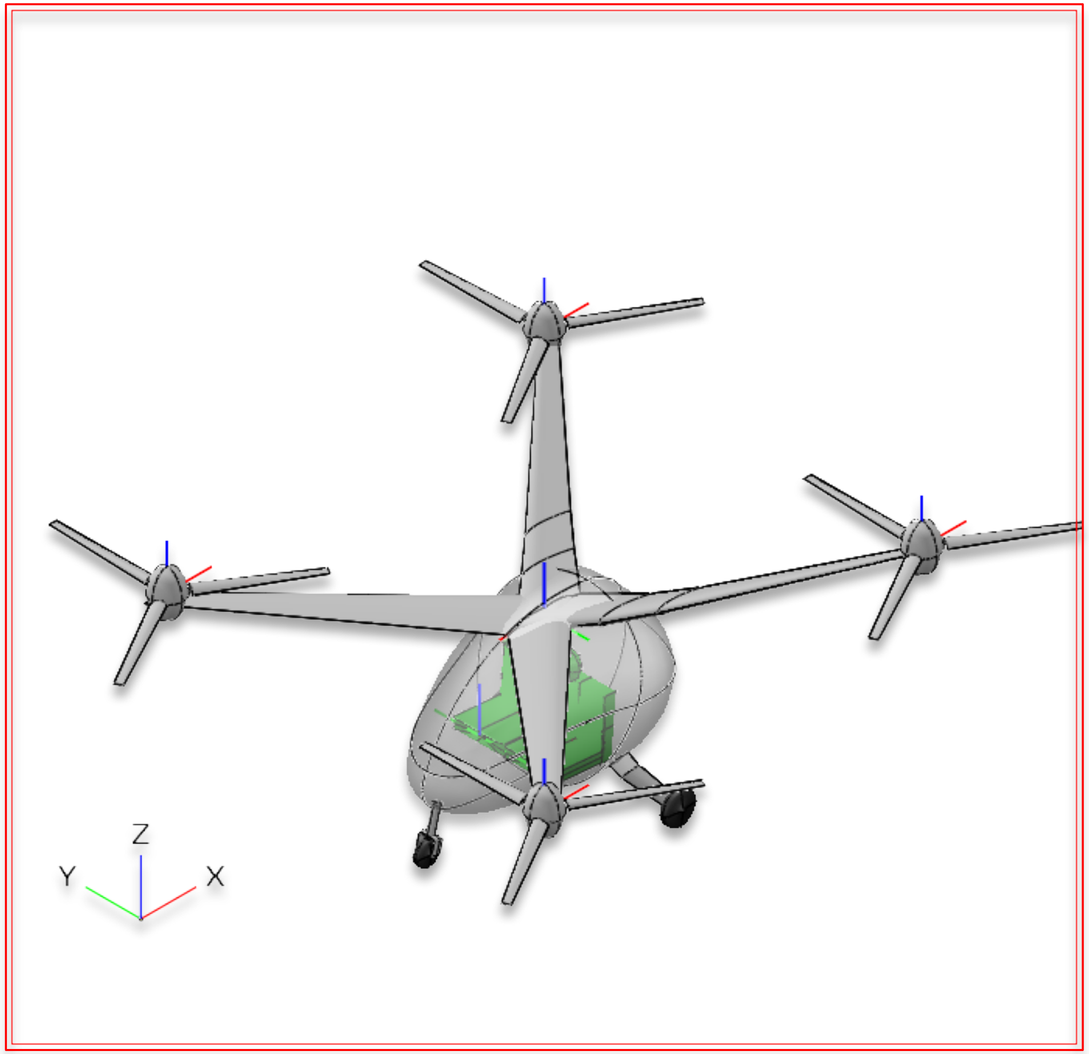
eVTOL Design for UAM



Isabella Motsco
Holton-Arms School ‘21
bella.motsco.2021@holton-arms.edu

Anubhav Datta
Associate Professor
Alfred Gessow Rotorcraft Center
University of Maryland
datta@umd.edu

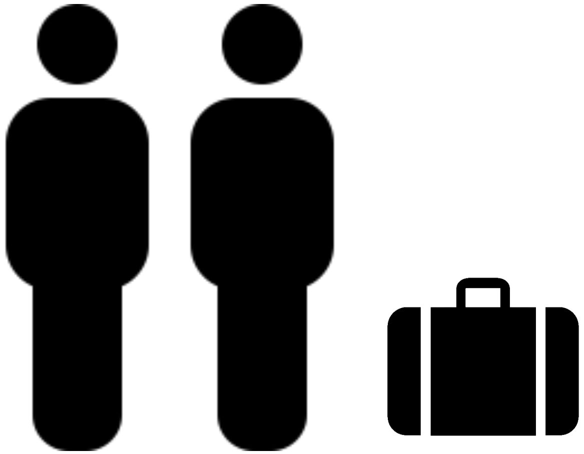
What are eVTOL and UAM?

- **eVTOL: electric vertical takeoff and landing aircraft with passengers**

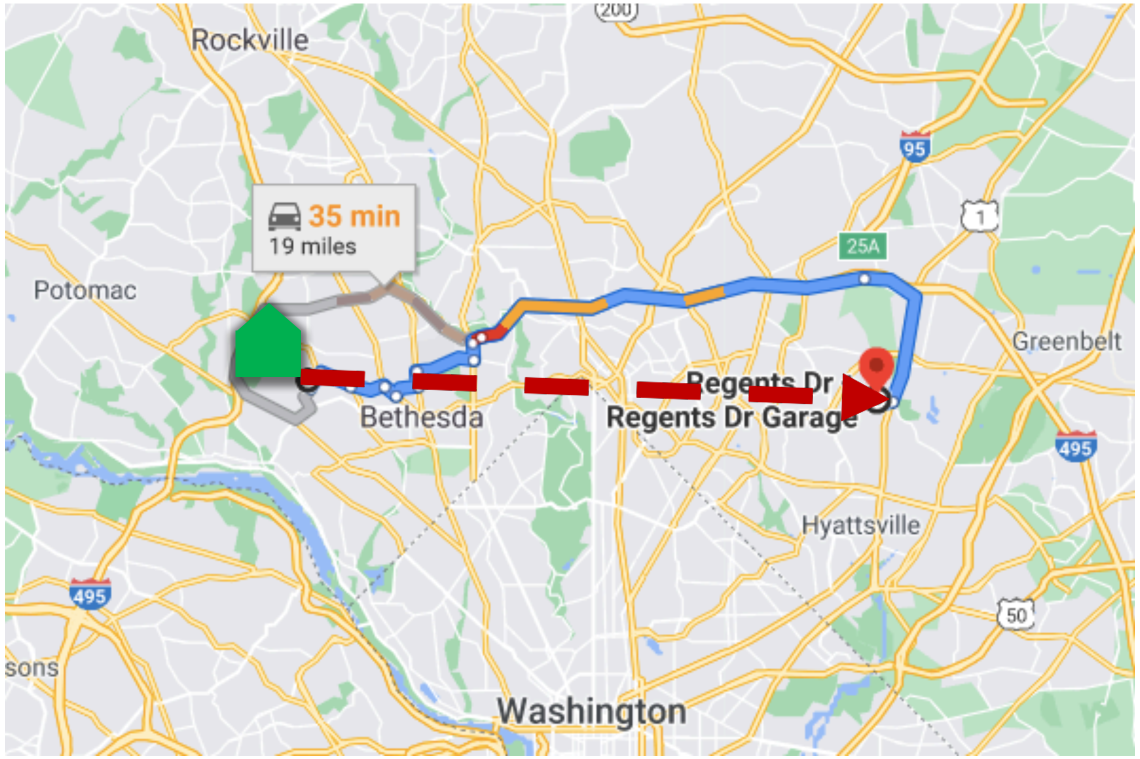
- **UAM: Urban Air mobility**
  - **UAM refers to urban transportation systems that move people by air**

How do we design eVTOL?

Decide: payload (W_{PAY}) and mission



$W_{PAY} \approx 400$ lbs



Distance ≈ 12.1 miles → Round trip ≈ 25 miles

Design Procedure

Given: a payload (W_{pay}) of 400 lbs and mission of 25 mi

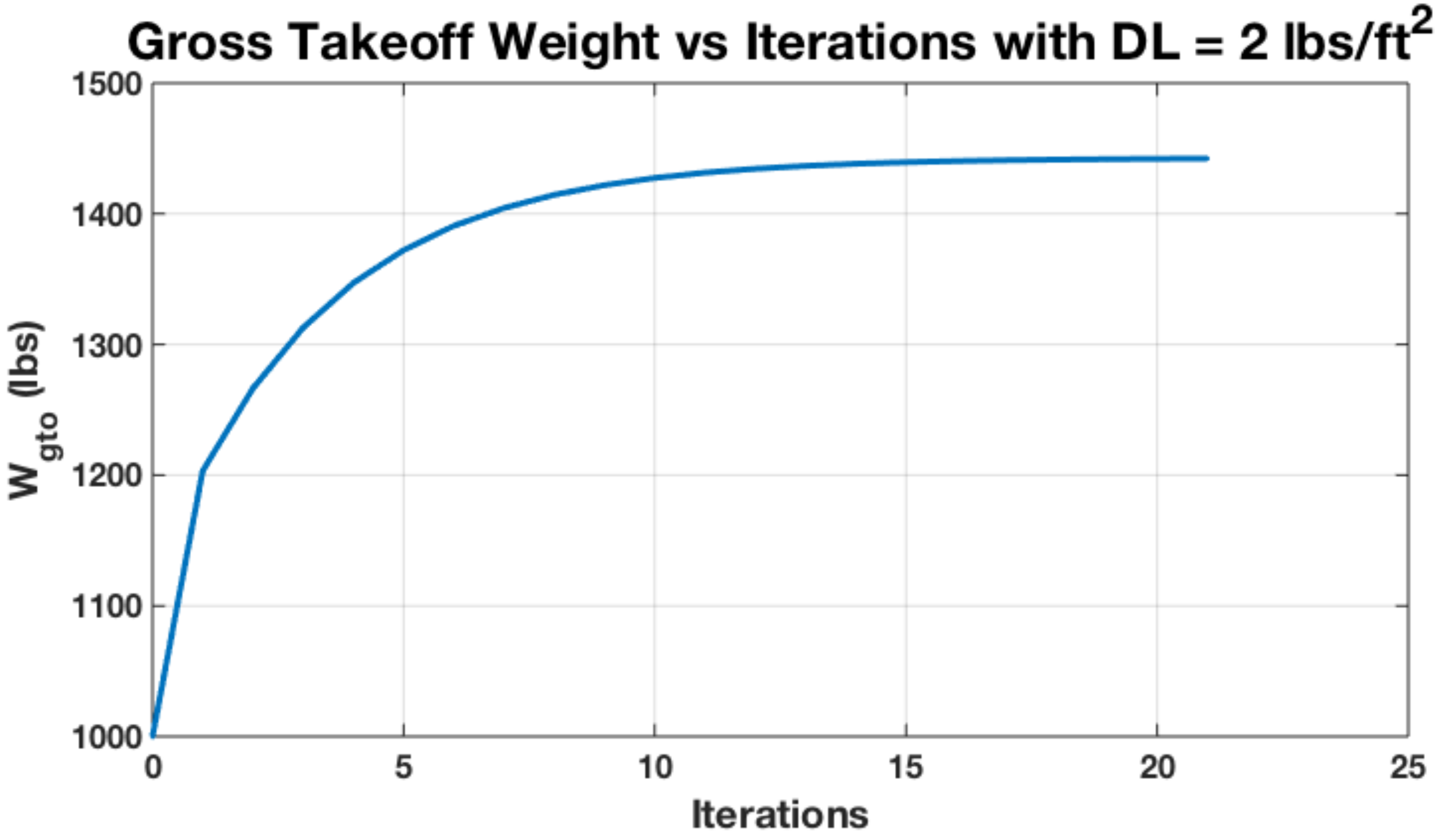
Find: minimum Gross Take Off weight (W_{gto}) and minimum radius R

