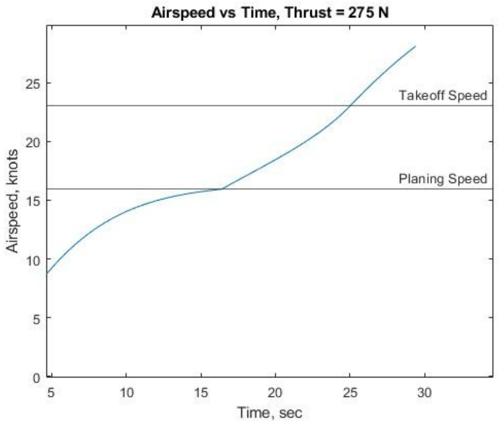
Take Off Power Sizes the Propulsion System

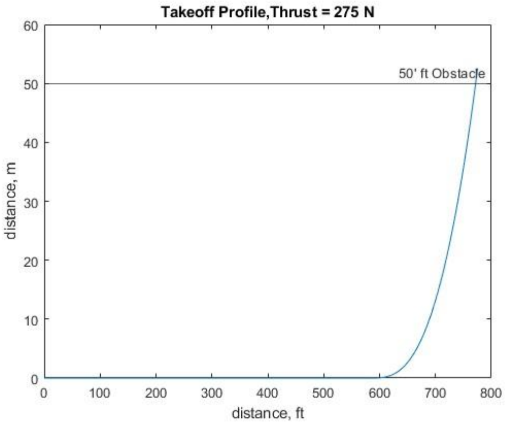
"What does the plane need to do that the solar panels can't provide?"

Take-Off Power >> Cruise Power

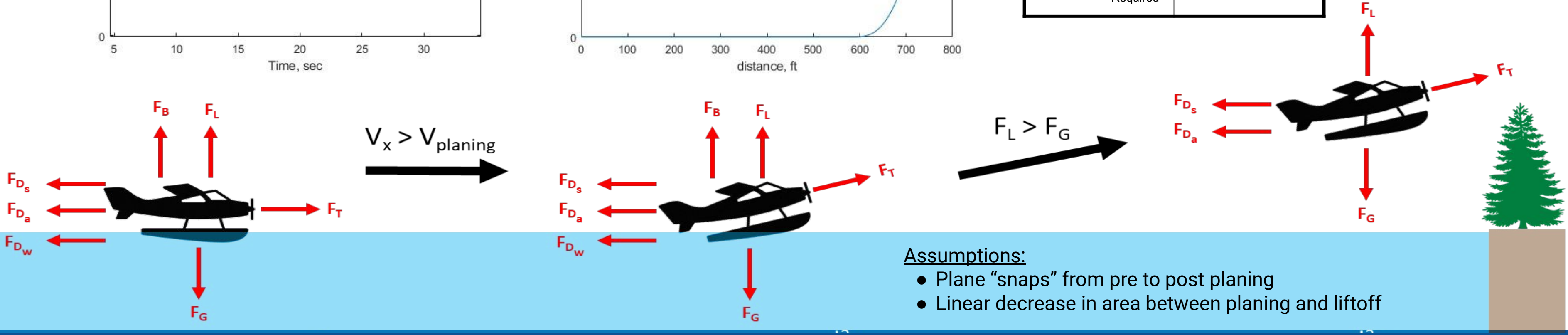


Planing Speed Sets Minimum Thrust



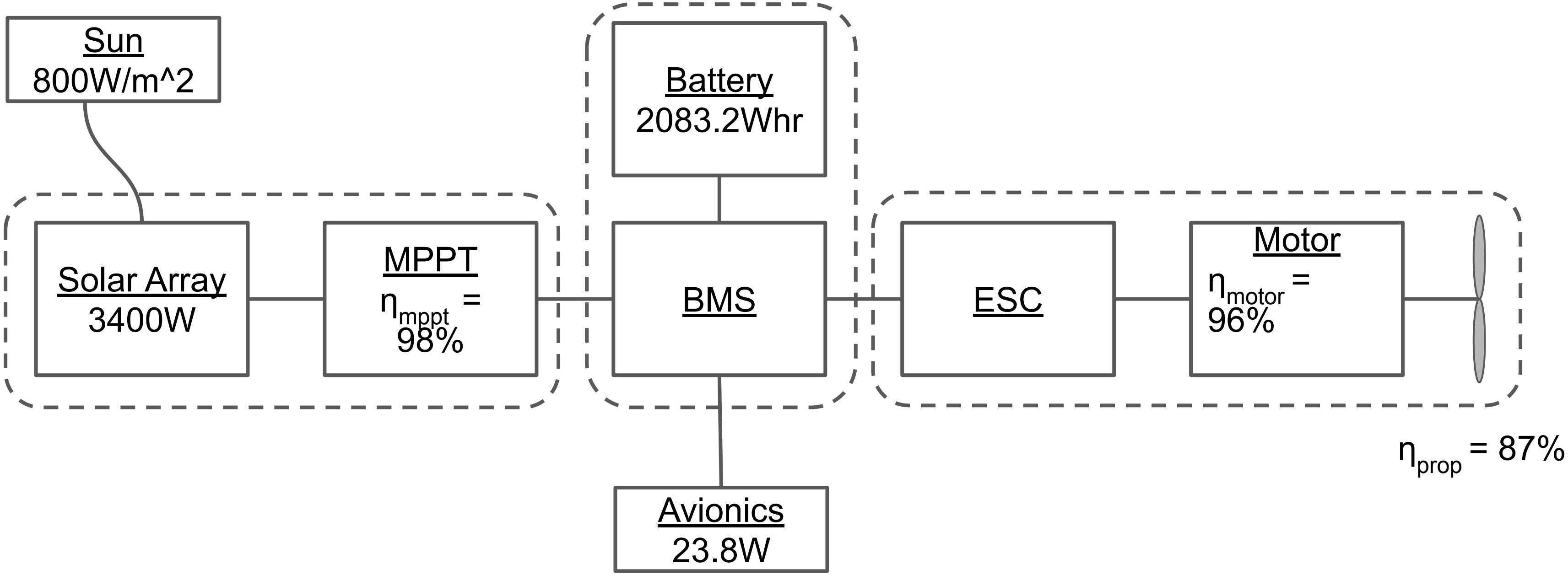


Propulsion Requirements	
Cruise Thrust	195 N
T/O Thrust	275 N
Cruise $P_{Required}$	3300 W
T/O $P_{Required}$	4000 W



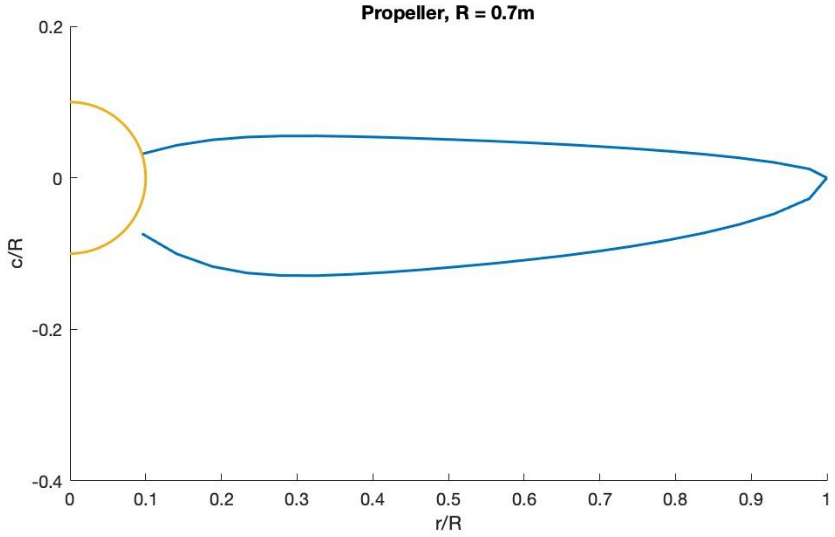
Assumptions:
- Plane “snaps” from pre to post planing
- Linear decrease in area between planing and liftoff

Powertrain Power Requirements & Efficiencies



Propeller Designed For Cruise

- QMIL Propeller Design
  - 2-bladed, 1.4m (4.6ft) diameter propellers
- Considerations:
  - Torque set < 20 Nm
    - $Q \propto W_{motor}$
    - $Q_{cruise} < Q_{max}$
  - Thrust / Power set by T/O Sim

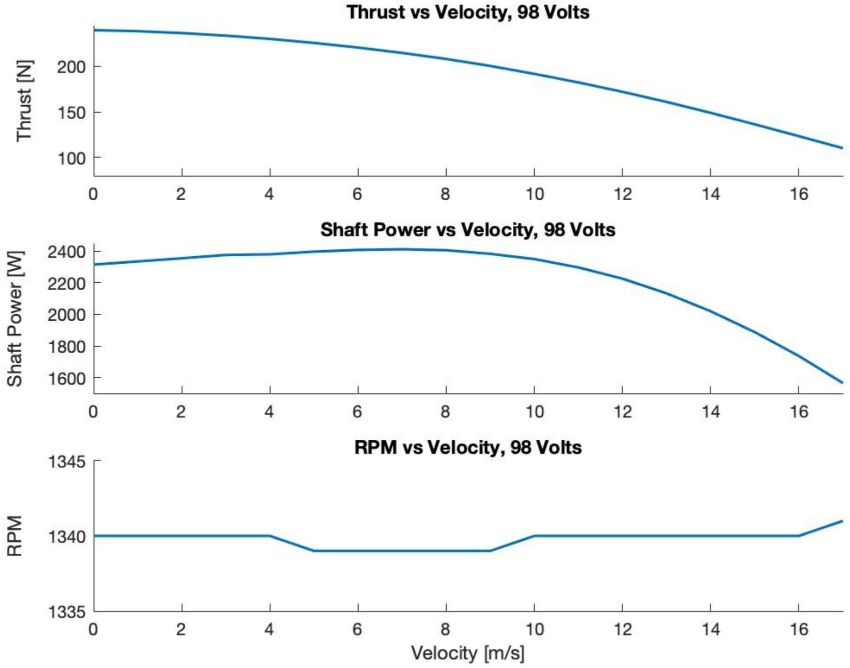


Propeller Performance

QPROP analysis*

λ	0.17
Ω_{cruise}	1340 RPM
$\eta_{prop,\ cruise}$	84%
Q_{cruise}	15.86 N-m
$P_{takeoff}$ (V=12 m/s)	2225 W
P_{cruise} (V=17 m/s)	1565 W
Voltage	96 V
$K_{V,\ required}$	14

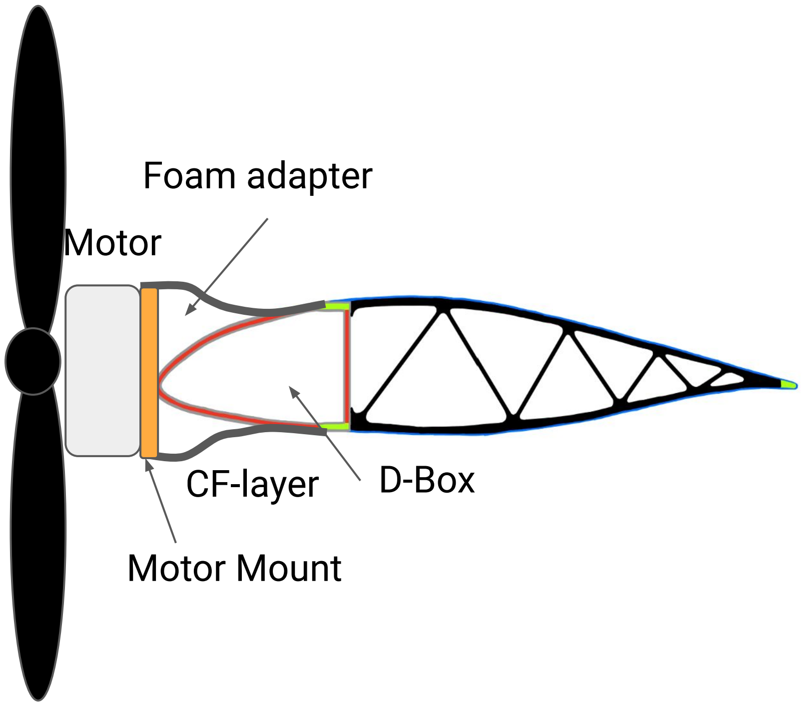
*per propeller



Motor/Motor Controller Selection

Manufacturer	MAGicALL
Model	6
Torque, max	18 N-m
RPM, max	8000
KV	83 (Will rewind)
Mass	1.5 kg
Efficiency	90.5%
Cooling	Air flow on fins
Dimensions	4.5” diam. 3.5” leng.