1. Assume a gross take of weight W_{GTO} to calculate hover power and max continuous power
2. From DL and number of rotors find radius R
3. Calculate cruise power P_C versus speed V_C with a prescribed L/D of 5 & with an L/D calculated from the rotor and fuselage drag
4. Calculate structural weight (W_s) from W_{GTO}
5. Calculate weight of the engine (W_P)
6. Calculate weight of the battery (W_{BAT})
7. Finally, up-date gross take off weight

$$\text{updated } W_{GTO} = W_{PAY} + W_S + W_P + W_{BAT}$$

Iterate steps 1-7 until W_{GTO} converges

Visualizing Data



Disk Loading

Disk Loading (DL): amount of force that rotors have to generate to overcome weight(W) per area

$$DL = \frac{W}{\pi * R^2 n} \rightarrow$$

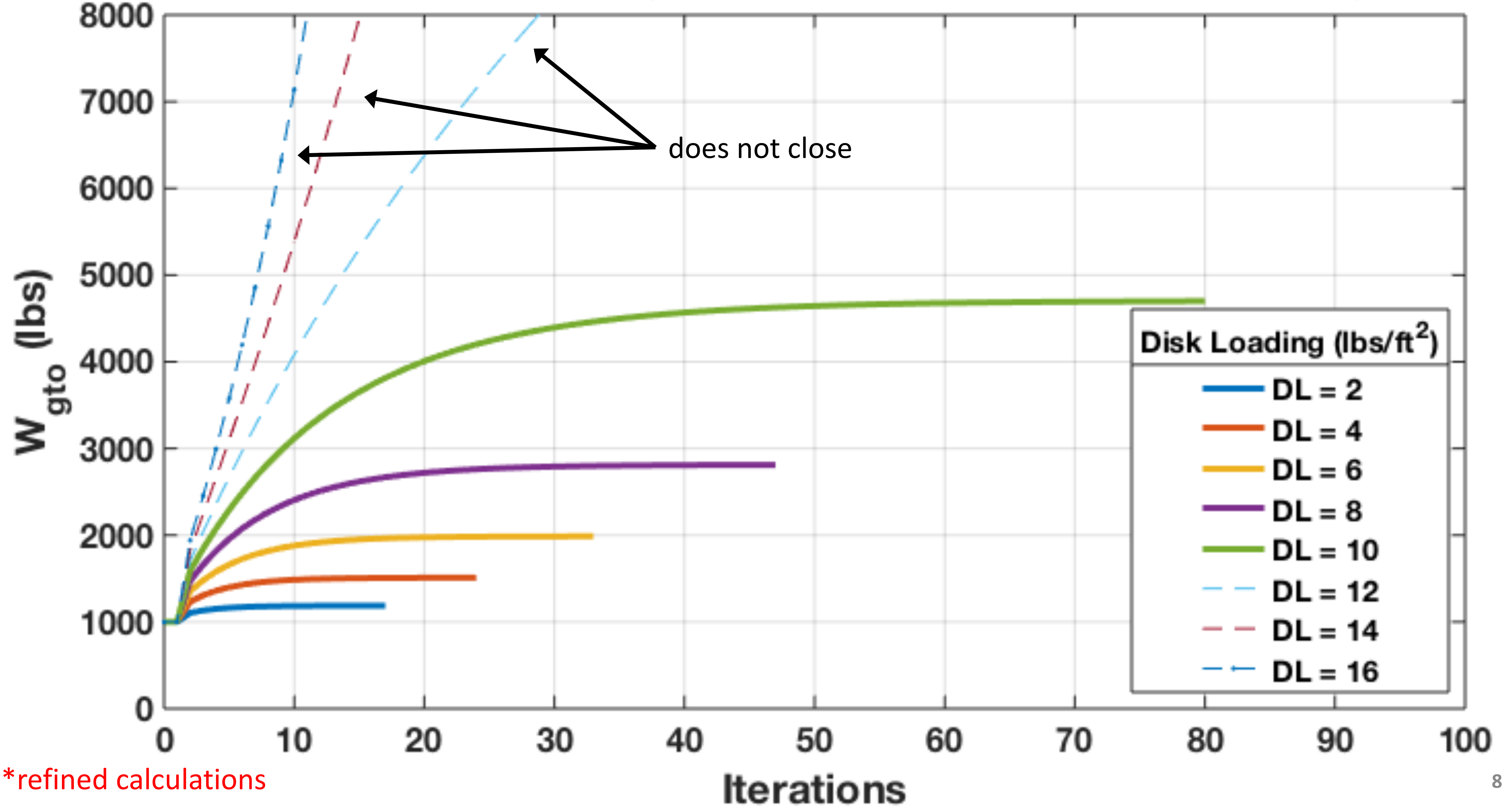
R = radius of rotor
n = number of rotors

Programming Calculations

```
%Given payload   WPAY  and  mission
%find:  minimum Gross Take Off weight   WGTO  and  max engine po

function [newW, LbyD] = sizing(w,ld)
Wgtolbs = w;  %in lbs
Wgto = Wgtolbs*4.44822; % in N
fprintf("\n\n\n Assume Wgto (in pounds): %.2f\n", Wgtolbs) %prin
fprintf("\tWgto (in Newtons): %.2f\n", Wgto) %prints Wgto

Wpaylbs = 400; %lbs
Wpay = Wpaylbs*4.4482; %Wpay in Newtons
fprintf(" Assume Wpay (in pounds): %.2f\n", Wpaylbs);
fprintf("\tWpay (in N): %.2f\n", Wpay);


DL_lbsPft2 = 6; %in lbs/ft^2
DL = DL_lbsPft2*247.88; %in N/m^ (DL)
fprintf(" Assume DL (in lbs/ft^2): %.2f\n", DL) %prints DL
fprintf("\tDL (in N/m^2): %.2f\n", DL) %prints DL

FM = 0.6;
fprintf(" Assume FM: %.2f\n", FM); %prints FM

rotorNum = 4;
fprintf(" Rotor #: %.2f\n", rotorNum) %prints rotorNum
ro = 1.225;

%STEP 1
fprintf("\n\n     -- STEP 1:  Assume Wgto to calculate hover pow

Ph = (1/FM)*Wgto*sqrt(DL/(2*ro));
fprintf("<strong>Ph: %.2f W\n</strong>", Ph); %prints Ph

PF = 1.5;
Pmcp = Ph*PF;
```

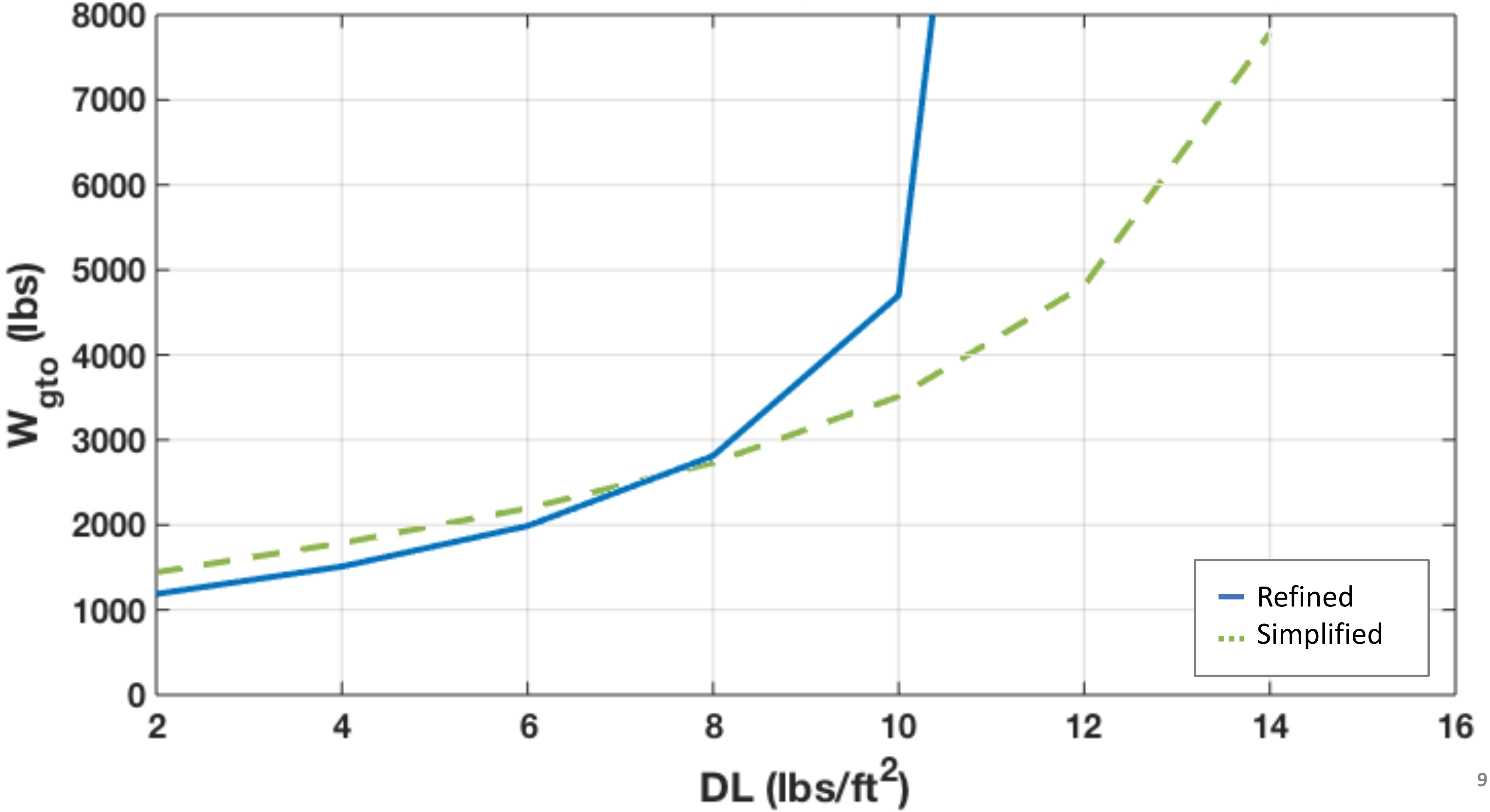
```
%find hover E
hovertimeMins = 5;
fprintf(" Assume hover time (mins): %.2f\n", hovertimeMins)
hovertime = hovertimeMins*60; %in seconds
fprintf("\tHover time (secs): %.2f\n", hovertime)
Eh = Ph*hovertime;
fprintf("<strong>Hover Energy Eh (Ws): %.2f\n</strong>", Eh) %J

%find total E (Wh)
Etotal = Ec + Eh; %in J which = Ws
fprintf("<strong>Total Energy (Ws): %.2f\n</strong>", Etotal)
EtotalWh = Etotal/3600; %Wh
fprintf("<strong>Total Energy (Wh): %.2f\n</strong>", Ec)

%find Wbat
dod = 0.8; %depth of discharge
maxSpecsforBat = 200*dod; %Wh/kg
fprintf(" Assume Battery Specific Energy (Wh/kg): %.2f\n", maxS
WbatKg = EtotalWh/maxSpecsforBat; %in kg
fprintf("<strong>Wbat (kg): %.2f\n</strong>", WbatKg)
Wfuel = WbatKg*9.80665; %Wbat in Newtons
fprintf("<strong>Wbat (N): %.2f\n</strong>", Wfuel)

%Pmcp--> kW then divide by battery mass --> kW/kg specific powe
batSpecPower = Pmcp/1000/WbatKg;
fprintf("\n<strong>Battery Specific Power (kW/kg): %.6f</strong
batCRate = Pmcp/(Etotal/3600);
fprintf("\n<strong>Battery C rate (1/h): %.6f</strong>\n", bat(


%STEP 6: update Wgto
fprintf("\n\n     -- STEP 6: Update Wgto --     \n\n")

fprintf("Wgto = %.2f + %.2f + %.2f + %.2f\n", Wpay, Ws, Wp, Wfu
newWgto= Wpay + Ws + Wp + Wfuel; %new Wgto in Newtons
```

Gross Takeoff Weight vs Iterations with varying DL

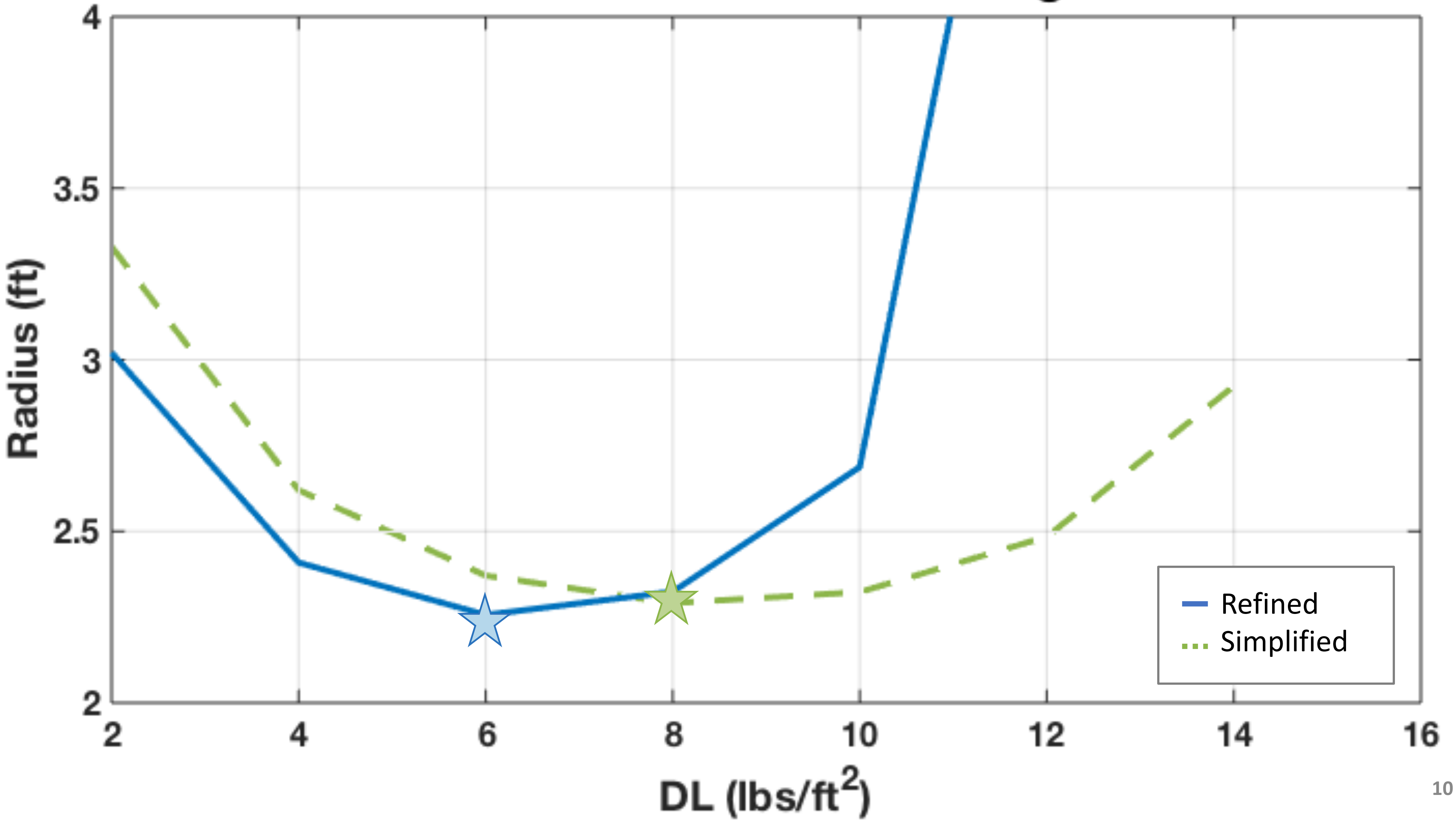


*refined calculations

Gross Takeoff Weight vs Disk Loading



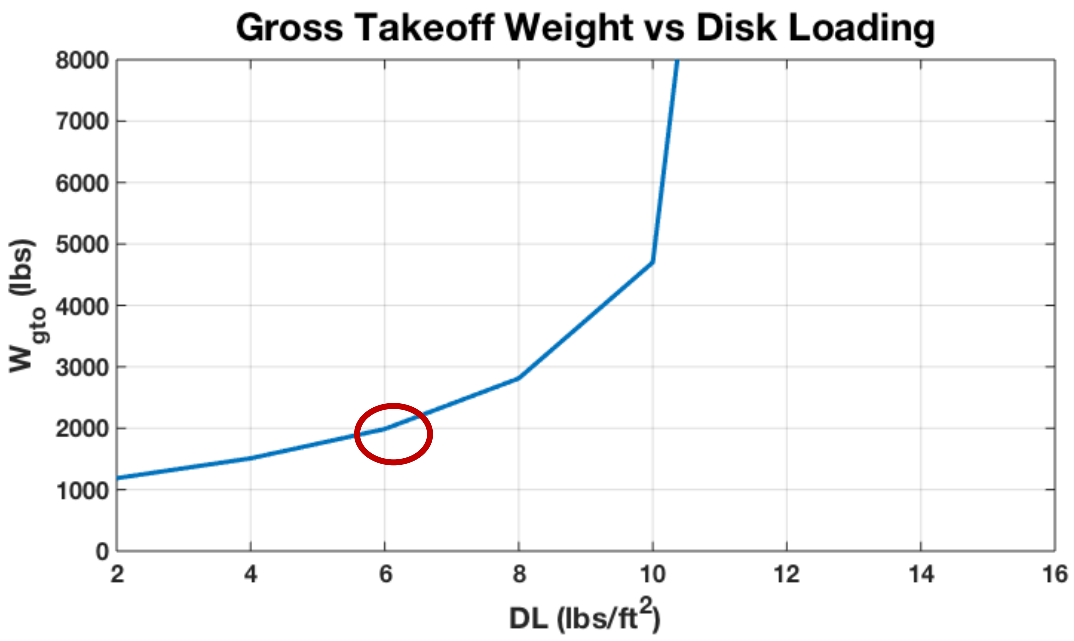
Radius vs Disk Loading

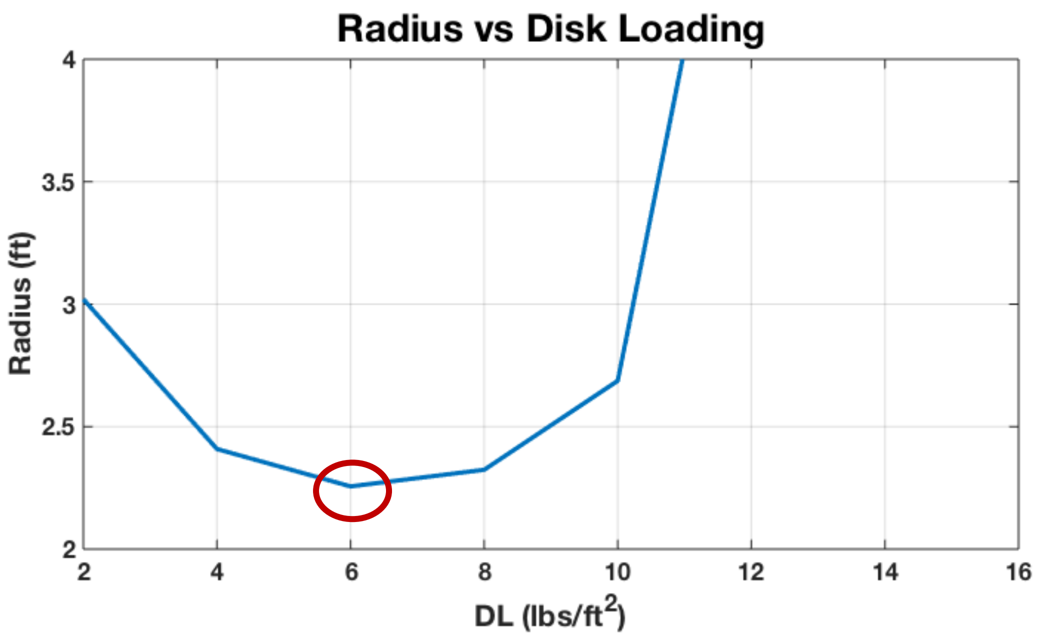


Choosing a DL

Constraints:

- Landing at my house → can't be much heavier than a car → **minimize weight**
- Stored in driveway → don't want to take up too much space → **minimize radius**