Motors Attached via Composite Mount



- Motors interfaced with main wing on D-box and main spar using foam adapters
- Attach motor mount via foam adapters and molded carbon fiber composite
- Screw motor on mounting plate

Battery Specifications & Selection

Battery Pack Specifications	
Chemistry	Li-Po
Capacity	21.7 Ah
Voltage	96 V
Cells in series	26
Cells in parallel	10
Weight	19.5 lbs
Volume	316 cubic inches

Battery Cell Specifications	
Capacity	2.2 Ah
Voltage	3.7 V
Max C-Rate	5
Cell Energy Density	260 Wh/kg

Battery Charge/Discharge

Flight Phase	Time	Battery Energy used	Battery Charge Used (21.7 Ah total capacity)	SOC (End of Phase)
Take-off	30sec	5.5Whr	0.054 Ah	99.66%
Climb (50ft)	8sec	10.80Whr	0.2 Ah	99.01%
Cruise (charging)	40min (13min / 1 DOD)	CV = 109.2V	-	100%
Cruise (Battery Powered)	30min	1650Whr	17.2 Ah	20.78%

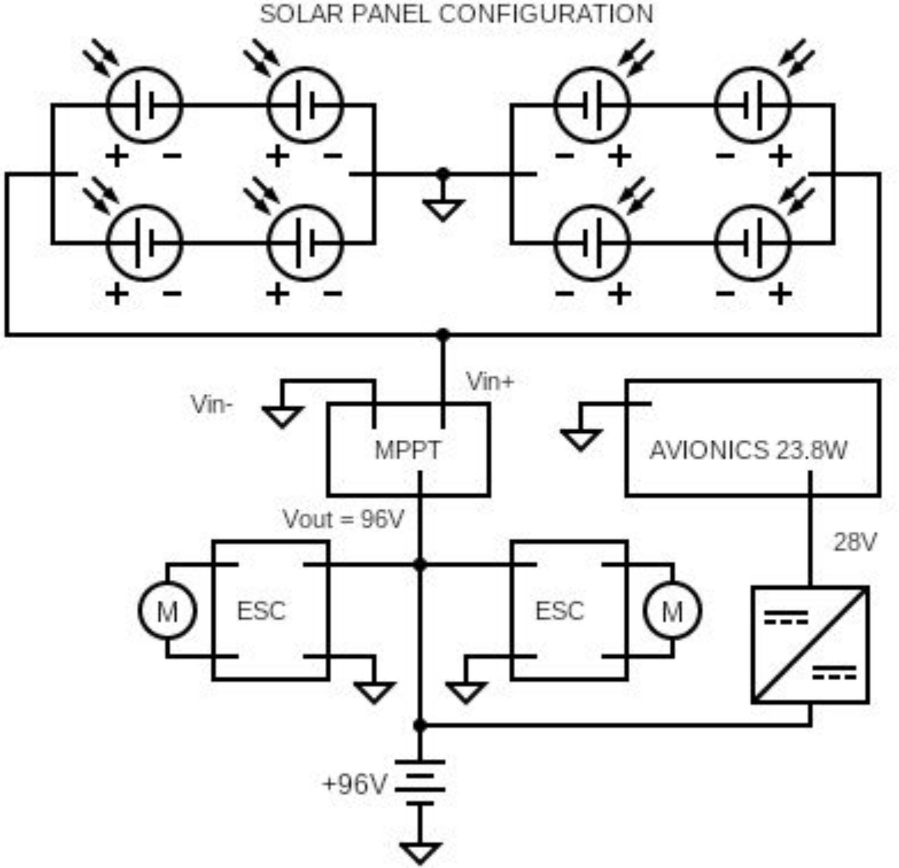
MPPT

Manufacturer	MakeSkyBlue
Model	96V45A
Max Current Output	45A
Voltage Output	96V
Max PV Input Power	4500W
Max Efficiency	98.2%
Total Mass	1.1kg
Dimensions/unit	8.5”x 4.5” x 2.0”

- Matches battery voltage
- PV power < Max input power

Circuit Diagram

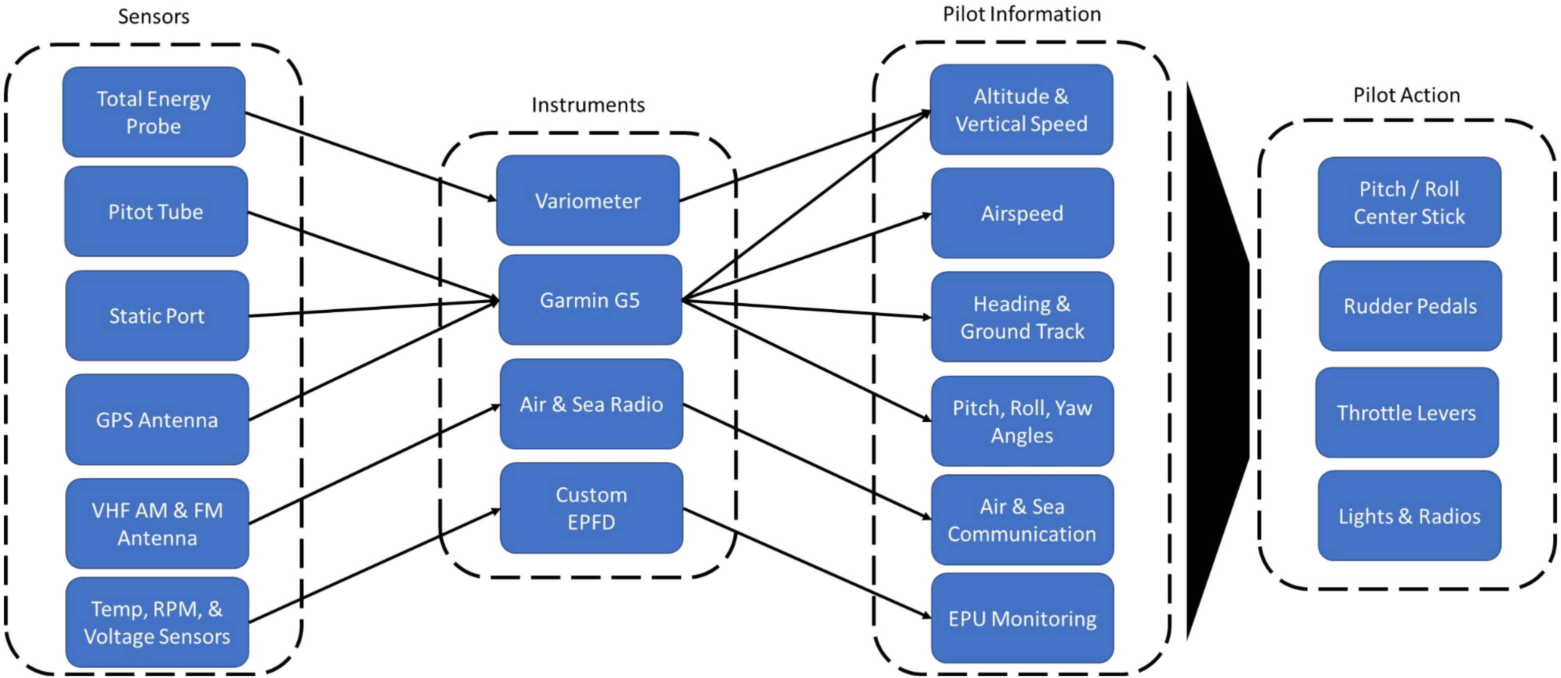
- MPPT inputs variable panel voltage (up to 500V), outputs 96V
- DC/DC converter inputs 96V from battery, outputs 28V for avionics



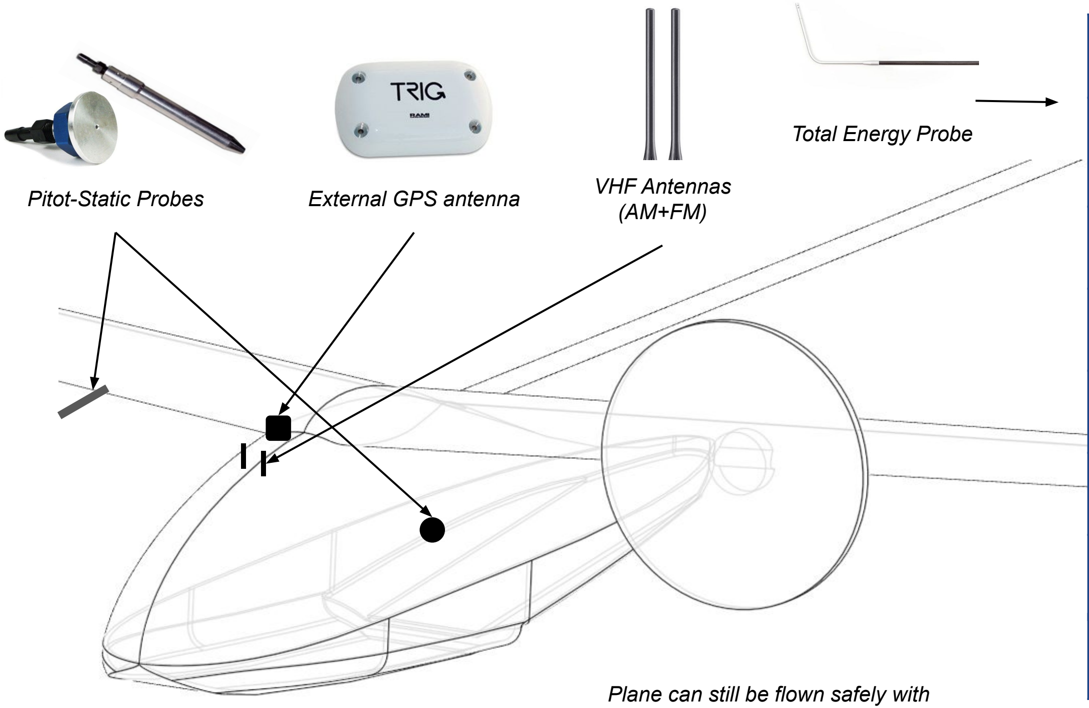
Outline

3. Subsystem Design
    a. Wing
    b. Fuselage
    c. Stabilizers
    d. Propulsion
    e. **Human-Machine Interface**
        i. Avionics
        ii. Cockpit
        iii. Control Routing

The Human-Machine Interface



Simple Sensors



Part	Weight (lbs)
Pitot Static Probes & ADC	1.50
Total Energy Probe	0.50
GPS Antenna	0.31
VHF Antenna Extension (x2)	1.10
LM90 Temp Sensors (x5)	0.50
Antenna + Signal Wiring	3.00
Total	9.73

Plane can still be flown safely with single or multiple sensor failures

Simple Instruments

MPPT

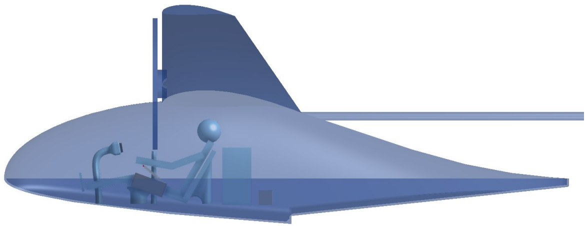
30W 96V/28V DC-DC

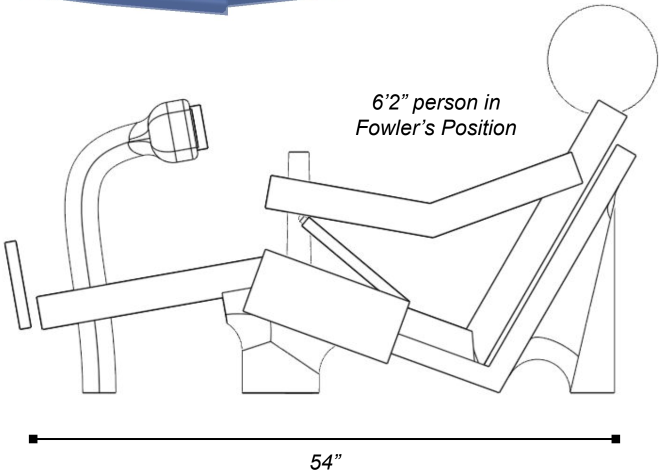
Part	Weight (lbs)	Power @ 28V (W)
Garmin G5	0.84	2.8
Custom EPFD	2.00	3.0
Strobe Lights (x2)	0.22	3.0
Air + Marine Radio	1.22	12
100’ 12AWG Wire	4.00	-
Variometer	1.01	0
Total	9.50	23.8

Presenter: Amira Malik

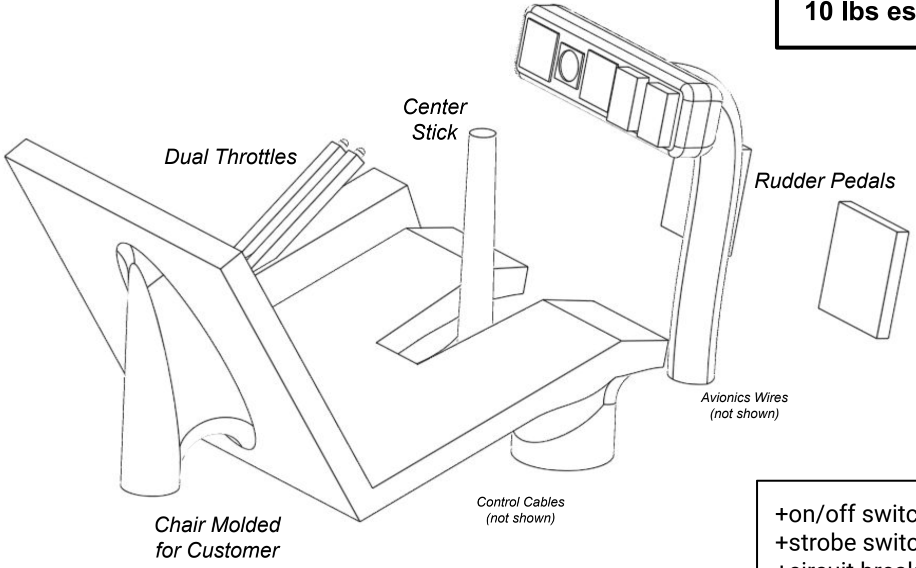
Simple Cockpit

Sensors | Instruments | Pilot Info





10 lbs est.