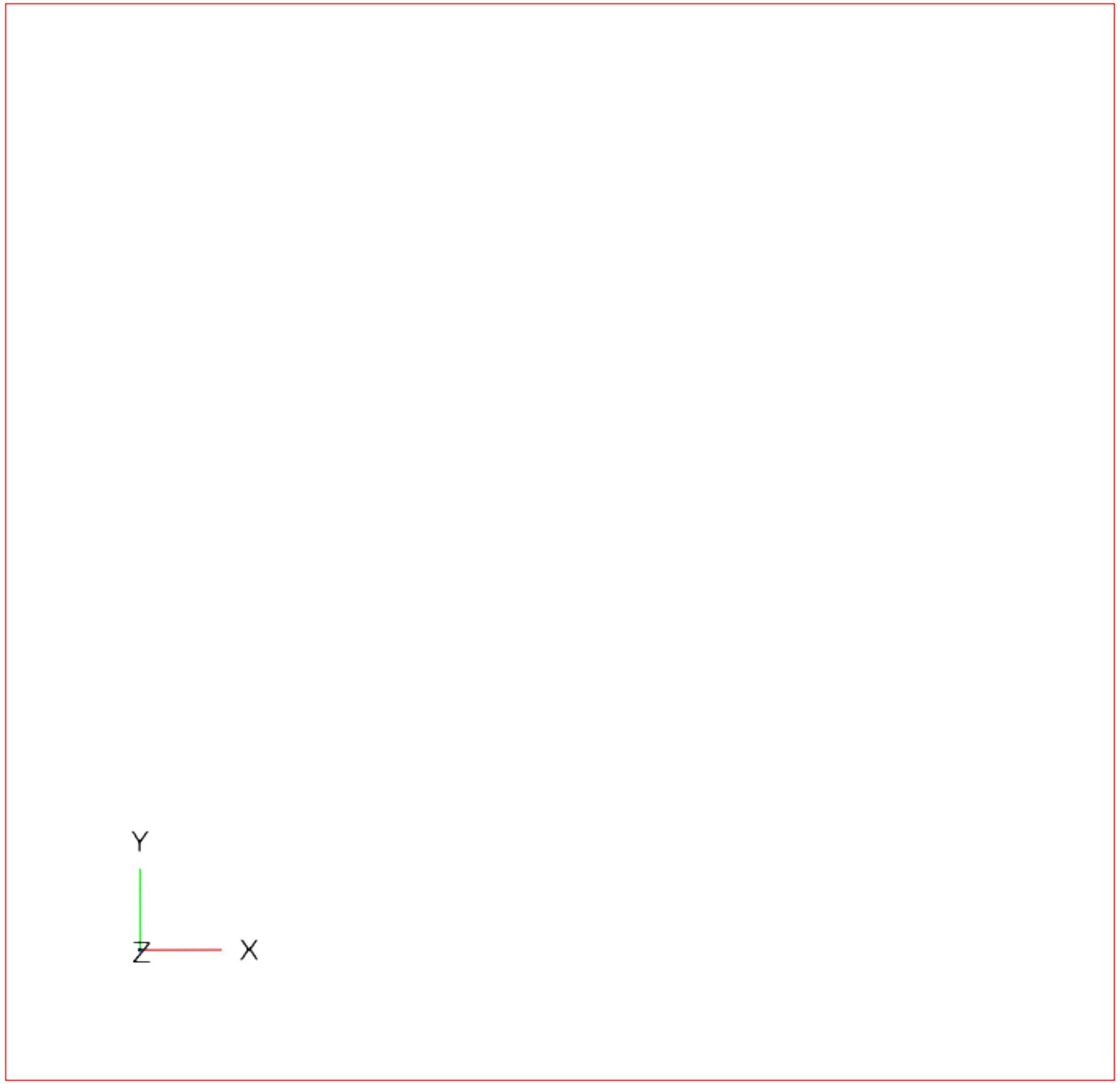
DL = 6 lbs/ft^2

W_{gto} ≈ 1987 lbs **Radius = 2.2561 ft**

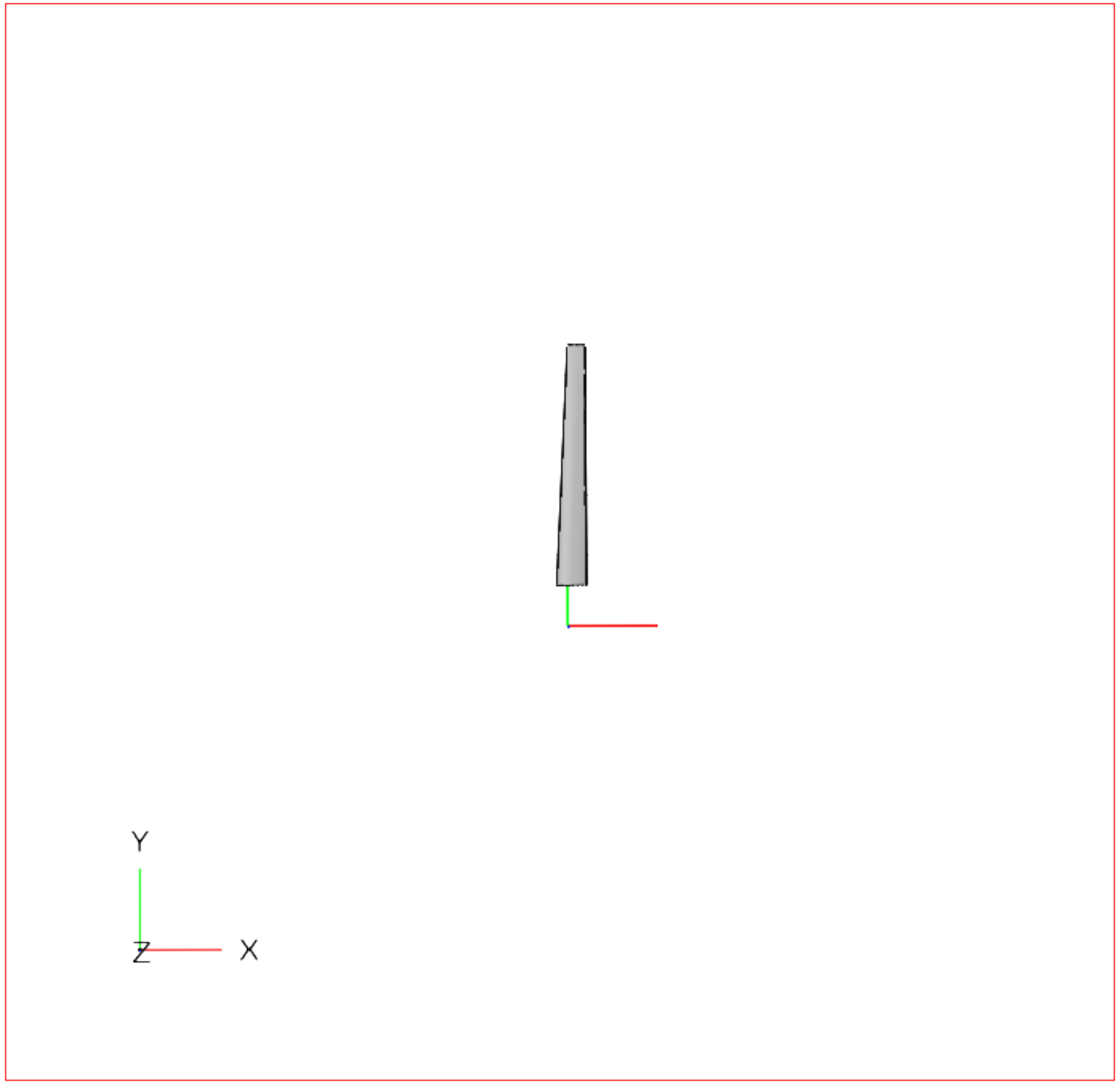
Rendering the Design with OpenVSP

Nasa Langley OpenVSP

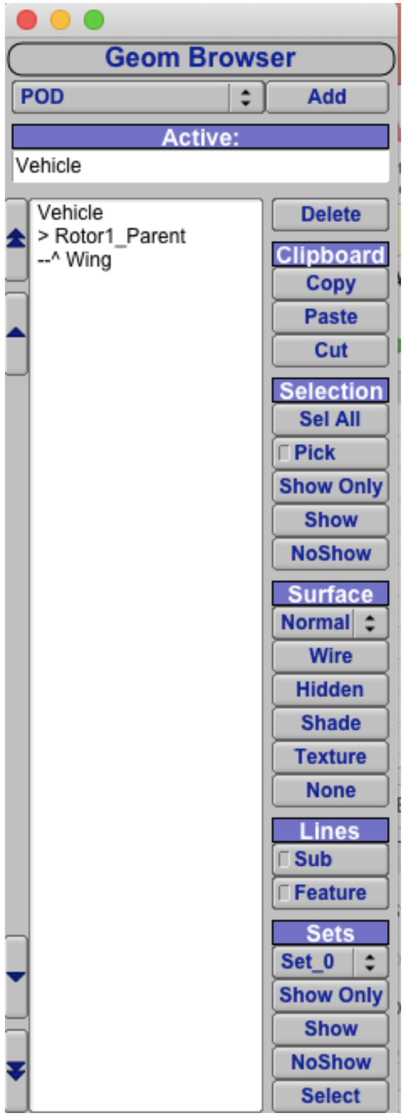
Visualization Process



Step 1: Blade



Y
Z
X



Geom Browser
POD
Add
Active:
Vehicle
Vehicle
> Rotor1_Parent
--^ Wing
Delete
Clipboard
Copy
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Cut
Selection
Sel All
Pick
Show Only
Show
NoShow
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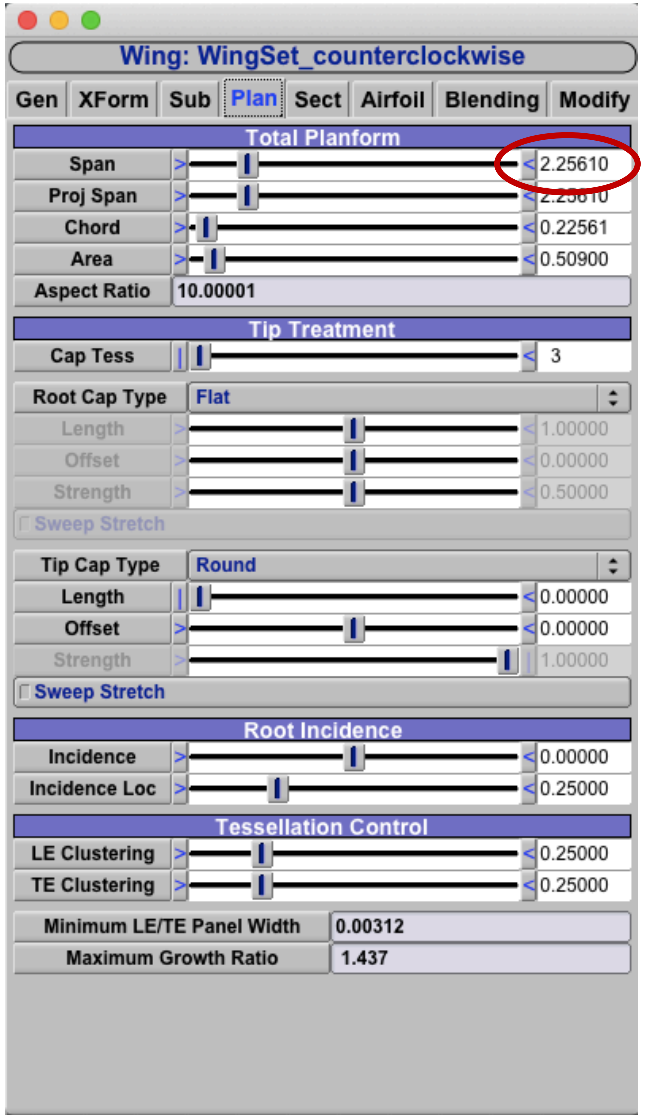
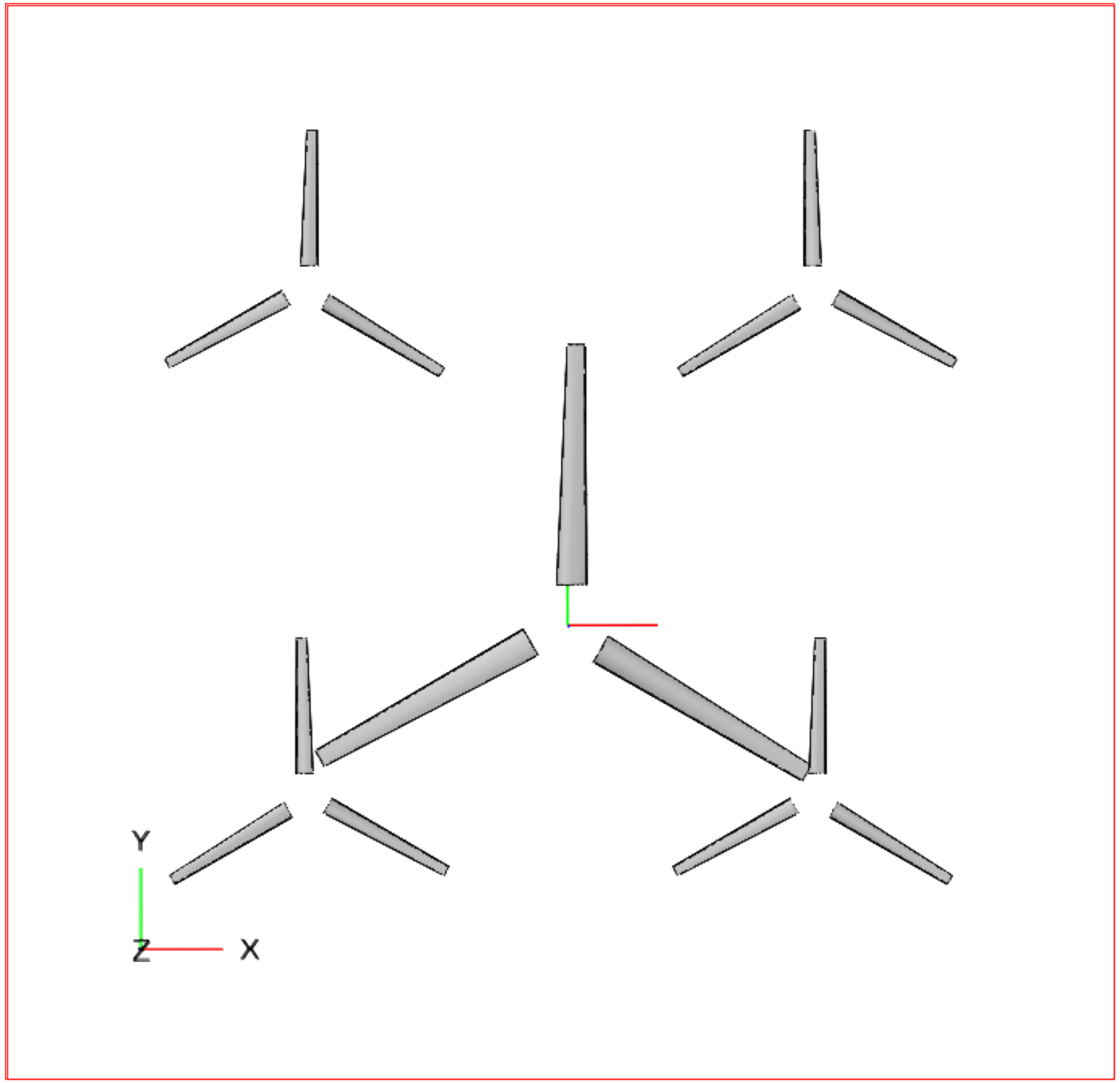
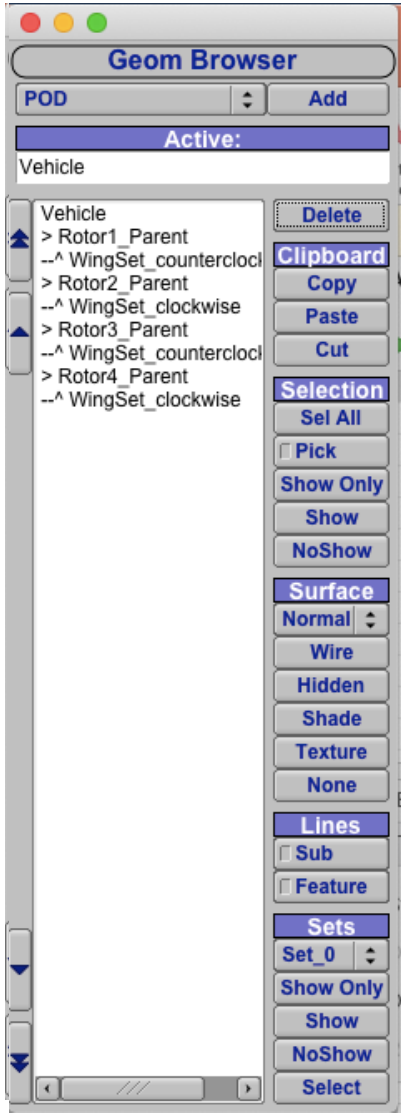
Show Only
Show
NoShow
Select

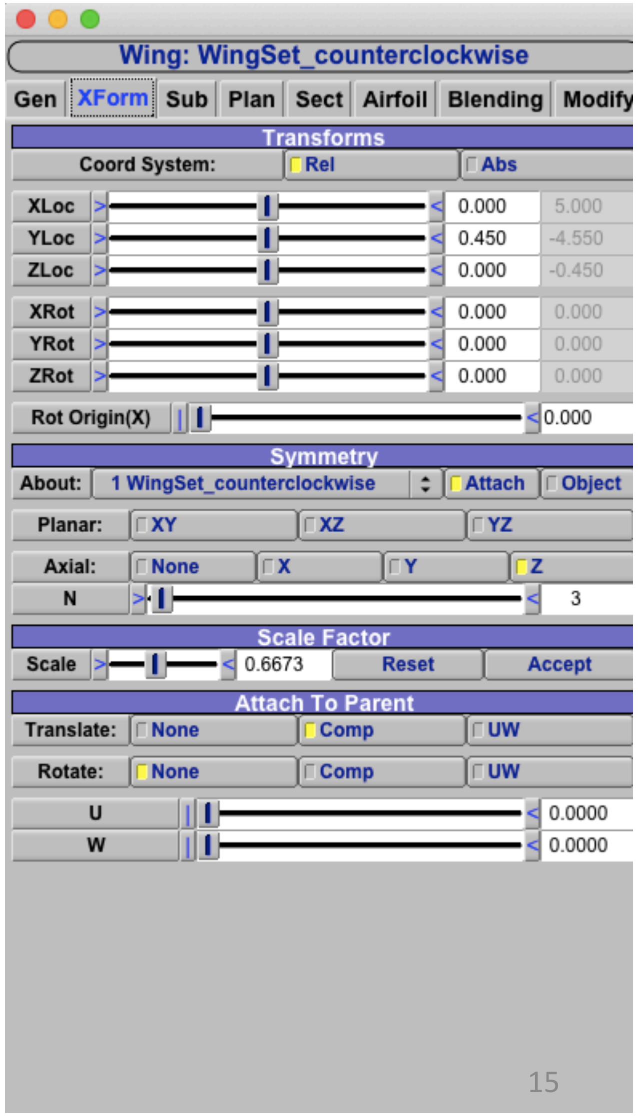


Wing: WingSet_counterclockwise
Gen
XForm
Sub
Plan
Sect
Airfoil
Blending
Modify
Total Planform
Span 2.25610
Proj Span 2.25610
Chord 0.22561
Area 0.50900
Aspect Ratio 10.00001
Tip Treatment
Cap Tess 3
Root Cap Type Flat
Length 1.00000
Offset 0.00000
Strength 0.50000
Sweep Stretch
Tip Cap Type Round
Length 0.00000
Offset 0.00000
Strength 1.00000
Sweep Stretch
Root Incidence
Incidence 0.00000
Incidence Loc 0.25000
Tessellation Control
LE Clustering 0.25000
TE Clustering 0.25000
Minimum LE/TE Panel Width 0.00312
Maximum Growth Ratio 1.437