+on/off switch
+strobe switch
+circuit breakers

Presenter: Amira Malik

Simple Panel

Sensors | Instruments | Pilot Info

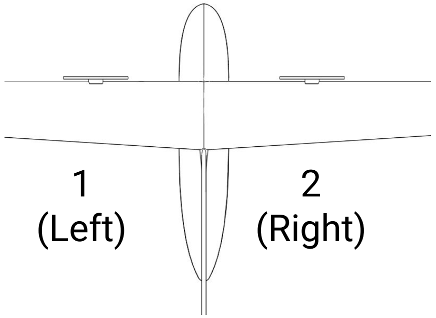
Electric Propulsion Flight Display (EPFD)

Variometer

Garmin G5

Stripped VHF Radios

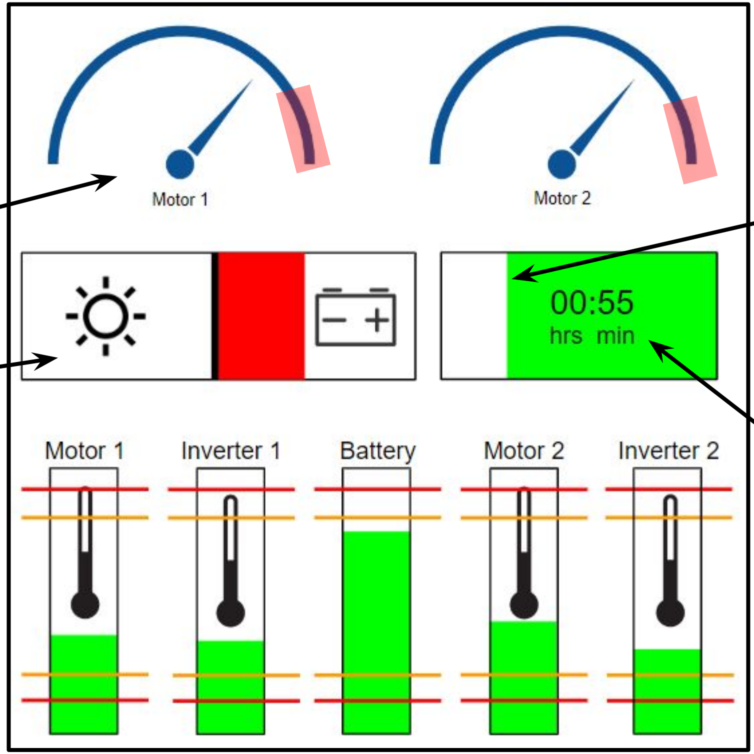
Simple Display



Motor RPM w/red line

Flux from Cells or Battery

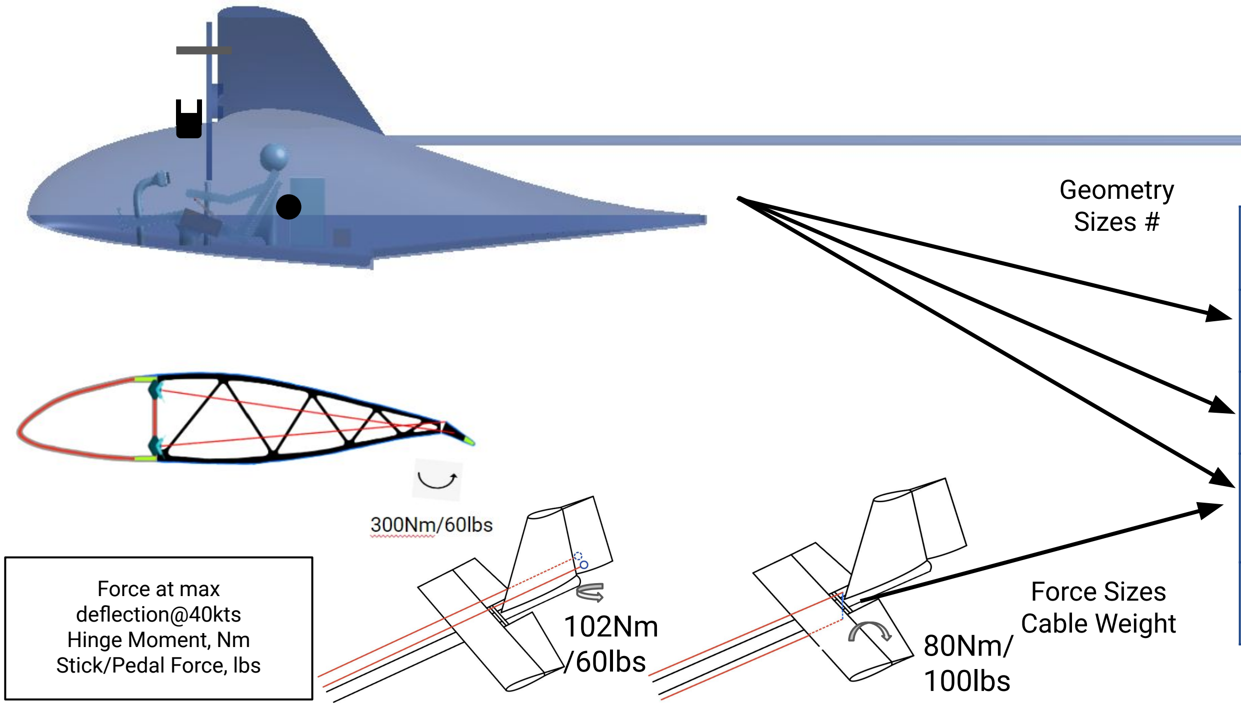
Temps with high & low indicators



Voltage Meter

~30sec Average of Endurance (just battery)

Simple Controls



Part	Weight (lbs)
2” Pulleys (x14)	0.23
Aileron Bellcranks	0.44
42 m Aramid Fiber Control Cable	0.57
Total	1.24

Force at max deflection@40kts
Hinge Moment, Nm
Stick/Pedal Force, lbs

Presenter:

Outline

1. Motivation
2. General Overview
3. Subsystem Design
4. **Risk**
5. Conclusion

Risks

- Project risk: Currently over ultralight requirement weight by 18 lbs
  - Key components to check: Electrical wiring, wing, planing hull.
- Current configuration allows a pilot of 170 lbs with full 30 lb cargo, or a pilot 155 lbs or lighter with no cargo.
  - To expand our pilot weight envelope, we can move the batteries or the entire hull a bit forwards to better align the CG's of the pilot and the empty weight
- Motors and Propellers currently not powerful enough to sustain necessary thrust
  - Will be analyzed and fixed

Presenter: Amira Malik

Outline

1. Motivation
2. General Overview
3. Subsystem Design
4. Risk
5. **Conclusion**
    a. Short Term
    b. What’s Next?
    c. Special Thanks!

Possible Short-Term Design Improvements

- Further airfoil modification for high L/D low Re
- Modeling viscous and interference drag more accurately
- Turbulent flow visualization for total energy probe placement
- Verify the dynamic stability polars are sufficient
- Load pathing between major elements
  - Tail -> Bulkheads -> D-Box
  - Pylon bracing to wing structure
  - Wing skin load paths

What’s Next?

Buy it - all components are either COTS or its constituents are defined

Build (some of) it - with current sketches, test structures can be built

Test it - each test section is verified before being built in their final form

Build (all of) it - from testing, the design can be modified and built

Fly it - on-ground system tests leading to flight tests

Sell it - purchase a factory and undergrad labor to assemble and deliver

Special Thanks

R. John Hansman

Mark Drela

Peter D. Sharpe

Jessie Stickgold-Sarah

Rebecca Thorndike-Breeze

Robert Liebeck

Demet

Team Air, our good competition

Backup Slides

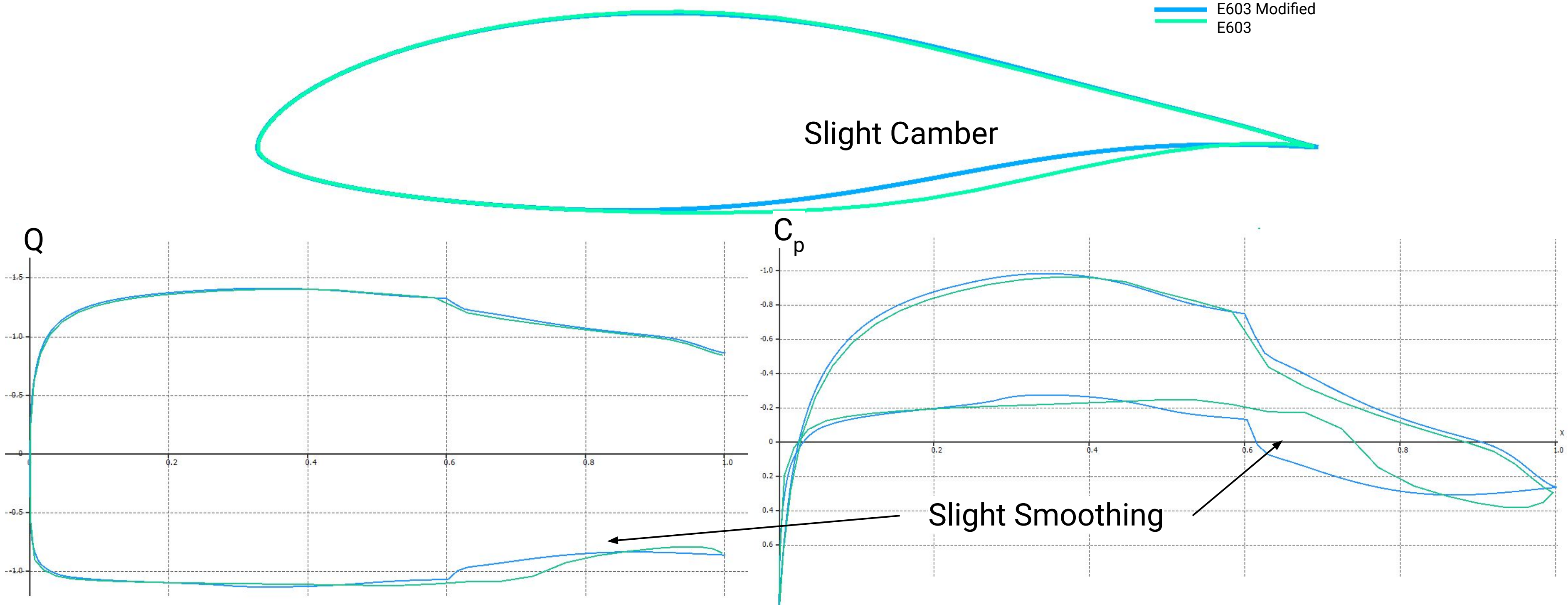
Possible Scale Models

Major Risk: Weight & Size **Mitigation:** Scale Design

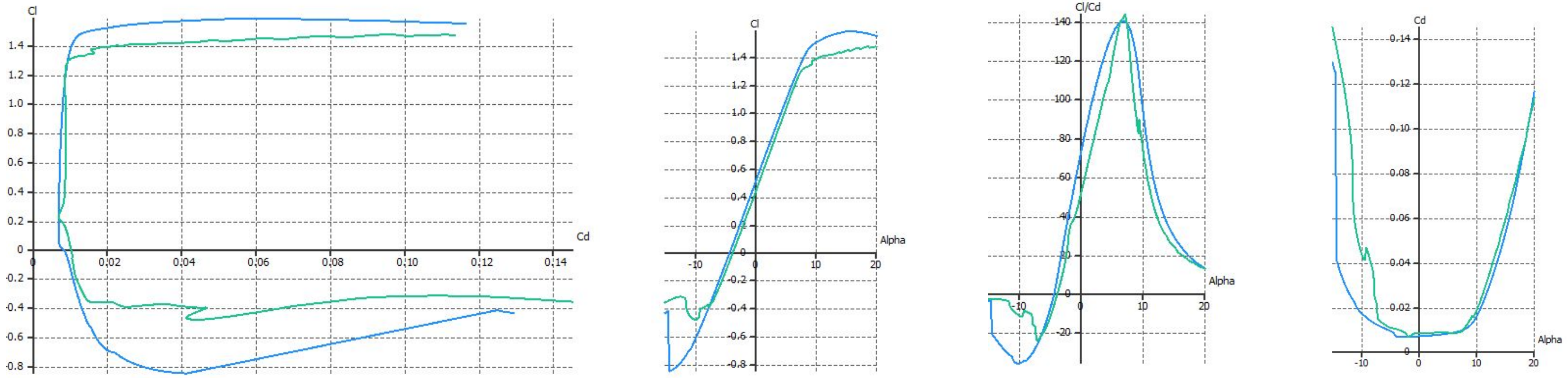
By Dimension	Wingspan (ft)	MTOW (lbs)	Payload (lbs)	Certification Type
Full Scale	74	582	260	Piloted Ultralight
6/7 Scale	63	370	163	Piloted Ultralight
3/4 Scale	56	245	110	UAV (Waiver Needed)
1/2 Scale	37	73	33	UAV (Waiver Needed)
4/9 Scale	33	51	23	107 Compliant
1/3 Scale	24	22	10	107 Compliant

Aerodynamics

Modified Eppler 603 Airfoil



Modified Eppler 603 Airfoil



Presenter: Amira Malik

Wing Design Formulation

Known Variables

The governing equations

$$L = \frac{1}{2} C_L \rho S V^2$$

$$D = \frac{1}{2} C_D \rho S V^2$$

$$P_{required} = \frac{S}{\eta_P} \sqrt{\frac{2}{\rho}} \left(\frac{C_D}{C_L^{\frac{3}{2}}} \right) \left(\frac{W}{S} \right)^{3/2}$$

$$P_{generated} = \eta_p \eta_m \eta_s \eta_a S Q$$

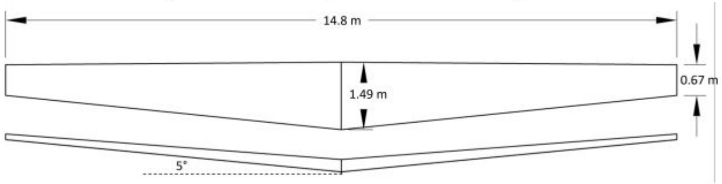
$$\frac{T}{W} = q C_D \left(\frac{1}{\frac{W}{S}} \right) + k \left(\frac{1}{q} \right) \left(\frac{W}{S} \right)$$

With W=L, all can be parametrized by speed
So, code sweeps speeds

Symbol	Known Variables	Value (SI units)
L, W	Weight-Force at Cruise [6]	2510 N
ρ	Density Altitude [6]	.91 kg/m^3
Q	Determined Value [2]	800 W/m^2
η_s	Determined Value [3]	22.4%
η_p	Determined Value [4]	76.5%
η_m	Determined Value [4]	96.22%
η_a	Determined Range [5]	[75%, 85%]