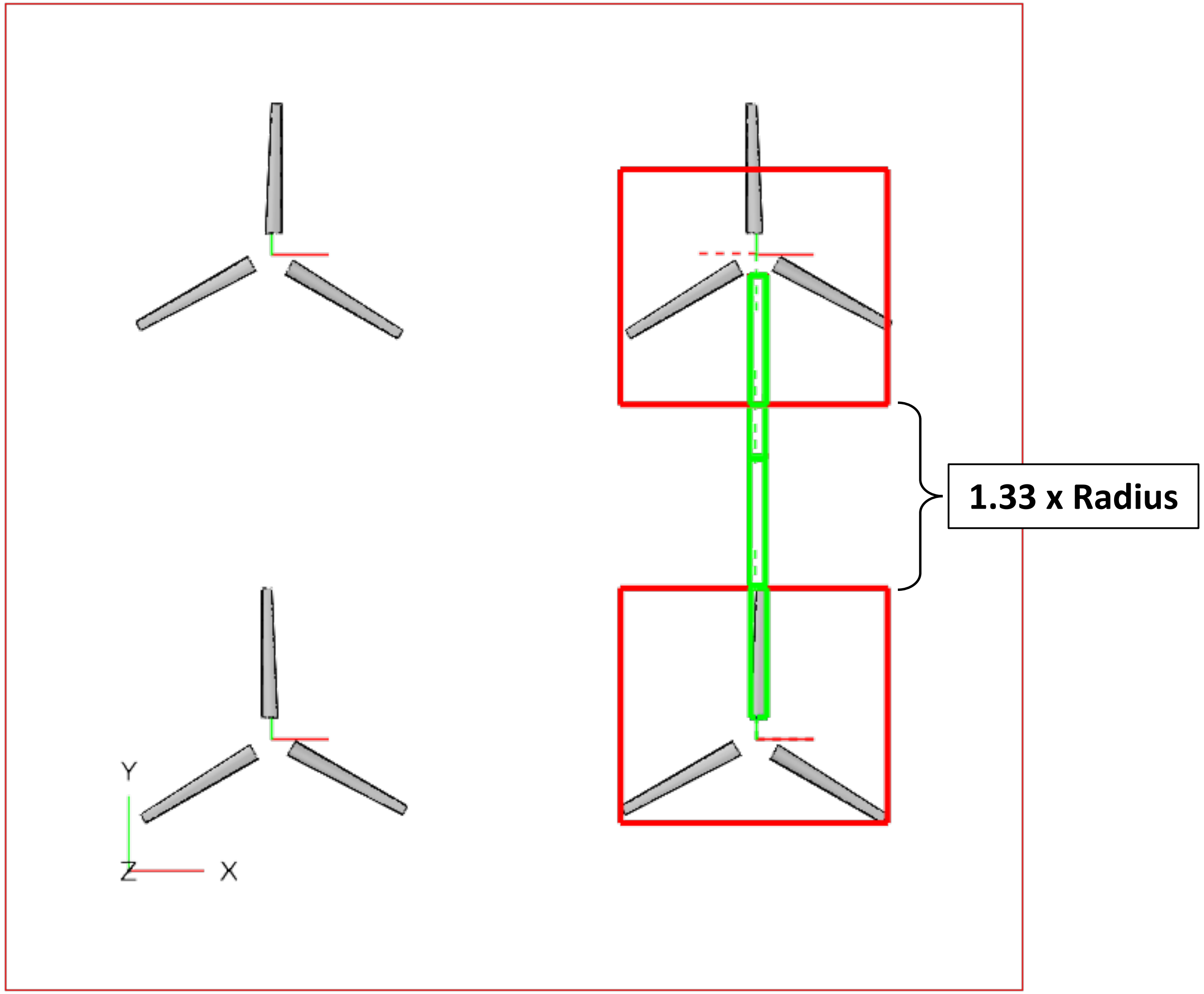
Step 2: Rotors



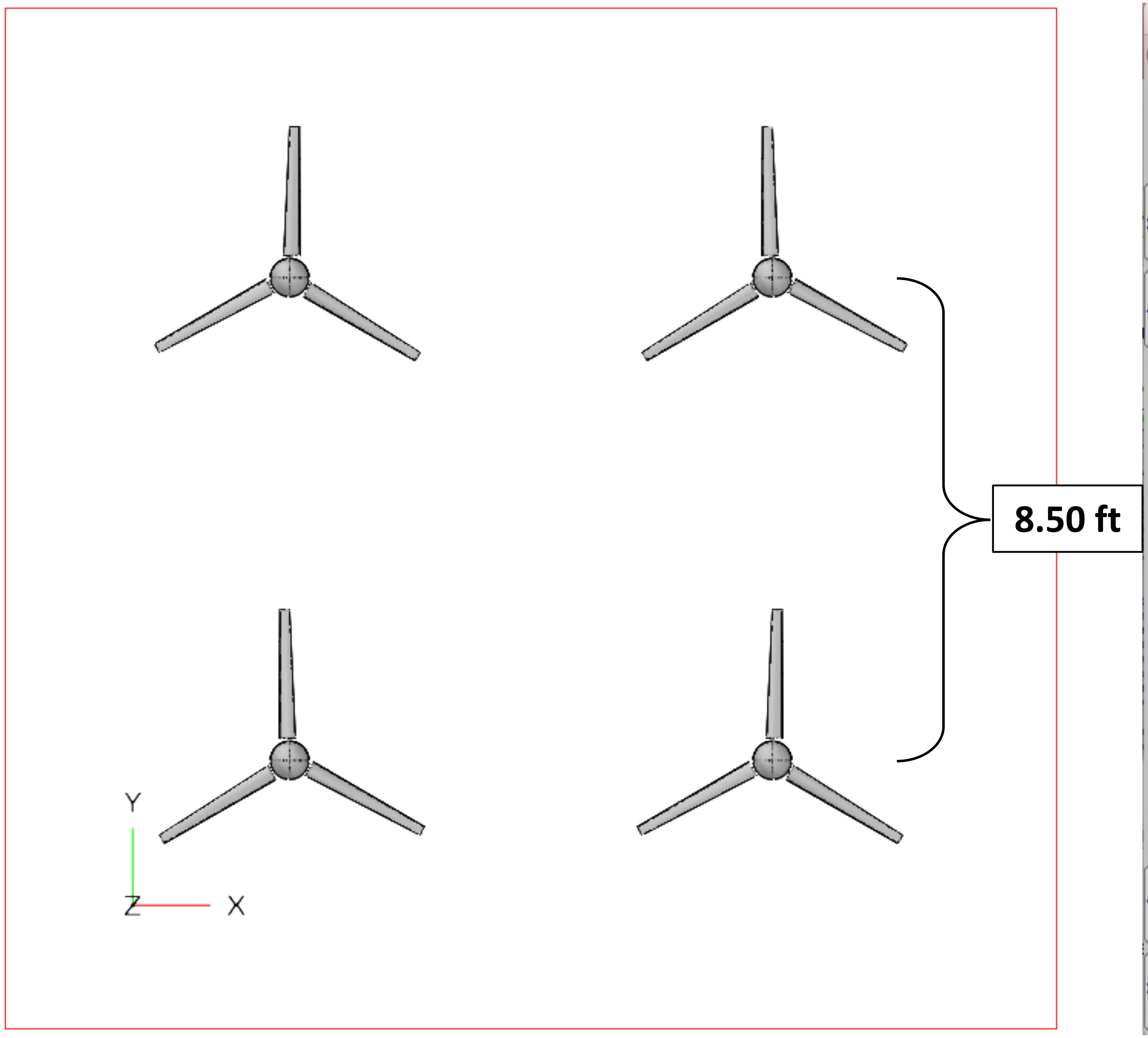


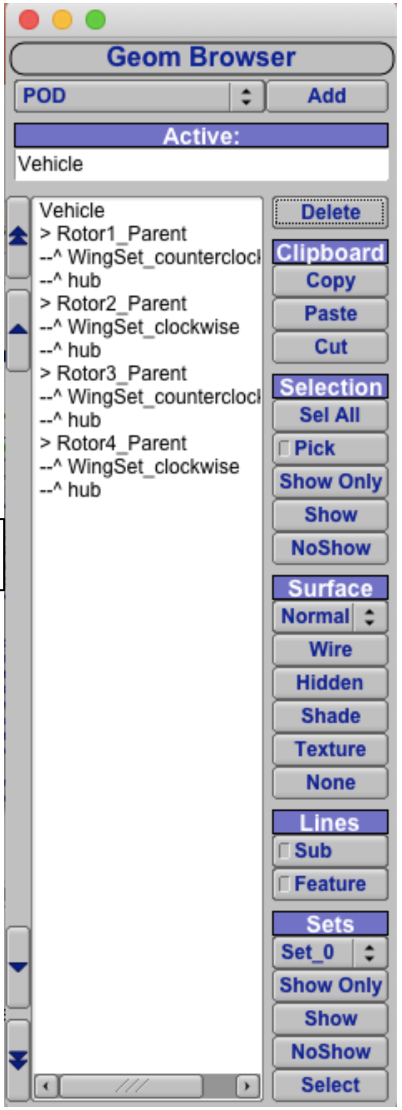


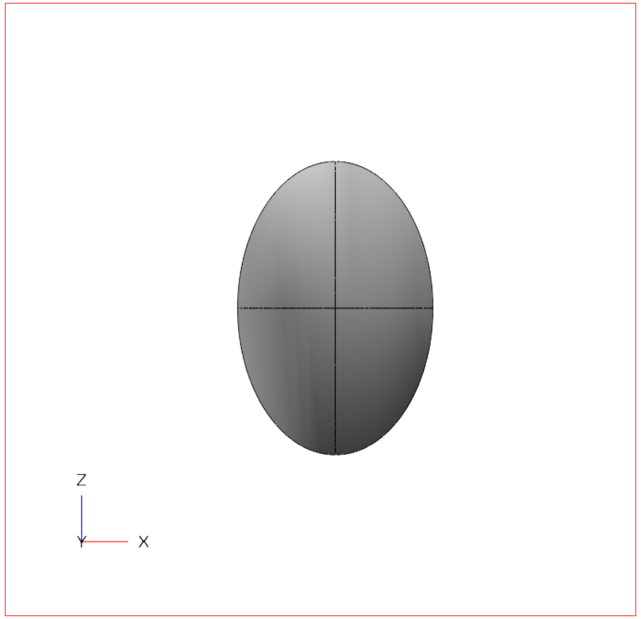
Step 2: Rotors



Step 3: Hubs

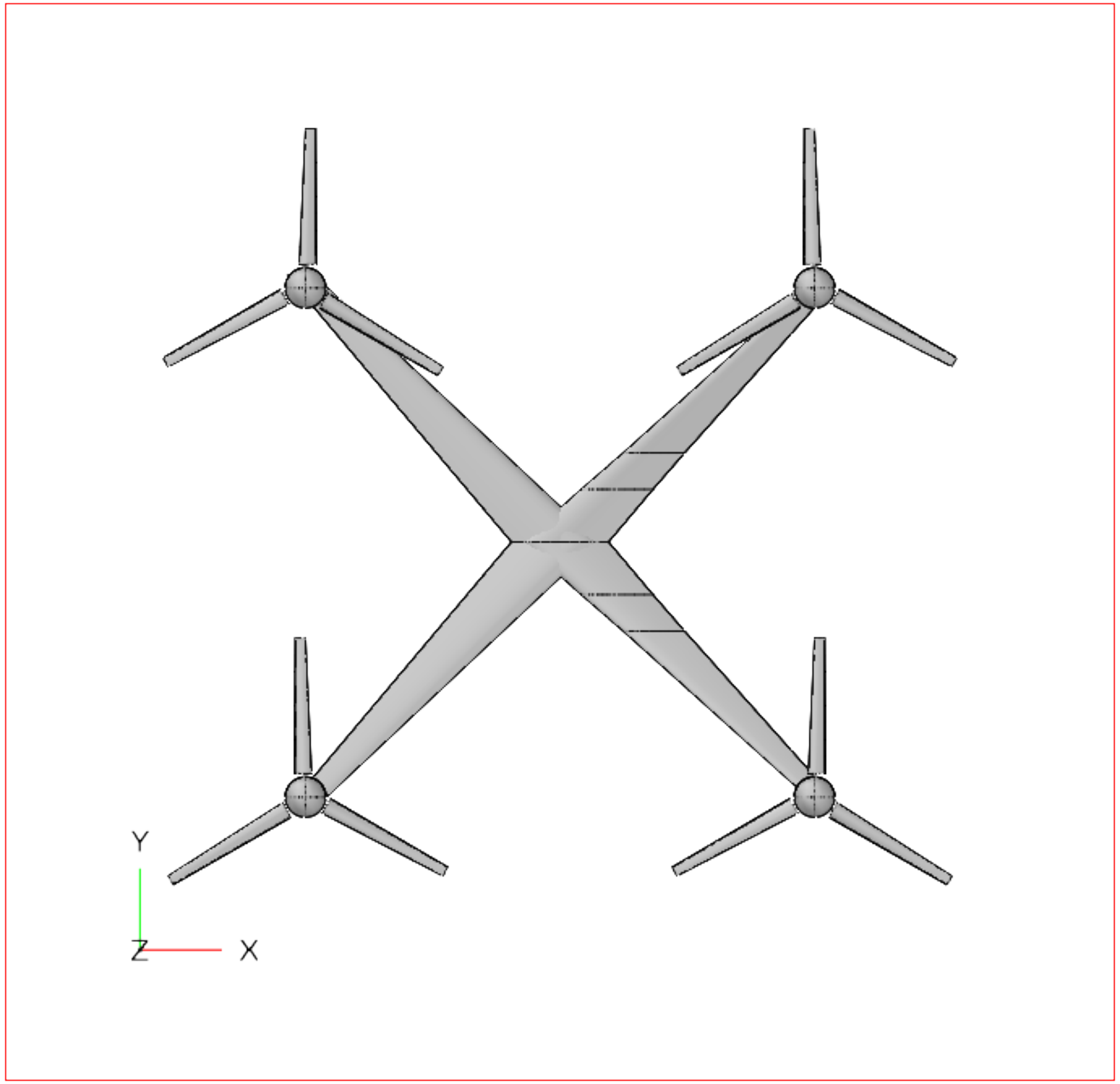






Side View

Step 4: Wings


Y
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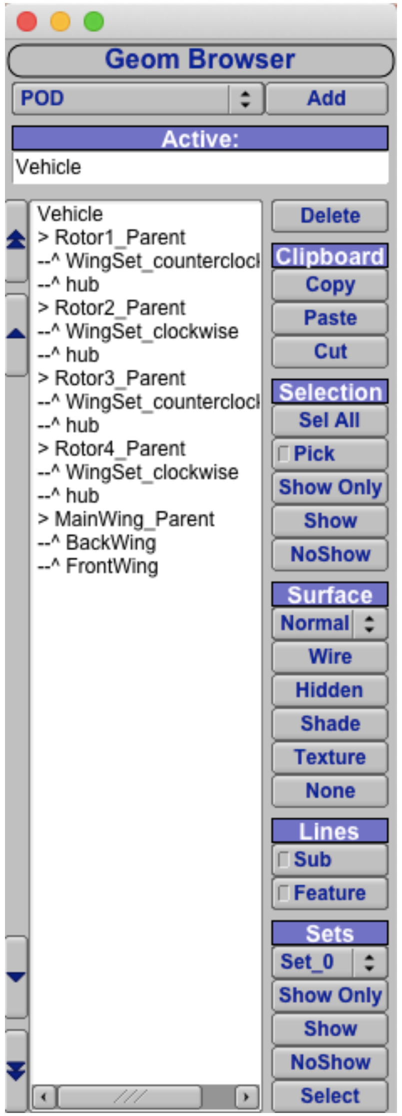
Geom Browser
POD
Add
Active:
Vehicle
Vehicle
> Rotor1_Parent
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> Rotor2_Parent
--^ WingSet_clockwise
--^ hub
> Rotor3_Parent
--^ WingSet_countercloc
--^ hub
> Rotor4_Parent
--^ WingSet_clockwise
--^ hub
> MainWing_Parent
--^ BackWing
--^ FrontWing
Delete
Clipboard
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Pick
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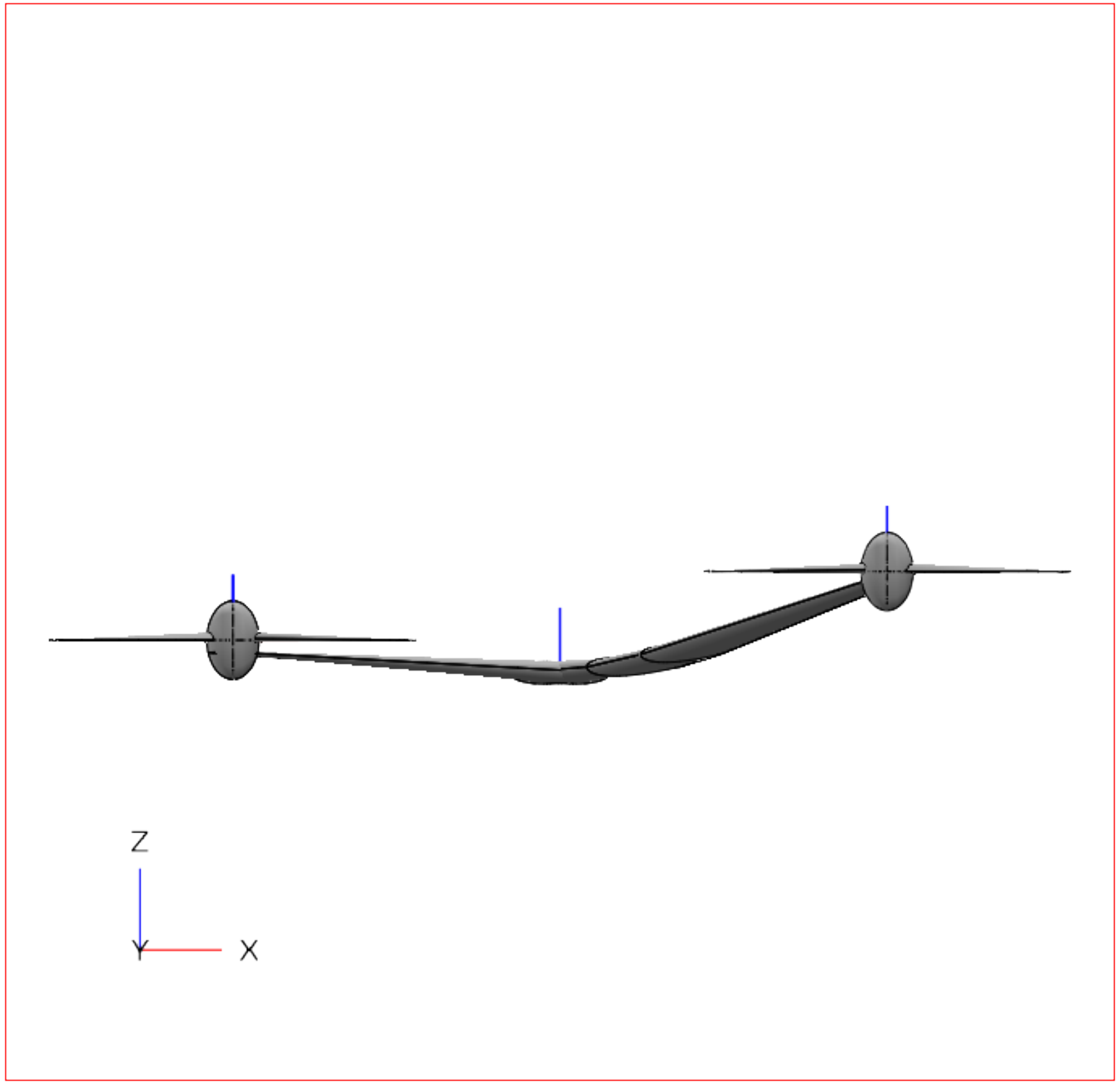
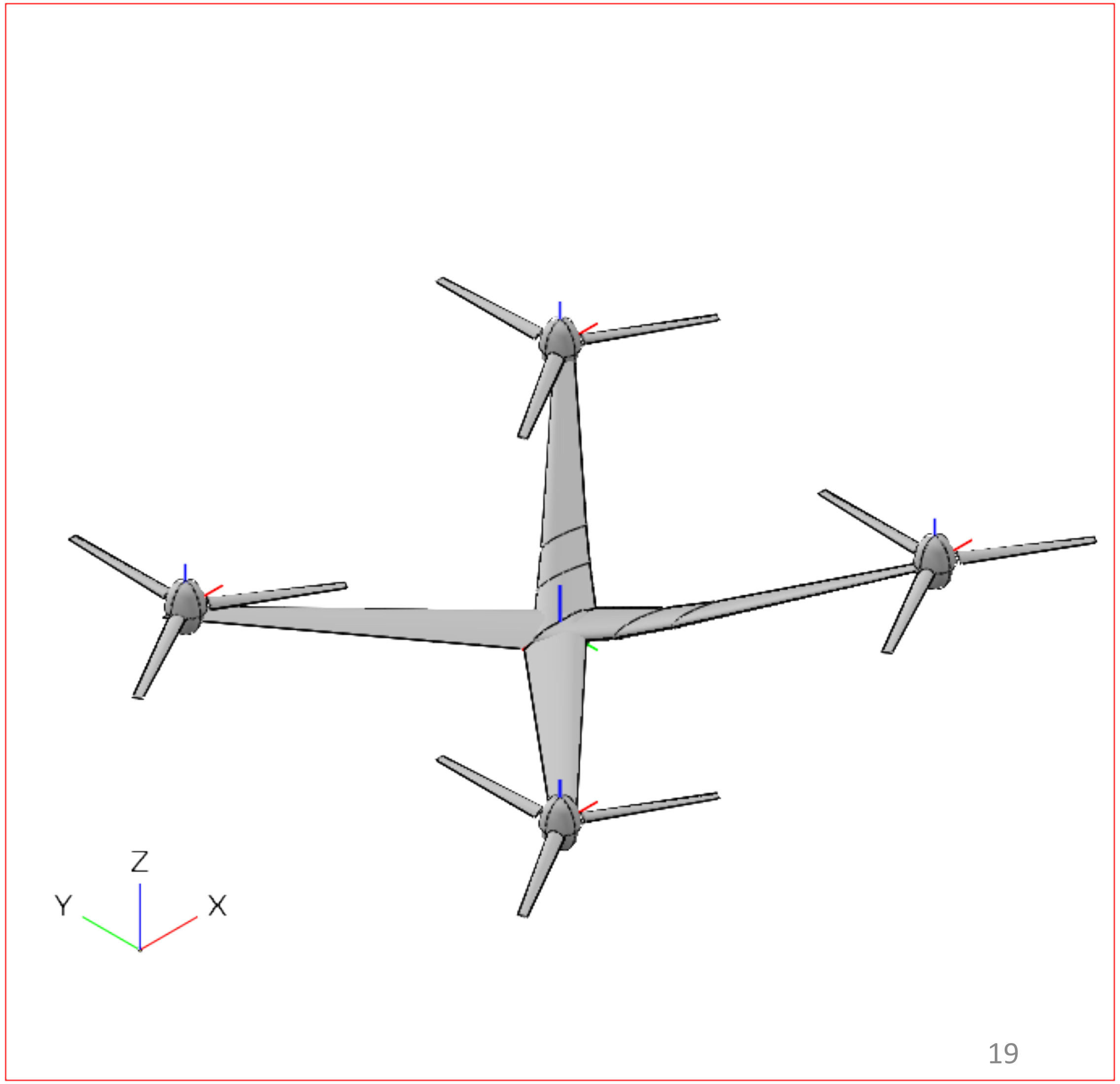
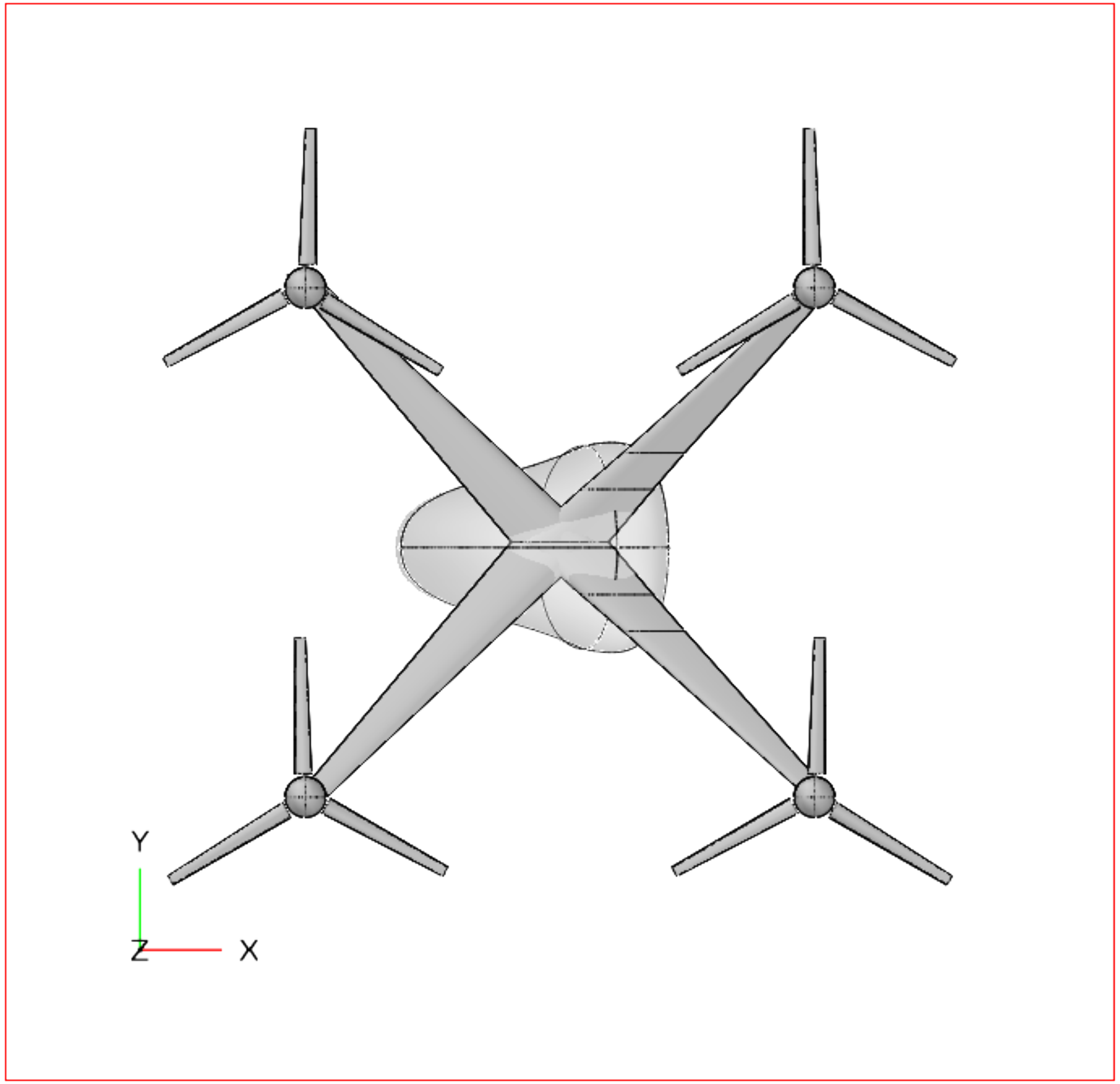
NoShow
Select