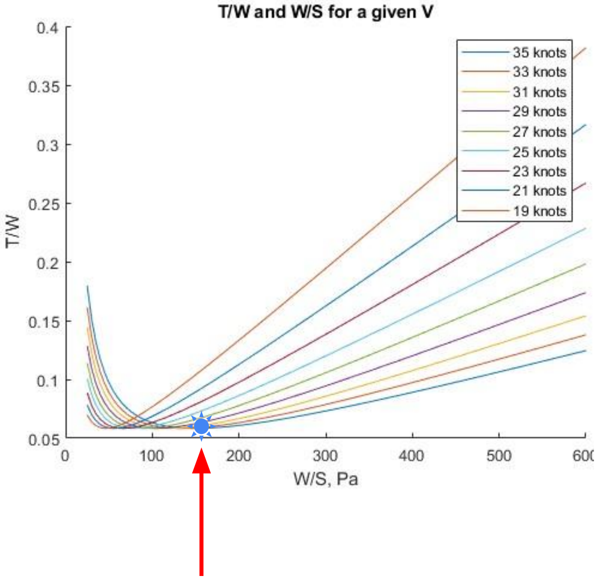
Initial Design

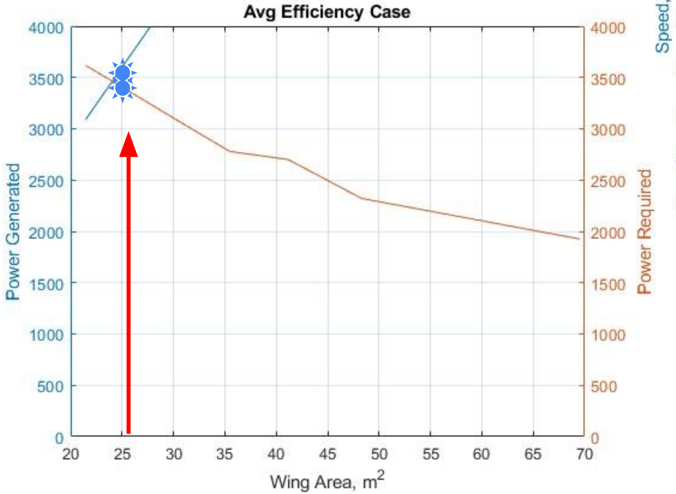
Variable	Assumed Value
airfoil	Eppler 603
L/D, aircraft	22
L/D, wing	36
Æ	15
e	.8
c_L	1.2

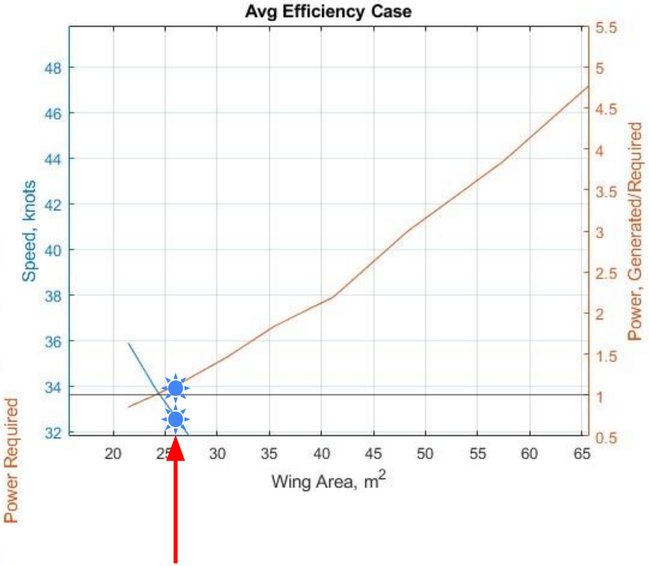


The dimensions of the wing dimensions from which we start

Wing Design Speed Sweep Results







Backup slide: Air Drag of Bodies Build Up

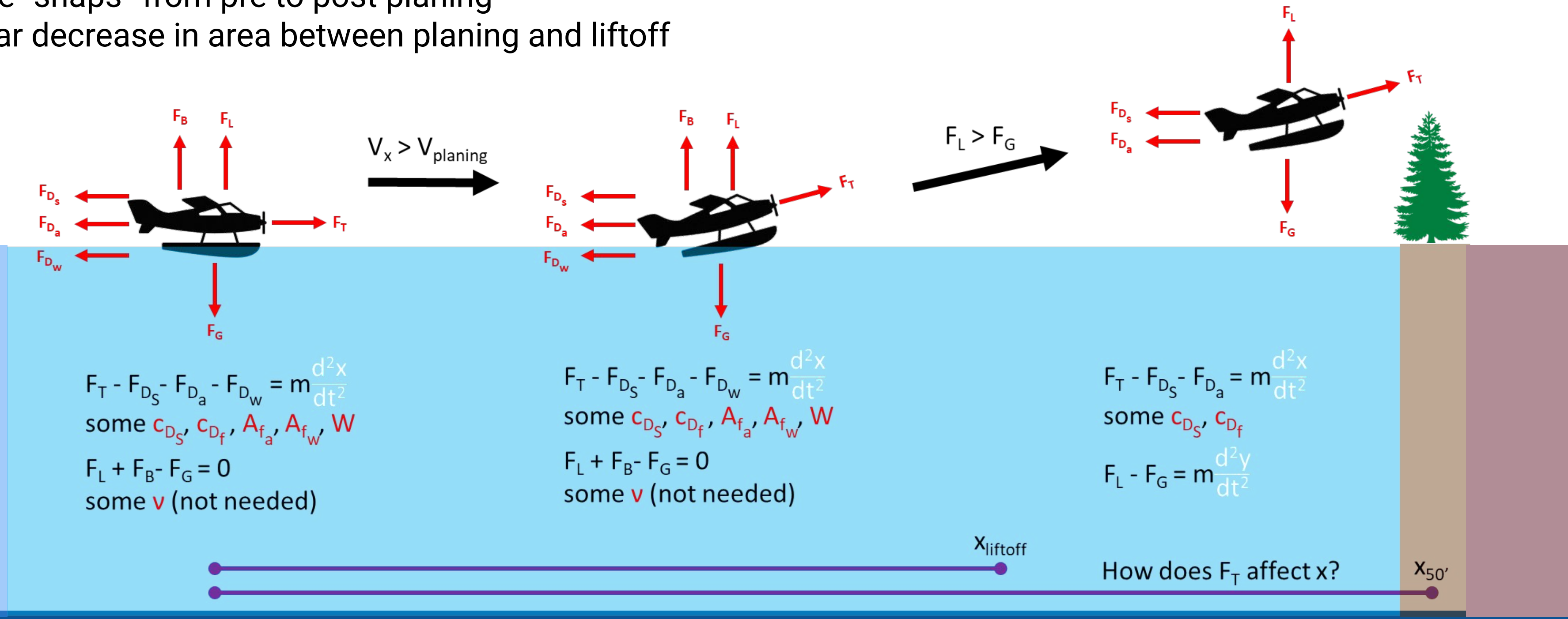
MASTER VARIABLES			WETTED AREAS			ESTIMATED CDs			CRUISE BODY DRAG		
Speed	17		Fuselage	9		Fuselage (NACA0030)	0.02		Fuselage	31.86225	91.0
Air Density	1.225		Sponsons	0.1884954		Sponsons (NACA0040)	0.01		Sponsons	0.3336604199	1.0
Water Density	1027		Tail Boom	0		Tail Boom (cylinder)	0		Tail Boom	0	0.0
			Struts	0.16		Struts (NACA0010)	0.005		Struts	0.14161	0.4
			Wing	25.76		Wing (Eppler 603)	0		Wing	0	0.0
			H-Stab	0.8461		H-Stab (NACA0008)	0.008		H-Stab	1.19816221	3.4
			V-Stab	1.05		V-Stab (NACA0008)	0.008		V-Stab	1.486905	4.2
									Drag	35.02258763	
									Lift	2510	
			CdA is comparable								
			CdA of a step is equal to the area of the step no question, always dragy						L/D	71.66821157	
									CD	0.00534673469:	

Power

Takeoff Simulation Forces

<u>Assumptions:</u>

- Plane “snaps” from pre to post planing
- Linear decrease in area between planing and liftoff



$$F_T - F_{D_S} - F_{D_a} - F_{D_W} = m\frac{d^2x}{dt^2}$$

some c_{D_S}, c_{D_f}, A_{f_a}, A_{f_W}, W

$$F_L + F_B - F_G = 0$$

some v (not needed)

$$F_T - F_{D_S} - F_{D_a} - F_{D_W} = m\frac{d^2x}{dt^2}$$

some c_{D_S}, c_{D_f}, A_{f_a}, A_{f_W}, W

$$F_L + F_B - F_G = 0$$

some v (not needed)

$$F_T - F_{D_S} - F_{D_a} = m\frac{d^2x}{dt^2}$$

some c_{D_S}, c_{D_f}

$$F_L - F_G = m\frac{d^2y}{dt^2}$$

Propulsion Requirements Recap

Cruise power comes from solar panels with 100W margin

Cruise-Climb power comes from solar panels with 0W margin (~100 fpm)

Takeoff power requirement comes from takeoff sim

Expedited climb has no requirement: if needed, will come from battery margin

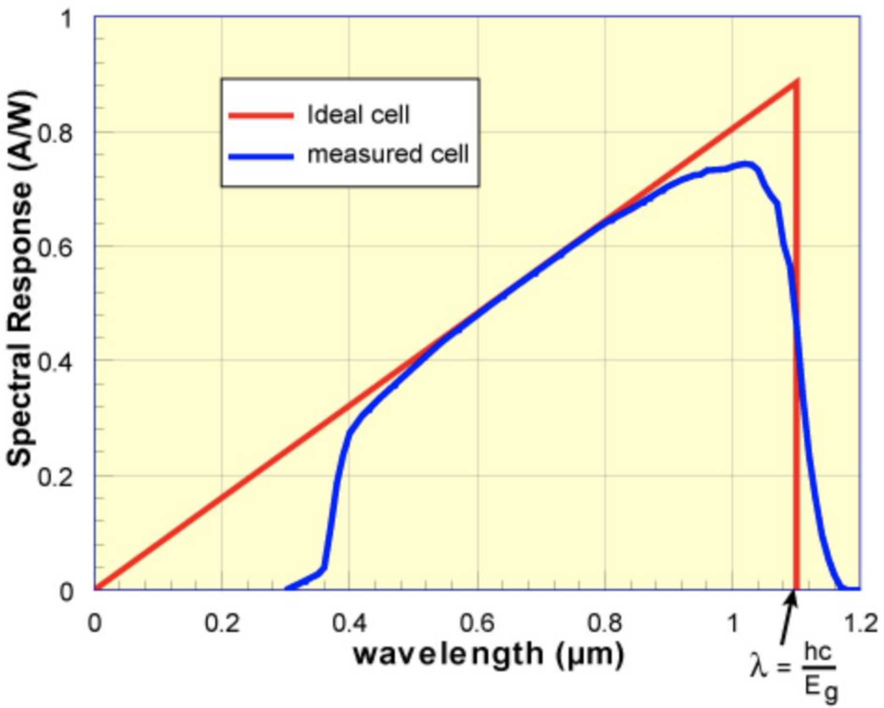
Cruise Propulsion	
Cruise Thrust	195 N
Cruise Speed	33 KCAS
Cruise Power	3300 W
Power Margin	+100 W

Climb Propulsion	
Climb Thrust	200 N
est. V_y Speed	35 KCAS
Climb Power	3400 W
Power Margin	-0 W

Takeoff Propulsion	
Takeoff Thrust	275 N
Avg. Speed	28 KCAS
Takeoff Power	4000 W
Power Margin	-600 W

Solar Cell Protection **Backup**

- Cover cells in a single layer of Halar® ECTFE
  - Resistant to UV light radiation → irrelevant!
- Typical solar cells perform **best** in **0.4–1.1 μm** wavelength range (visible light and IR)
  - Outside of UV **0.01-0.4 μm** wavelength range



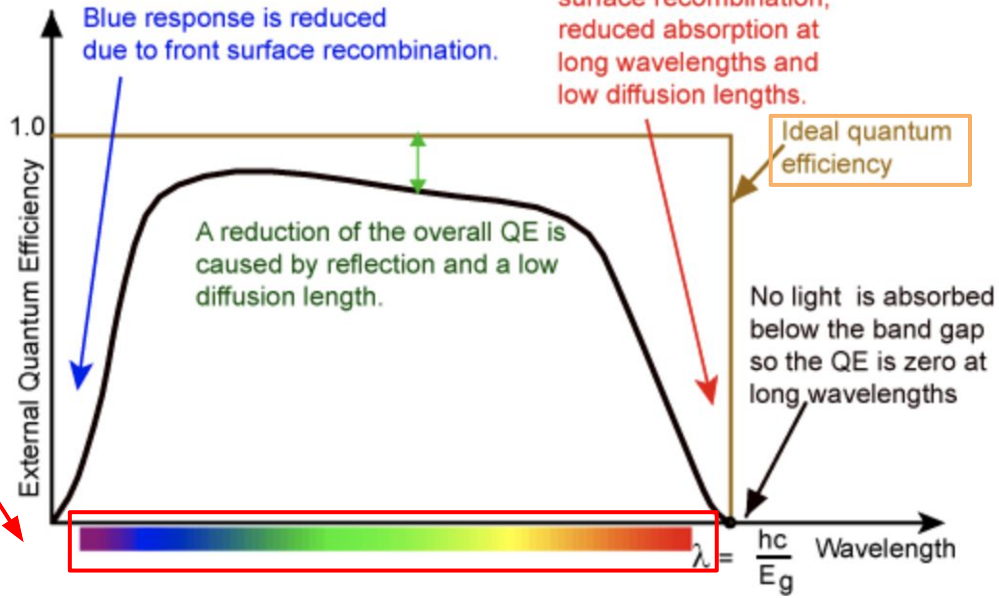
SR = current generated by cell ÷ power incident on cell

Solar Cell Protection **Backup**

- Cover cells in a single layer of Halar® ECTFE
  - Resistant to UV light radiation → irrelevant!
- Highest quantum efficiency in **visible light spectrum** for typically solar cell
- SunPower C60 cells also do well in IR

number of carriers collected by cell ÷ number of photons of a given energy incident on the solar cell

Quantum efficiency curve for an ideal solar cell



Battery Weight Breakdown Backup Slide

Sized by voltage of 96 V → cells in series

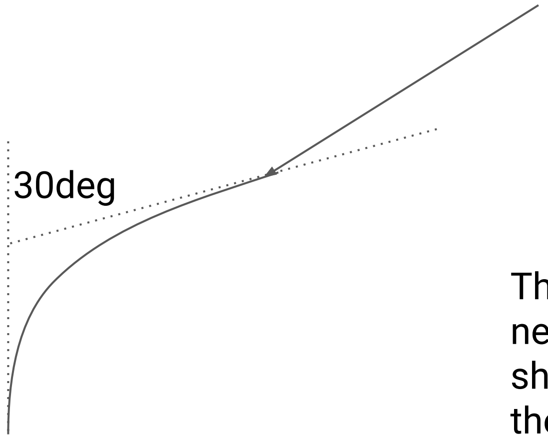
Sized by max power needed and capacity → parallel strings

	Endurance Sizing	Power Sizing	
cells in series	26.0	26.0	
parallel strings	11.0	7.0	
number of cells	286.0	182.0	
cell mass	9.0	5.7	kg
pack mass (inc BMS)	9.7	6.2	kg
pack mass in lbs	21.4	13.6	lbs

Specific Energy	260	Wh/kg	Li-ion
Specific Power		W/kg	Li-ion
depth of discharge	0.8		
cell capacity	2.2	Ah	
cell voltage	3.7	V	
max C rate	5		
mass per cell	31.3	g	High Rate Discharge Li Polymer Battery part
battery packing factor	0.92		

Solar Cell Placement Backup

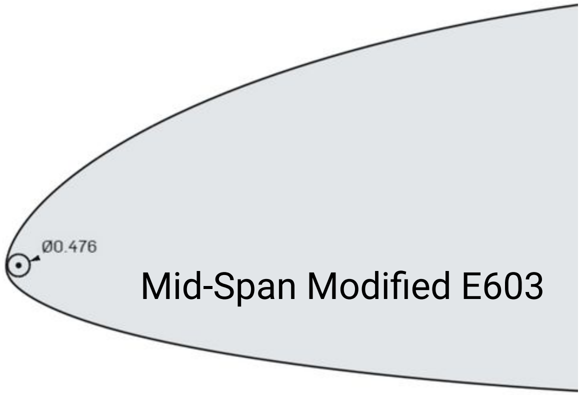
Solar cell max bend angle = 30deg



S=R(theta)

0.238m = min radius

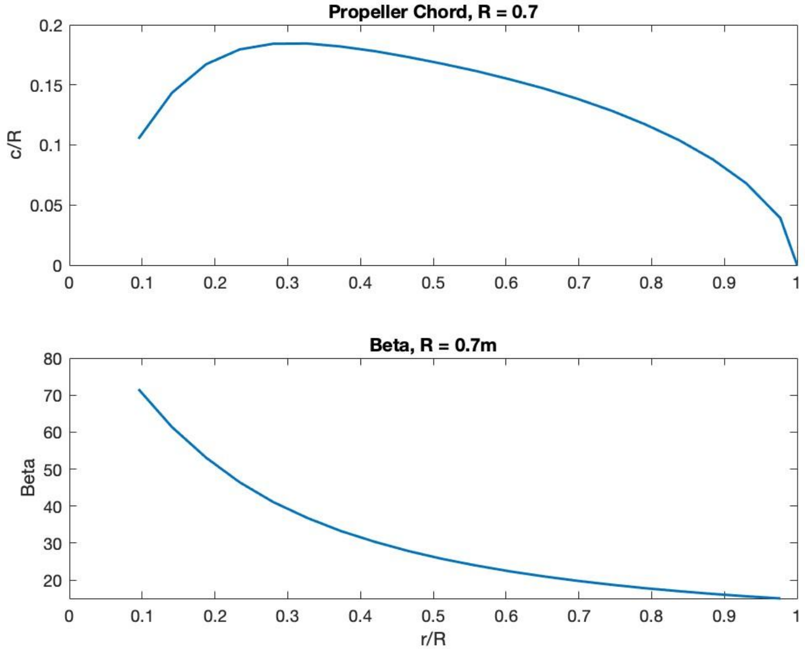
The contour of the wing never forms a curve that's sharper than this circle so the solar cell can be placed anywhere



Presenter:

Propeller Backup

- η_i = 89%
  - Induced efficiency is a little low, could increase propeller radius to help
- Power consumption sensitive to voltage, thrust, dβ
- Variable pitch is an option, but increases motor weight



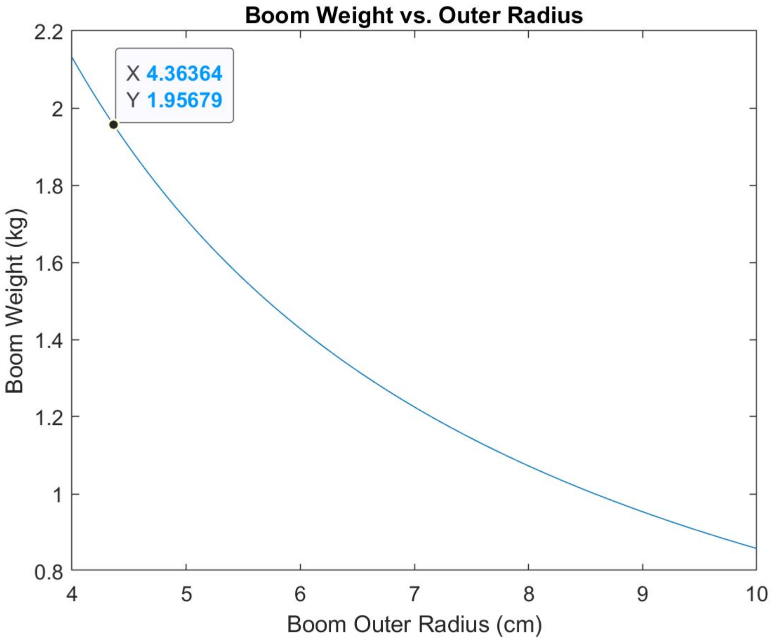
Structures

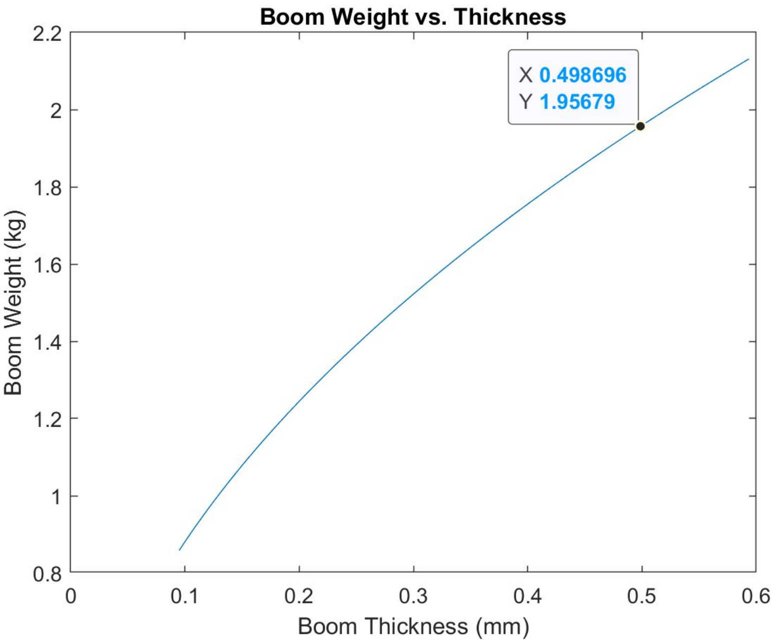
Presenter:

Wing Weight Breakdown

Component	Weight [lbs]	Weight [kg]	Sizing Case
D-Box	31.6	14.3	Torsional stiffness
Spar Caps	26.4	12.0	Bending stiffness
Ribs	10.8	4.9	Bending stiffness
Fabric	13.3	6.0	Standard
Trailing edge support, aileron hinge	6.5	2.9	Best guess
Total	**88.6**	**40.2**	

Boom Weight and Sizing from Bending





Presenter:

Assumed Forces for Boom and Stabilizer Calcs

Force	Value	Notes
Horizontal stabilizer lift	812 N	-z direction, elevator fully deflected
Vertical stabilizer lift	552 N	+/- y direction, rudder fully deflected
Weight of horizontal stabilizer	30 N	-z direction
Weight of vertical stabilizer	35 N	-z direction

Stabilizer CF Layer Thicknesses

Quantity	Value	Notes
# of layers on skin	2	For both horizontal and vertical stabilizers
# of layers for D-box	2	For both stabilizers, 4 total with skin layered on top
# of layers in web	4	For both stabilizers
# of layers for kevlar membrane	1-2	For both stabilizers
Horizontal stabilizer sparcap area	0.0151 in^2	Cross-sectional area
Vertical stabilizer sparcap area	0.0114 in^2	Cross-sectional area

Hull Design

Presenter:

Fuselage/Planing Hull Sizing References

1) Hoerner's Fluid Dynamic Drag
   a) For axisymmetric streamlined components (assuming d = 1.37 m and l = 6.096 m)
2) Planing Flow Lift and Drag Modeling Module on Canvas
3) Gudmundsson's General Aviation Aircraft Design: Applied Methods and Procedures Appendix C3: Design of Seaplanes

Presenter:

Fuselage/Planing Hull Sizing

Froude's liquid resistance formula:

$$R_{Froude} = f \cdot S_{wet} \cdot V^n \qquad \text{(C3-18)}$$

Where:
- f = Coefficient of frictional resistance
- S_{wet} = Wetted area in ft²
- V = Speed in knots
- n = Constant, dependent on surface quality.

The term f varies depending on surface quality. For surfaces ranging from 2 to 20 ft in length, it can be taken to be 0.012 to 0.010 for smooth surfaces, 0.0231 to 0.0137 for surface quality resembling fine grit sandpaper, 0.0257 to

$$V = Fr_{\min}\sqrt{g\ell}$$
$$C_L \simeq C_{L_{\max}}$$
$$S_{\min} = \frac{W}{\frac{1}{2}\rho V^2 C_L}$$

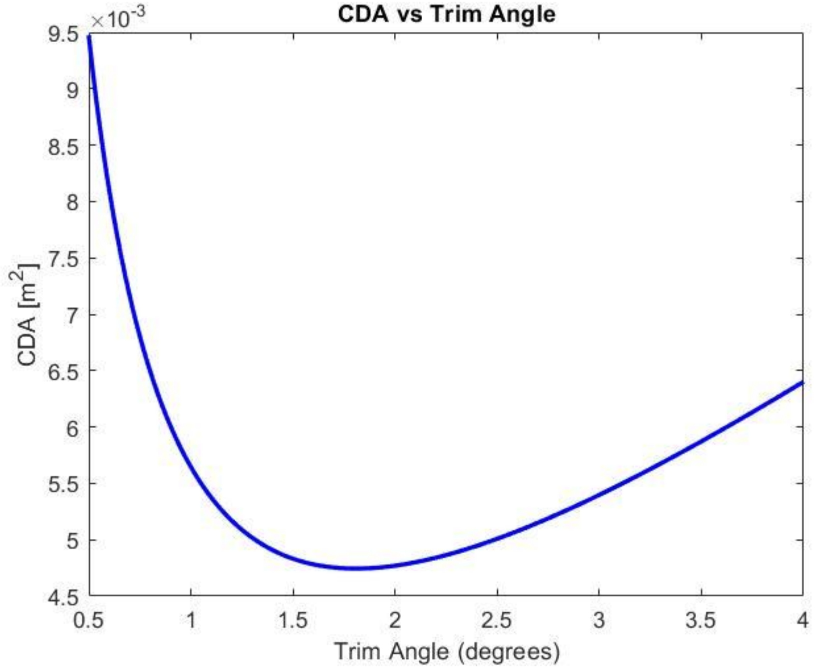
$Fr_{\min} = 1.5$ and $C_{L_{\max}} = 0.1$, although the
ull shapes. Another requirement is that the

$$\mathcal{V}_{\min} \geq k\frac{W}{\rho g}$$

$$C_L \simeq \begin{cases} \frac{\pi}{2}\frac{AR}{1+AR}\alpha & , \quad AR \gg 1 \\ \frac{\pi}{4}AR\,\alpha + 0.88\,\alpha^2 & , \quad AR \ll 1 \end{cases}$$

Presenter:

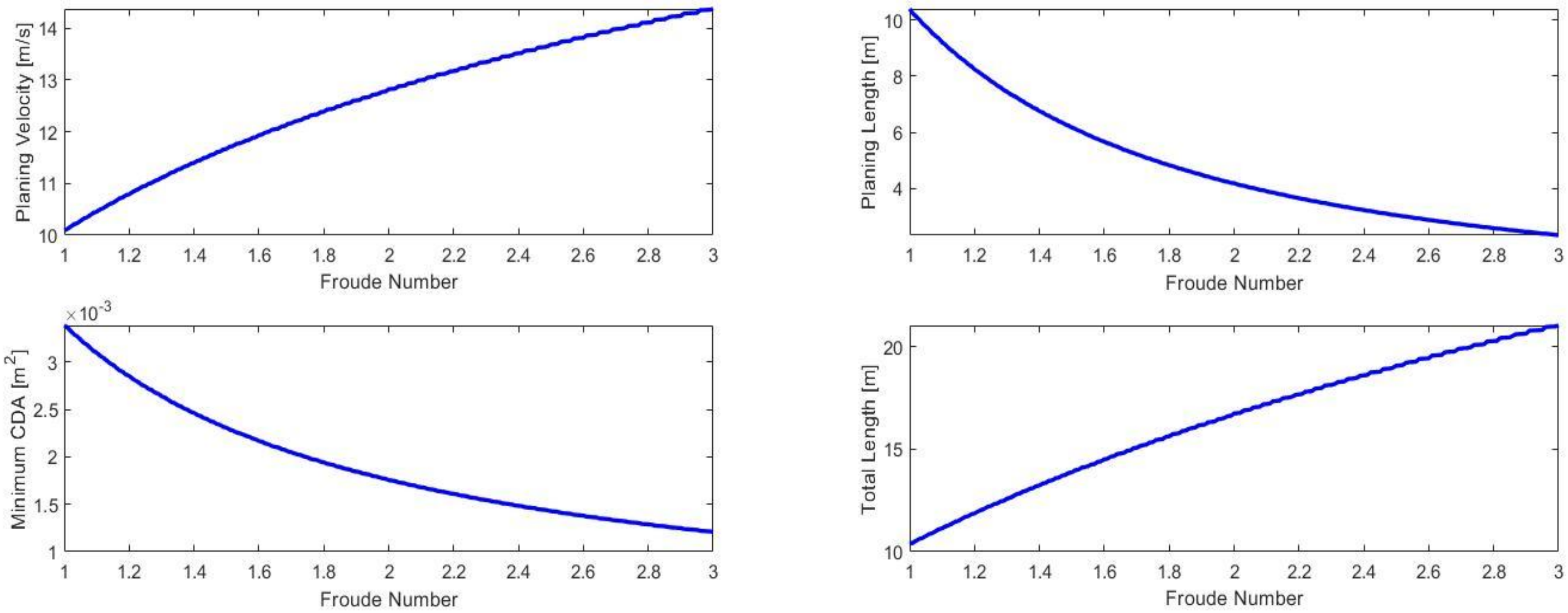
CDA vs alpha



Although alpha and planing length are coupled in the equations we see before, we can actually get a sense of what the optimal alpha value is for a given length. The graph is a CDA vs alpha graph of our dimensions. As you can see, an alpha of 4 degrees results in a CDA of about 0.006 m^2.

Presenter:

Planing Hull Optimization Results

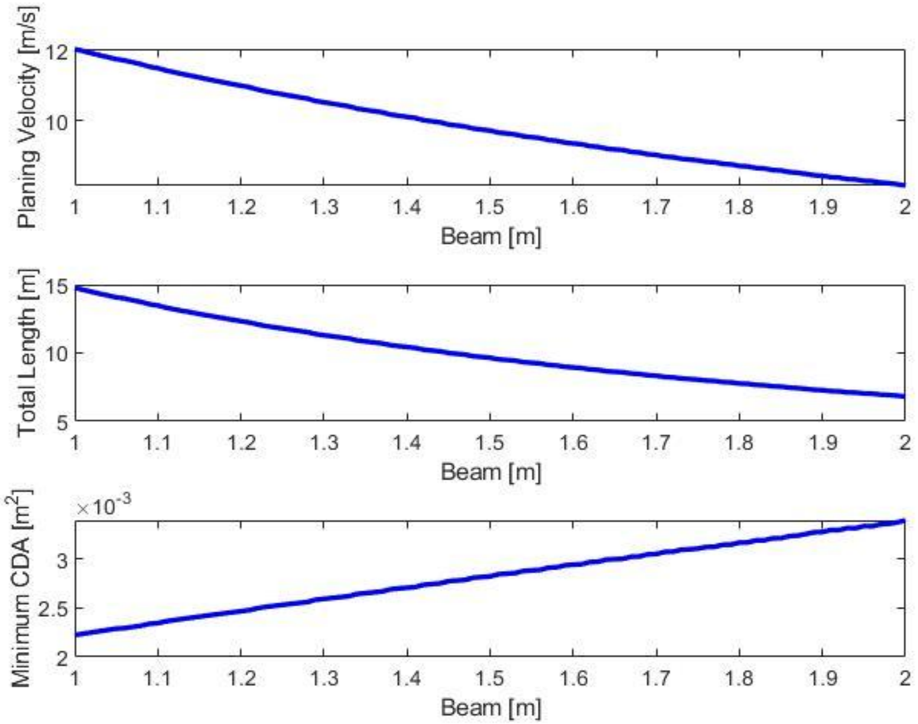


Presenter:

Context for the graphs on the previous slide

By varying the Frmin and freezing the beam length to be 1.0668 m, we can see how Frmin affects our hydrodynamic performance. The graph on the left show Min CDA vs Frmin and the respective planing velocity. Although the Fr number decreases the min CDA during planing, the planing velocity is actually significantly increases. This can explained with the graph on the right. The length of the planing surface is decreasing because, but because the Froude number^2 is a ratio of the total length vs the planing length, the total length of the hull actually increases (explaining the increase in planing velocity). We want to be planing quick to reduce the effects of pre-planing drag.

Planing Hull Optimization Continued



From these graphs, it is clear that although you are potentially increasing the planing CDA by about 50 percent going from a beam length of 1 m to 2 m, the total length of the hull decreases significantly, as well as the planing hull. This is consistent with the block diagram where we want a larger beam so that we can plane quicker.

Presenter:

Fuselage/Planing Hull Sizing

The total drag, based on wetted area is consequently

$$C_{D_{wet}}/C_f = 1 + 1.5\,(d/l)^{3/2} + 7\,(d/l)^3 \qquad (28)$$

The graph shows that the third term of this equation is practically negligible up to $d/l \approx 0.2$.

Frontal Area. The wetted surface area of streamline bodies is approximately

$$S_{wet} = (0.7 \text{ to } 0.8)\, \ell \text{ (perimeter)}$$

$$CDA = A_{wet}\bar{C}_f K_f \qquad \text{(streamlined component)}$$

friction coefficient $\bar{C}_{f(Re_\ell, Re_{x_{tr}})}$ is assumed to correspond to that on :
ix of laminar and turbulent flow values $\bar{C}_{f_l}, \bar{C}_{f_t}$, and depends on the le
umber Re_ℓ, and the transition-length Reynolds number $Re_{x_{tr}}$. Approxi
ven in many references, e.g. Schlichting's *Boundary Layer Theory*,

$$\bar{C}_{f_l} = \frac{1.328}{Re_\ell^{1/2}} \qquad \text{(fully laminar)}$$

$$\bar{C}_{f_t} = \frac{0.455}{(\log_{10} Re_\ell)^{2.58}} \qquad \text{(fully turbulent)}$$

Presenter:

Fuselage/Planing Hull Drag

Given the beam, Fr, alpha, and hull lengths, I approximated the CDA of the skin friction drag on the fuselage to be 0.081 m^2. It is safe to say that the induced drag from the fuselage is negligible because the ratio max fuselage width (roughly 4.5’) to the total span of the main wing is miniscule. I didn’t account for any appendages either. Either way, the equations above tell is that larger fineness ratios larger fineness ratios (i.e. smaller D/L) result in lower CDA fuselage which again supports the block diagram in the main presentation (slide 38). Our numbers on slide 39 provide acceptable CDAs for both cruise and takeoff (at 1000’).

Human-Machine Interface

Sensors/Instruments Justification

Why Any Primary Flight Display (PFD)?
There is no requirement for ultralights and little need for VFR flight outside of airspeed and altitude. However, we prioritize safety and want to mitigate inadvertent IFR flight, so having airspeed, altitude, pitch angle, roll angle, turn coordinator makes the plane much much safer.
Why a Variometer?
We have twin electric motors and can fly on just solar power, but with our wing, you can also simply soar! To have an accurate vertical speed and aircraft energy, a variometer is very helpful.
Why Strobes?
We have a large wingspan and being electric, we are quiet. We need some sort of lighting for hazard avoidance and for people to notice the aircraft approaching unprepared bodies of water. There is no real need for navigation, landing, or taxiing lights, and strobe lights strobe, and so draw more attention. And being on either wingtip shows people on the ground how large our wingspan is.
Why custom EPFD?
We need to know the state of charge, charge flux, and temps for each component, and motor RPM. It's likely either no COTS solution would exist for this specific use case or that such solution would have to be heavily modified, so we assume a custom EPFD.
Why two radios?
While both are VHF radios, marine and air radios are either AM or FM and thus have different circuits and antennas. Since we fly but also land on water, we need both types to communicate with all other relevant vehicles to our operation.
Why external antennas?
We are concerned about EMI in the aircraft; if, once built, EMI is not an issue, the antennas can be easily relocated inside the cabin

Handheld Radios are Lighter & Cheaper

Panel Mounted Aviation Radio

Panel Mounted Marine Radio

Handheld Aviation Radio

Handheld Marine Radio

Weight (lbs)	Price	Antenna Included	Operational Cons
1.91 lbs	$1425	No	-Additional wiring -Extra mounting
2.2 lbs	$130	No	
.57 lbs	$300	Yes	-Finding radio -Hands Occupied
.65 lbs	$200	Yes	

Electronic PFD is Lighter (primary flight display)

Traditional Attitude Indicator

Traditional Altitude Gauge

Traditional Airspeed Indicator

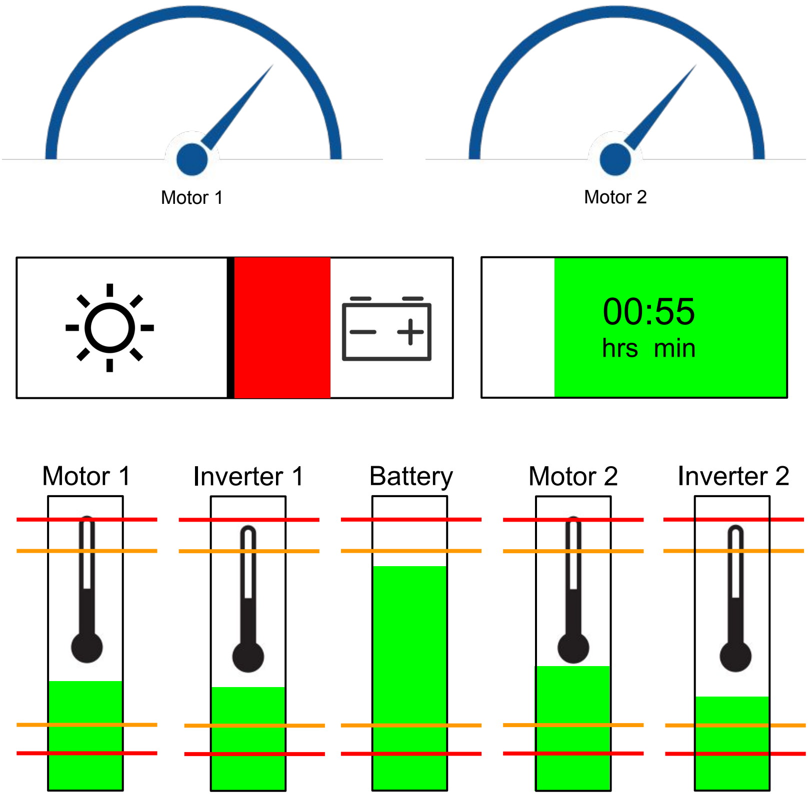
Garmin G5

Weight (lbs)	Operational Pros	Operational Cons
2.4	Zero Power Required	More complicated IP wiring / routing Larger IP
.66		
.78		
.84+.31+.50	Much smaller IP	2.8W during cruise

*Low Voltage Bus needs to exist anyway for lights, radio, and EPFD, so the Bus itself is not a con for G5

AI weight: does not include associated vacuum system
G5 weight: G5+GPS+ADC

Drawing the EPFD



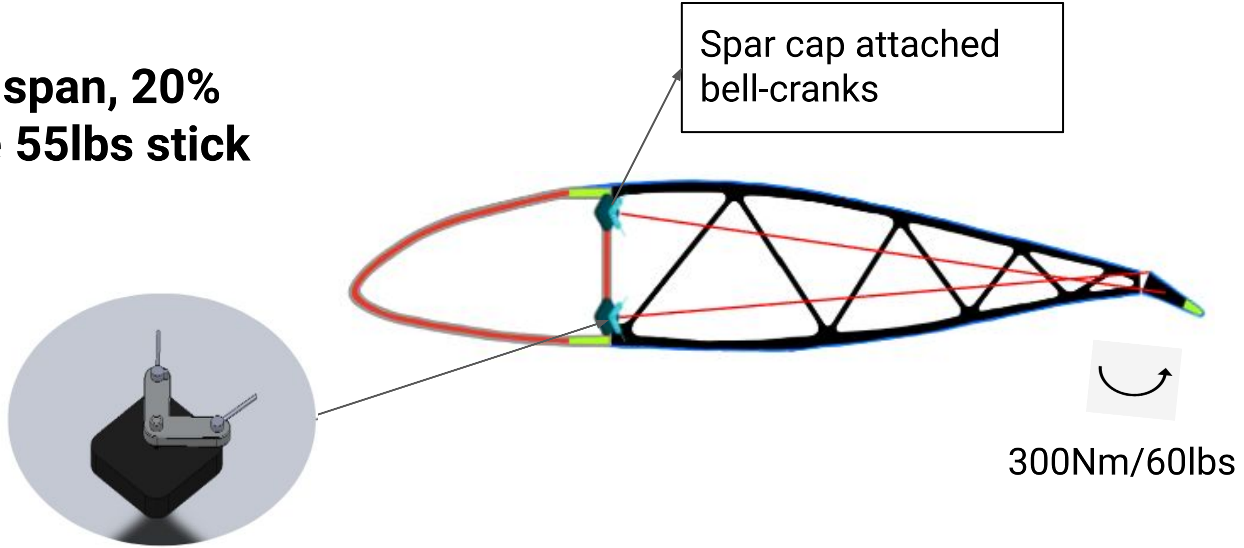
Presenter:

Control Hinge moment and Stick Force

Takeaway:

Max deflection, 40kts

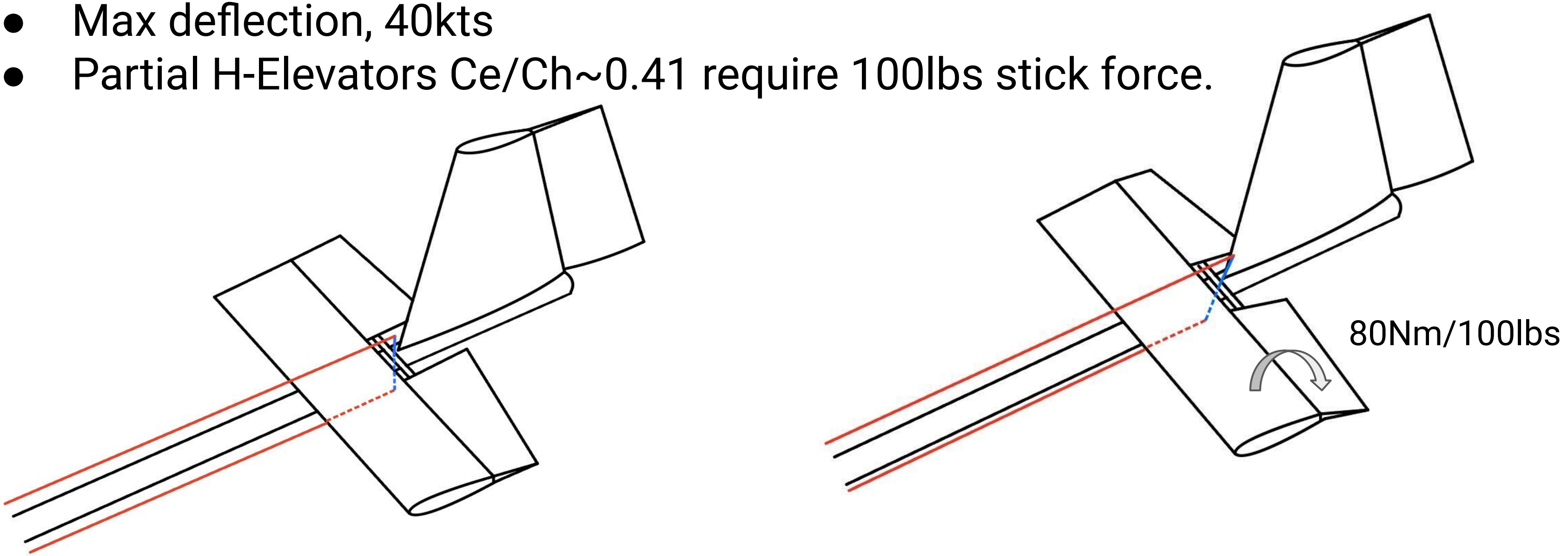
- **Aileron(20% semi span, 20% Chord)** experience **55lbs stick force**



Control Hinge moment and Stick Force

Takeaway:

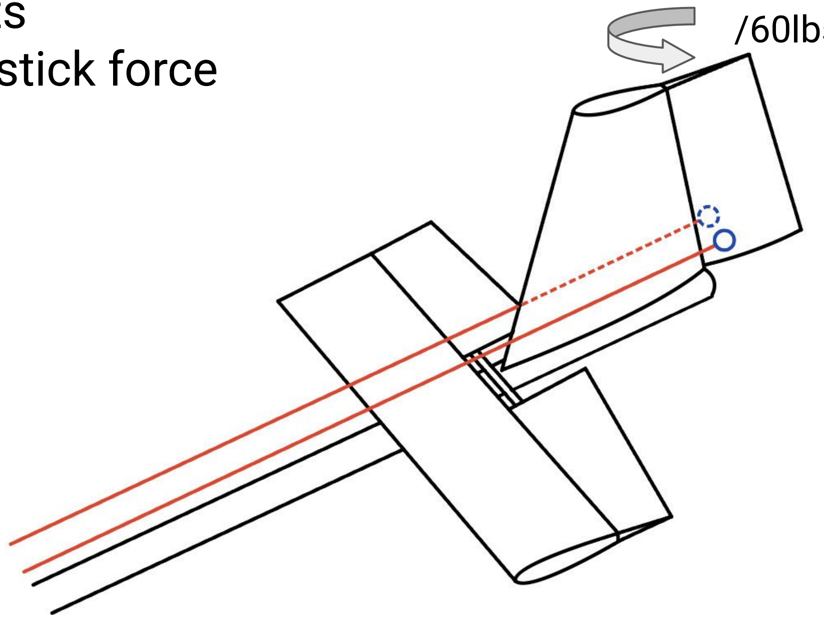
- Max deflection, 40kts
- Partial H-Elevators Ce/Ch~0.41 require 100lbs stick force.



Control Hinge moment and Stick Force

Takeaway:

- Max deflection, 40kts
- Full V-Stab at 60lbs stick force



Slide Contributors: Mohamed (L), Summer

Generalised Controls Modelling of Pulleys

Model Constraints and Assumption:

- General legal constraints of 40-67lbs stick forces for ailerons and 100lbs-167lbs for elevator as in figure 2
- All pulleys will be modelled in the fashion of figure 1

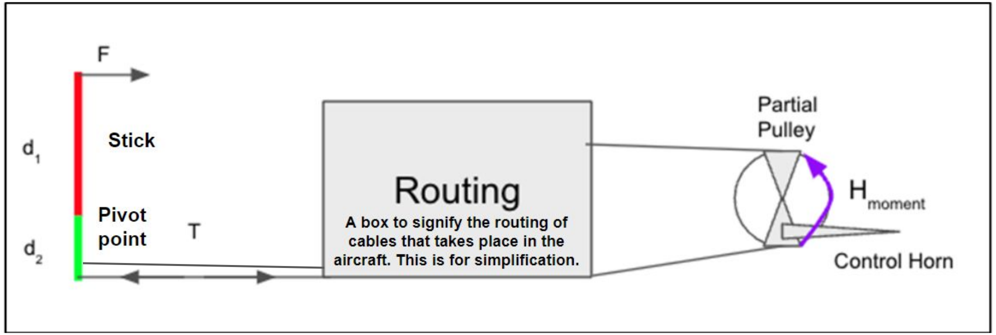


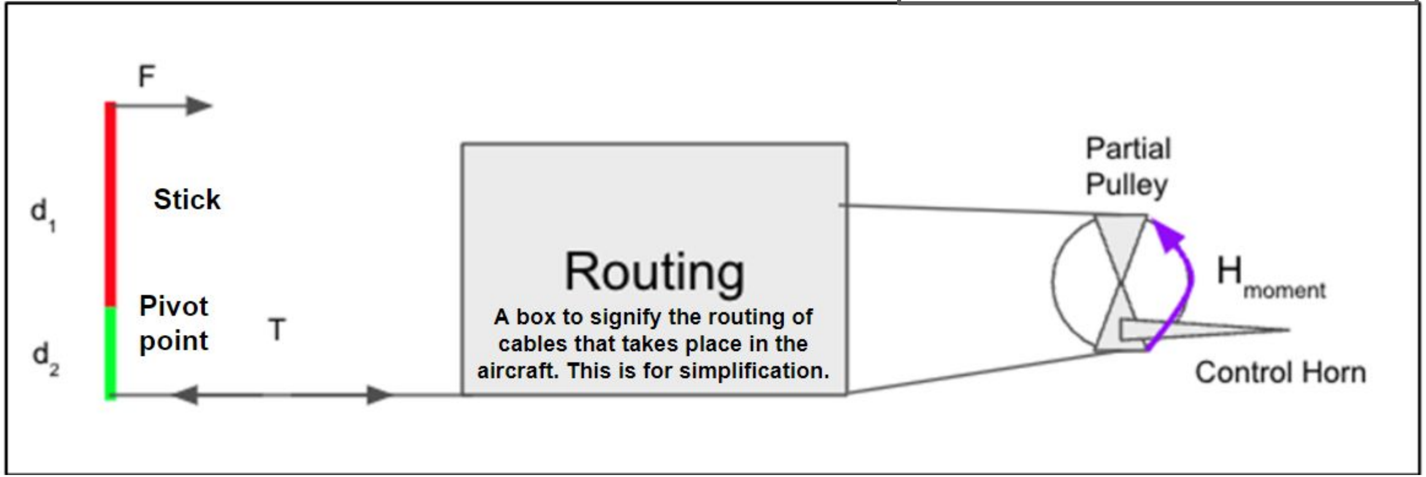
Fig 1

Control	Maximum forces or torques for design weight, weight equal to or less than 5,000 pounds[1]	Minimum forces or torques[2]
Aileron:		
Stick	67 lbs	40 lbs.
Wheel[3]	50 D in.-lbs[4]	40 D in.-lbs.[4]
Elevator:		
Stick	167 lbs	100 lbs.
Wheel (symmetrical)	200 lbs	100 lbs.
Wheel (unsymmetrical)[5]	....	100 lbs.
Rudder	200 lbs	150 lbs.

Fig 2

Pulley Modelling and Equations

$$F * d_1 = T * d_2$$
$$T * d_{pulley} = H_{moment}$$
$$F * d_1/d_2 = H_{moment}/d_{pulley}$$
$$d_p = (H_{moment}/F) * (d_2/d_1)$$
$$d_1 + d_2 = 1\,m$$



Aileron Hinge Moment and Pulley Analysis

Design Choice:

- Based on XFLR5 analysis, it seems appropriate to use a 0.8m lever arm with a pulley radius of 0.27m causing a cable tension of 980N and matching 300 Nm hinge control moment at 55 lbs stick force.

$$M / b = q * C_M * c_{ref}^2$$

Definition:

M, Moment, Newton − meter

b, Aileron Span, meter

C_m, Moment Coefficient, Dimensionless

c_{ref}, Chord reference, meter

q, Dynamic Pressure, Pascal

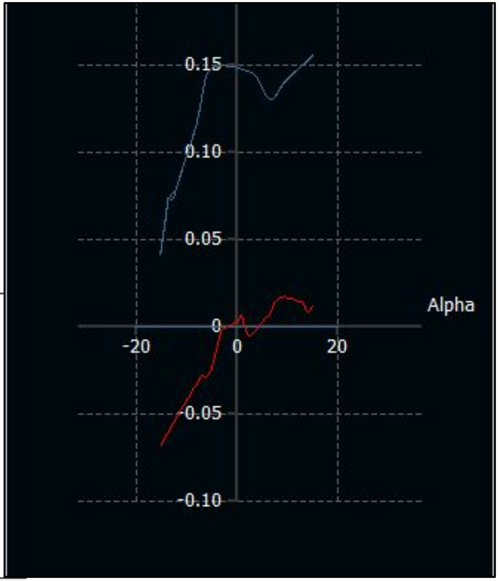


Fig: Non-dimensional moment coefficient vs AoA at 40kts

Presenter:

Elevator Hinge Moment and Pulley Analysis

Design Choice:

- Based on XFLR5 analysis, it seems appropriate to use a 0.8m lever arm with a radius~0.04m for the aileron bell-crank pulleys causing a cable tension of 1780N and matching 80Nm control hingemoment at 100lbs for maximum deflection.

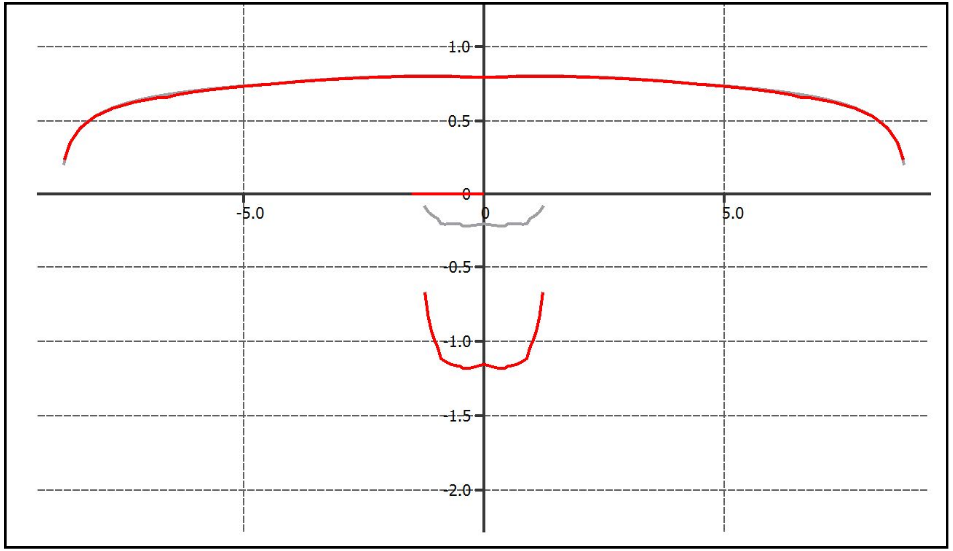


Fig Jax River. Local Cl vs Span at 0 AoA. Red is at max deflection of 25°

Elevator Hinge Moment and Pulley Analysis

Design Choice:

- The previous Local Cl vs Span profile can be used to deduce a lift and hence a theoretical upper bound moment, if we take the lift generated at cruise speed as acting at the Cg of the elevator and assume Cl of +-1.25. We are also assuming a Cp~1 across the surface on the partial elevator.

$$C_l = 2L/\rho u^2 S$$

$$1.2 = 2 * L/(1.224 * 21^2 * 1.2)/$$

$$L = 389N$$

$$H_{moment,elevator} = 259N * 0.17\ m$$

$$H_{moment,elevator} = 66\ Nm$$

Fig calculating hinge moment of elevator

Cable Routing Estimates

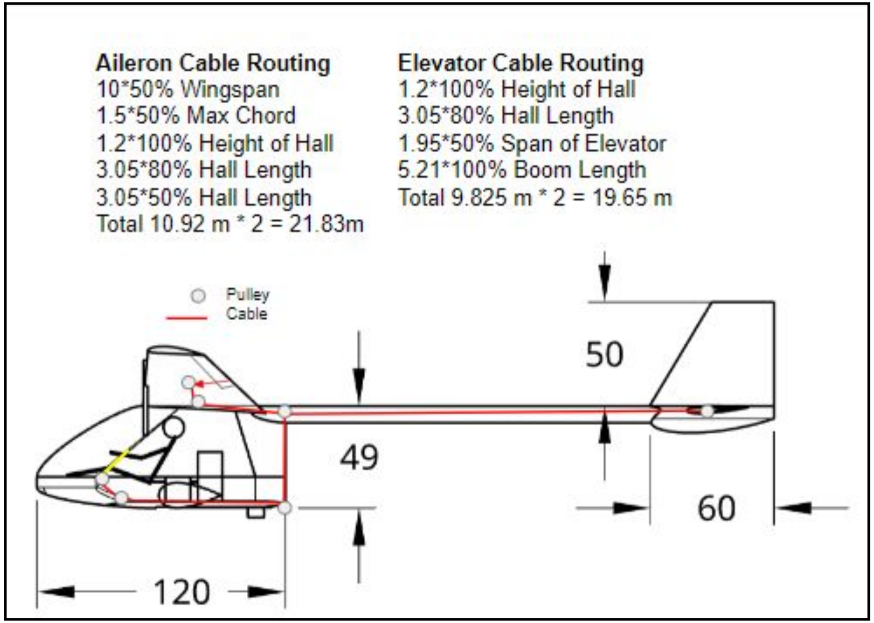
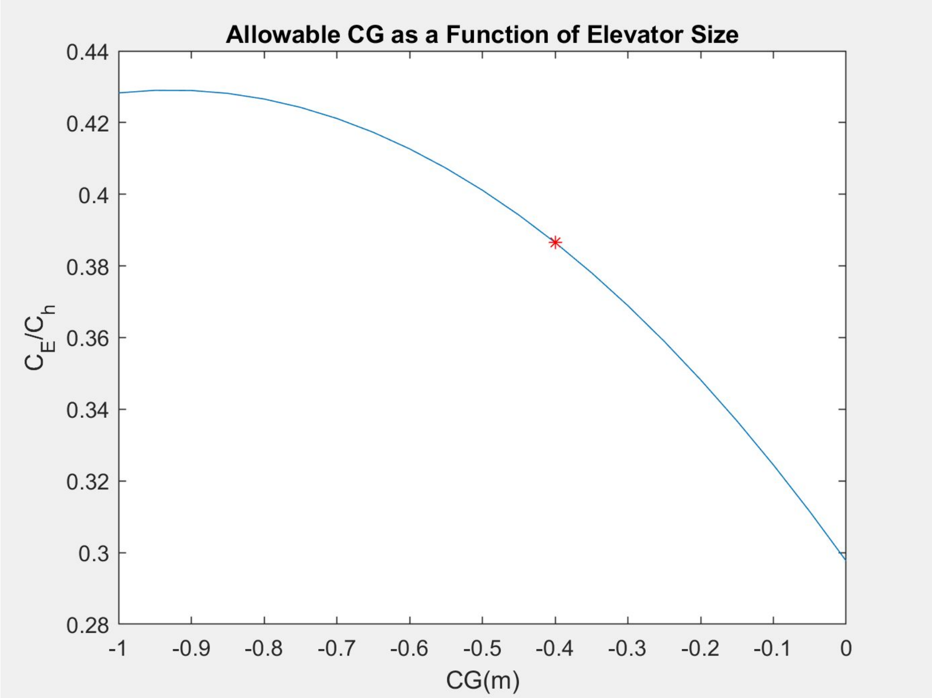


Fig Lower Bound Cable Length

Control Surfaces

Elevator Performance

- Chosen size gives us an additional 0.13 m in allowable aft CG Range
- This size was also chosen to account for possible underestimations in the sizing process

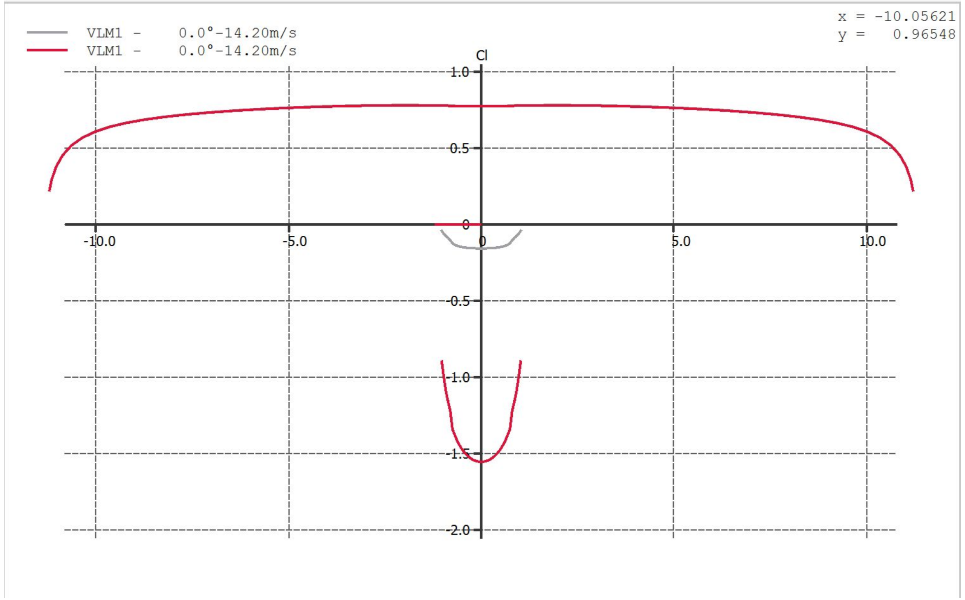


* : current plane CG estimation

Elevator Performance

Coefficient of Lift for the Elevator: **-1.2**

Maximum Elevator Stick force



Courtesy of Jax Rivera via XFLR5

Elevator Sizing Calculations

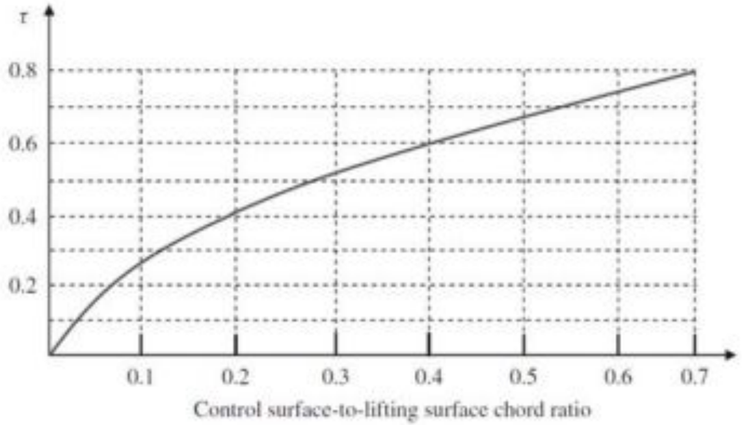
$$L_h = \frac{\begin{pmatrix} L_{wf}\left(x_{mg}-x_{ac_{wf}}\right)+M_{ac_{wf}}+ma\left(z_{cg}-z_{mg}\right)- \\ -W\left(x_{mg}-x_{cg}\right)+D\left(z_D-z_{mg}\right)-T\left(z_T-z_{mg}\right)-I_{yy_{mg}}\ddot{\theta} \end{pmatrix}}{x_{ac_h}-x_{mg}}$$

$$C_{L_h} = C_{L_{\alpha_h}} \alpha_h + C_{L_{\alpha_h}} \tau_e \delta_e$$

$$\alpha_h = \alpha + i_h - \varepsilon$$

$$\varepsilon = \varepsilon_0 + \frac{\partial \varepsilon}{\partial \alpha} \alpha_w$$

$$\delta_e = \frac{\left(\frac{T * z_T}{\bar{q} * S * \bar{C}} + C_{m_0}\right) C_{L_\alpha} + \left(C_{L_1} - C_{L_0}\right) C_{m_\alpha}}{C_{L_\alpha} C_{m_{\delta_e}} - C_{m_\alpha} C_{L_{\delta_e}}}$$



$$C_{m_{\delta_e}} = -C_{L_{\alpha_h}} \eta_h \bar{V}_h \frac{b_e}{b_h} \tau_e$$

$$C_{L_{\delta_e}} = C_{L_{\alpha_h}} \eta_h \frac{S_h}{S} \frac{b_e}{b_h} \tau_e$$

Elevator Performance Metrics

τ_e(Elevator Effectiveness)	0.62
$C_{m\delta e}$(Rate of change of the aircraft pitching moment with respect to elevator deflection)	-1.11 1/rad
$C_{L\delta}$(Rate of change of the aircraft lift coefficient with respect to elevator deflection)	0.129 1/rad

Presenter:

Rudder Sizing Calculations

$$N = N_{wing} + N_{w\delta_a}\delta_a + N_{fuselage} + F_v(X_{Vcl} - X_{cg}) - TY_p - DY_p - F_p(X_{cg} - X_p)$$

$$L = L_{wing} + L_{w\delta_a}\delta_a - F_V(Z_v)$$

$$\frac{N}{qS_w b} = C_N = 0 = -\frac{(T+D_{engine\ out})}{q\,S_w\,b} + C_{n\delta_r}\delta_r$$

$$C_{n\delta_r} = -C_{L\alpha_V}\,\eta_{VT}V_{VT}\,\tau$$

$$V_{VT} = (X_{VTCl} - X_{cg}) * S_{VT} / b * S_w$$

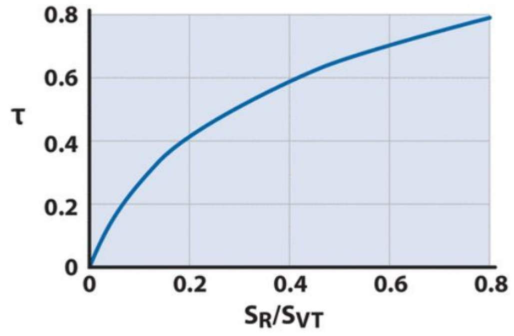


Figure 21.14 Rudder effectiveness chart (from data in Fig. 9.10).

Rudder Sizing Assumptions

Dengine out	7.5 N	Estimated upper-bound of additional drag from dead engine
C_lv	4.5 1rad	Approximation of lift curve slope for tail with similar airfoils
eta_v	0.9	Assumption gathered from example calculations in textbooks
tau	0.3	Gathered from analysis of common aircraft configurations (Figure 21.14)
dh/dt	500 ft/min	Assumption based on requirements of slow aircraft
a	2734 ft/min^2	Assuming takeoff thrust and distance of 1000 ft

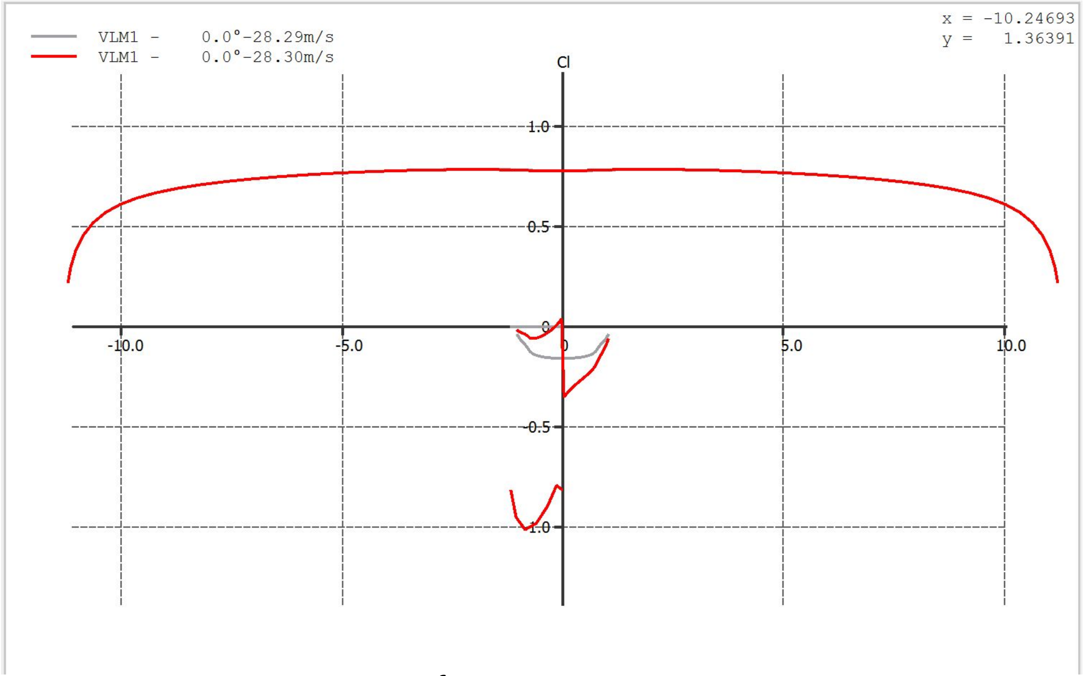
Rudder Performance

Lift Force Generated by Rudder at Max Deflection at Max Allowable Speed:

210 N

Resultant Pedal Force:

~ 60 lbs



Courtesy of Jax Rivera via XFLR5

Sizing - Roll Rate/Lift Force Equations

Lift Equation

$$L = Cl\, q\, A \qquad q = \frac{\rho(V^2)}{2}$$

Calculations done at 55 kts

Roll Moment Coefficient relative to Aileron

$$c_{la} = \frac{L_A}{qSb} \qquad L_A = 2 * L_{aileron} * y_d$$

Roll rate

$$w_x = -2 * \frac{v}{b} * \frac{c_{la}}{c_{lp}} * \frac{\delta_{Aleft} - \delta_{Aright}}{2}$$

Equations from Introduction to Aircraft Stability and Control
David A. Caughey Cornell M&AE 5070

Water Rudder (S 38)

Chosen for additional control during taxi

Retractable rudder attached to bottom of planing hull

1 ft^2 total area