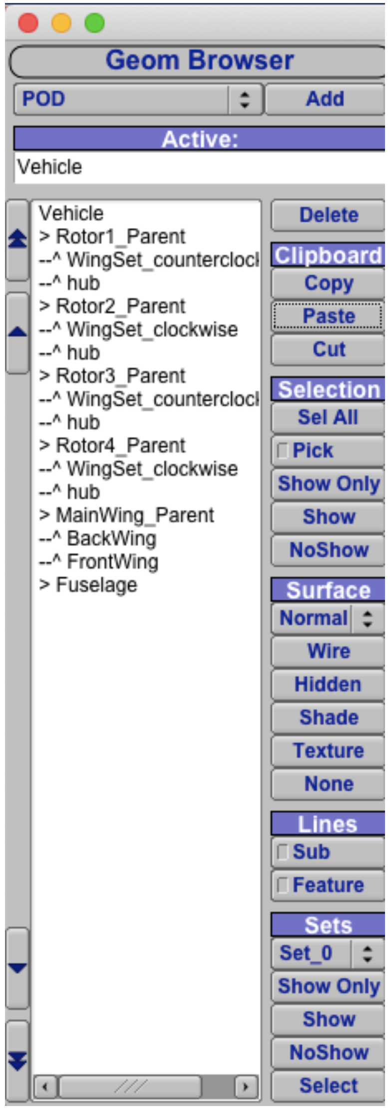
Step 4: Wings

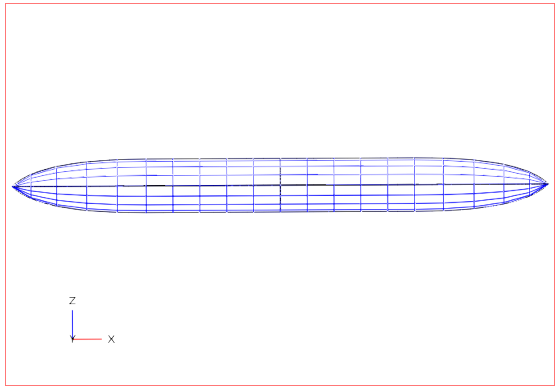


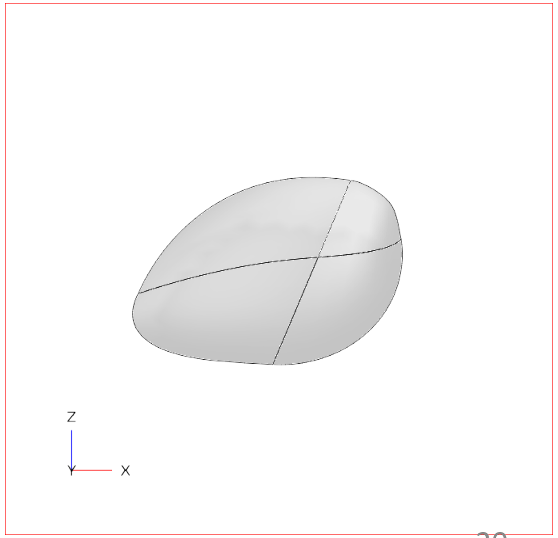


Step 5: Fuselage

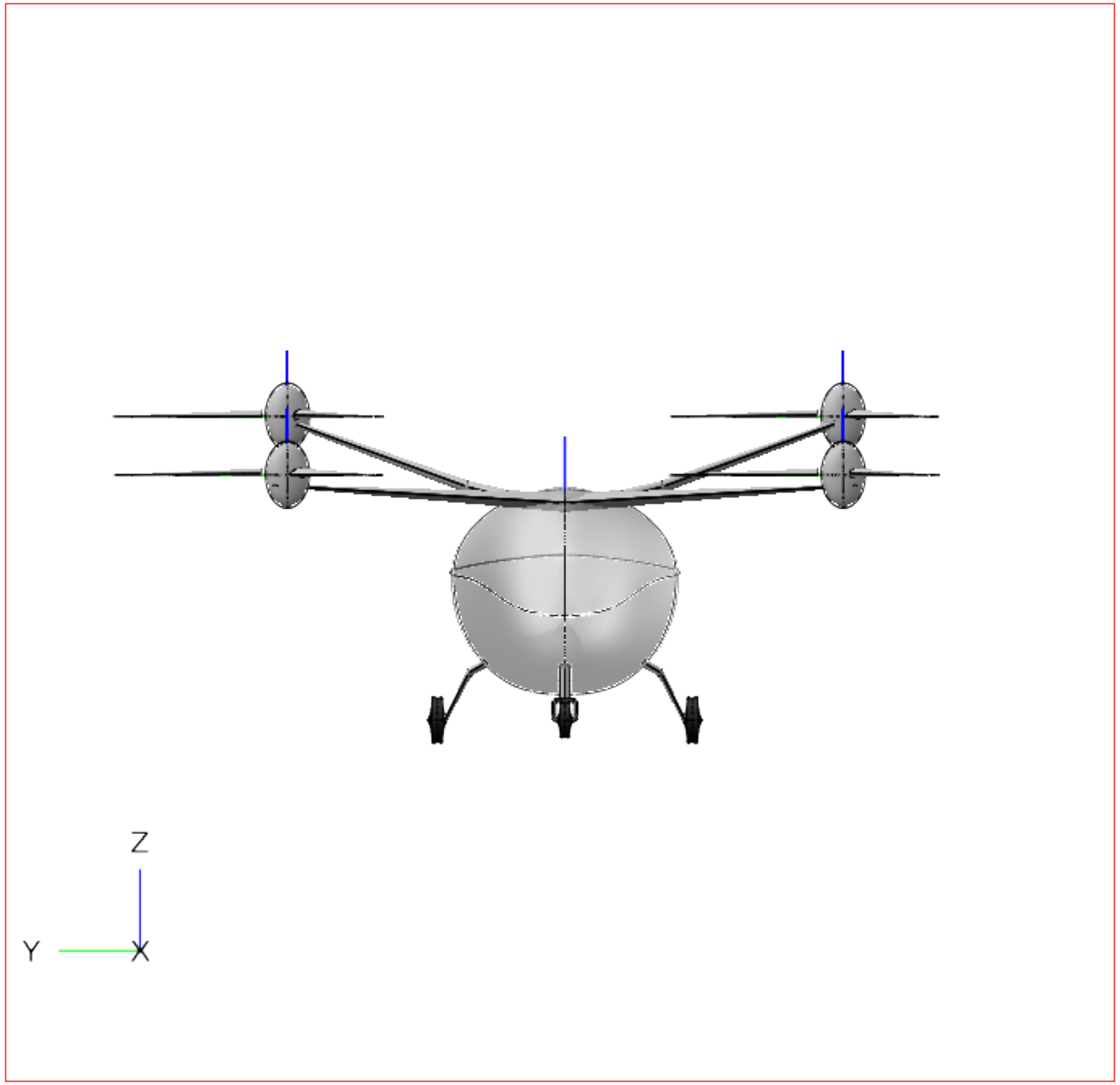


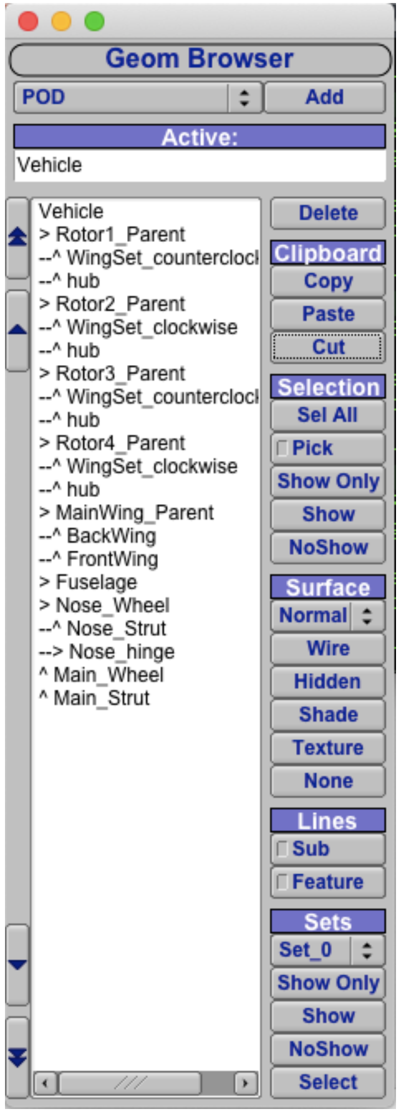




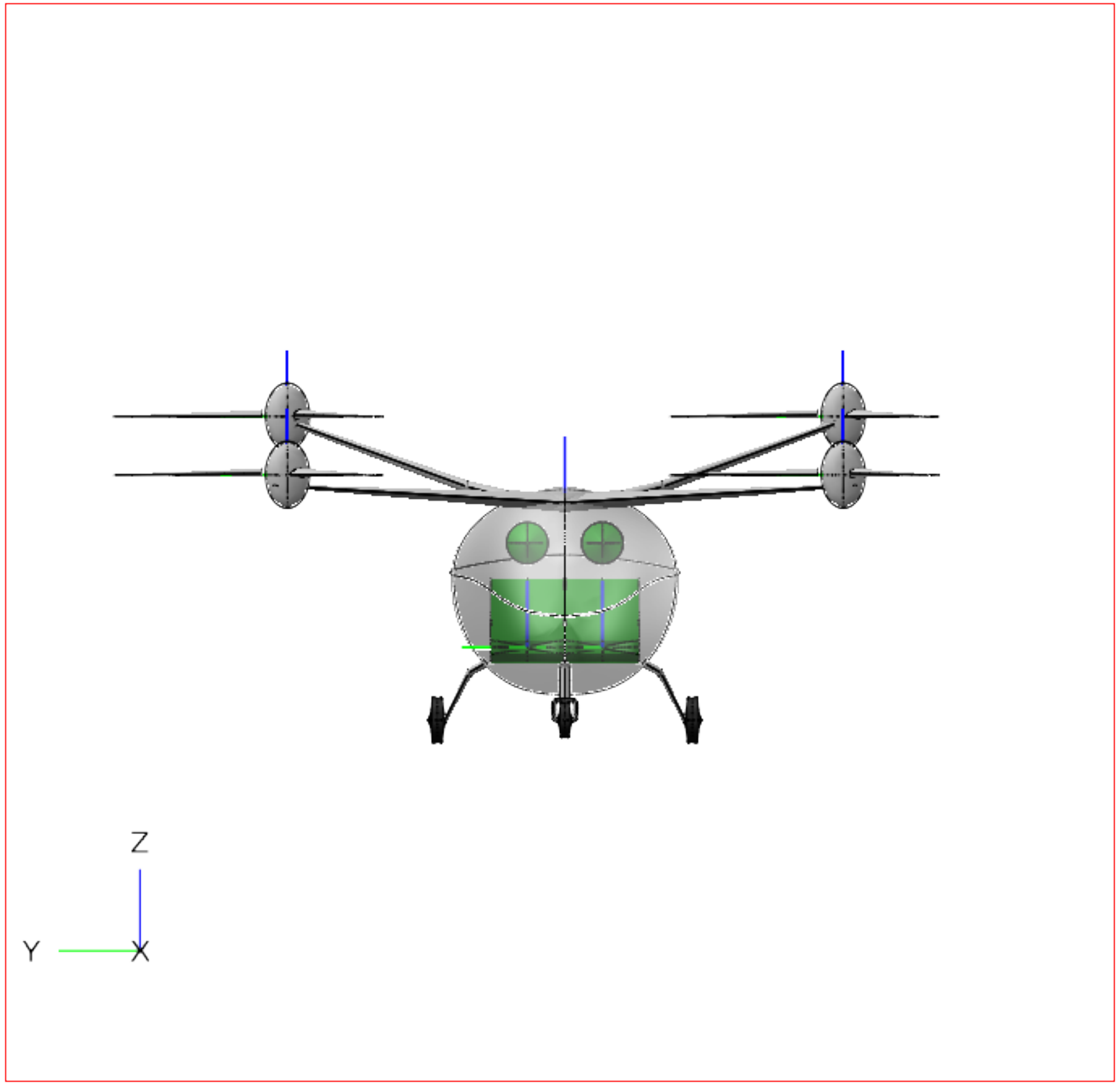


Step 6: Landing Gear





Step 7: Seats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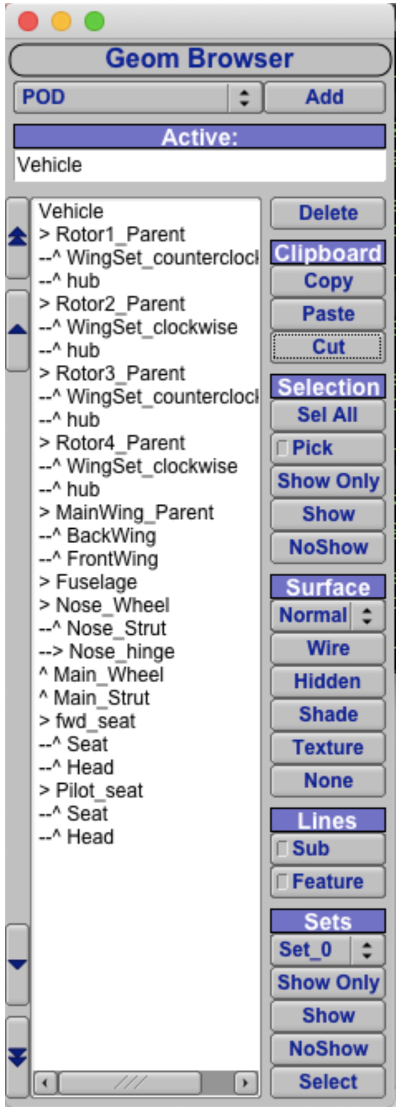
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--^ hub
> Rotor3_Parent
--^ WingSet_counterclocl
--^ hub
> Rotor4_Parent
--^ WingSet_clockwise
--^ hub
> MainWing_Parent
--^ BackWing
--^ FrontWing
> Fuselage
> Nose_Wheel
--^ Nose_Strut
--> Nose_hinge
^ Main_Wheel
^ Main_Strut
> fwd_seat
--^ Seat
--^ Head
> Pilot_seat
--^ Seat
--^ Head
Delete
Clipboard
Copy
Paste
Cut
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Sel All
Pick
Show Only
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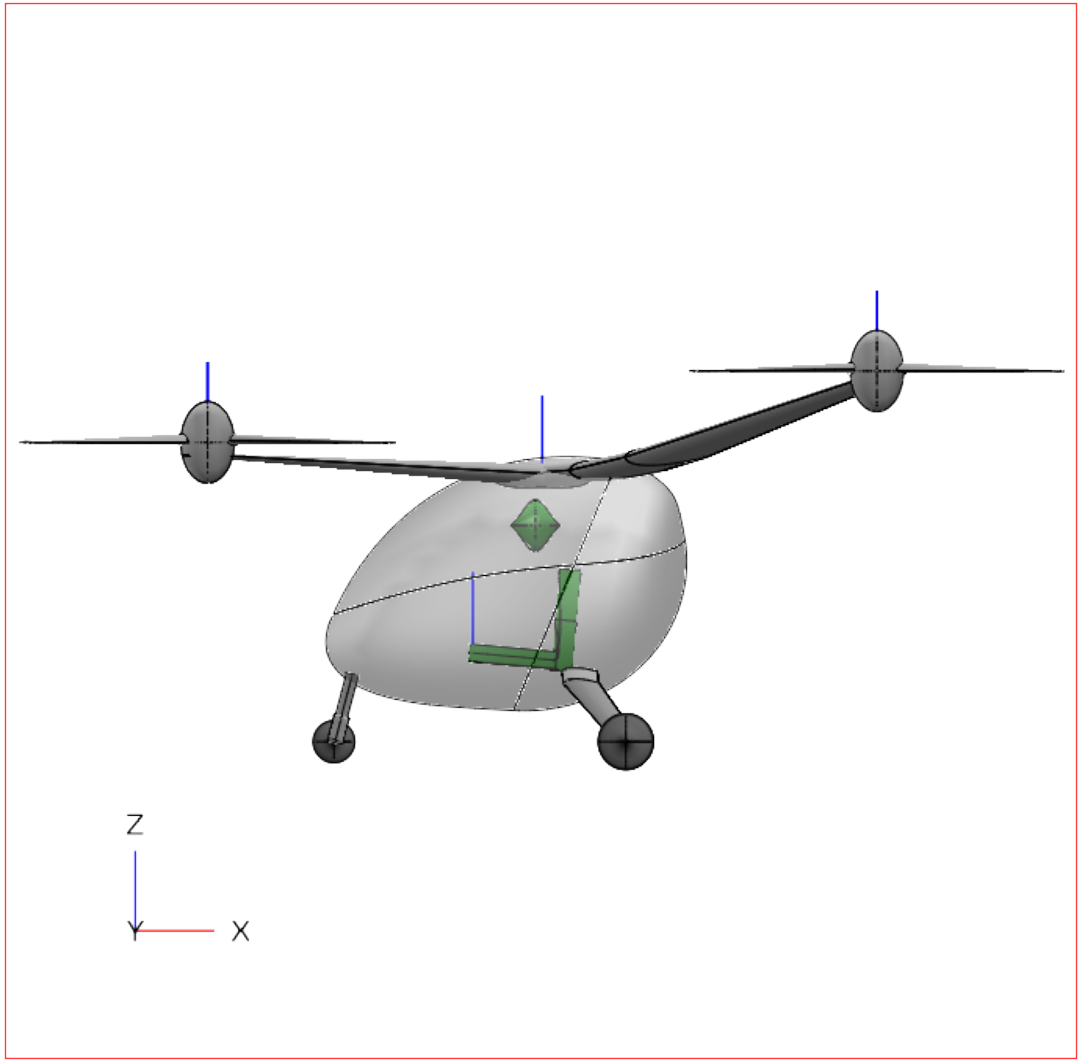
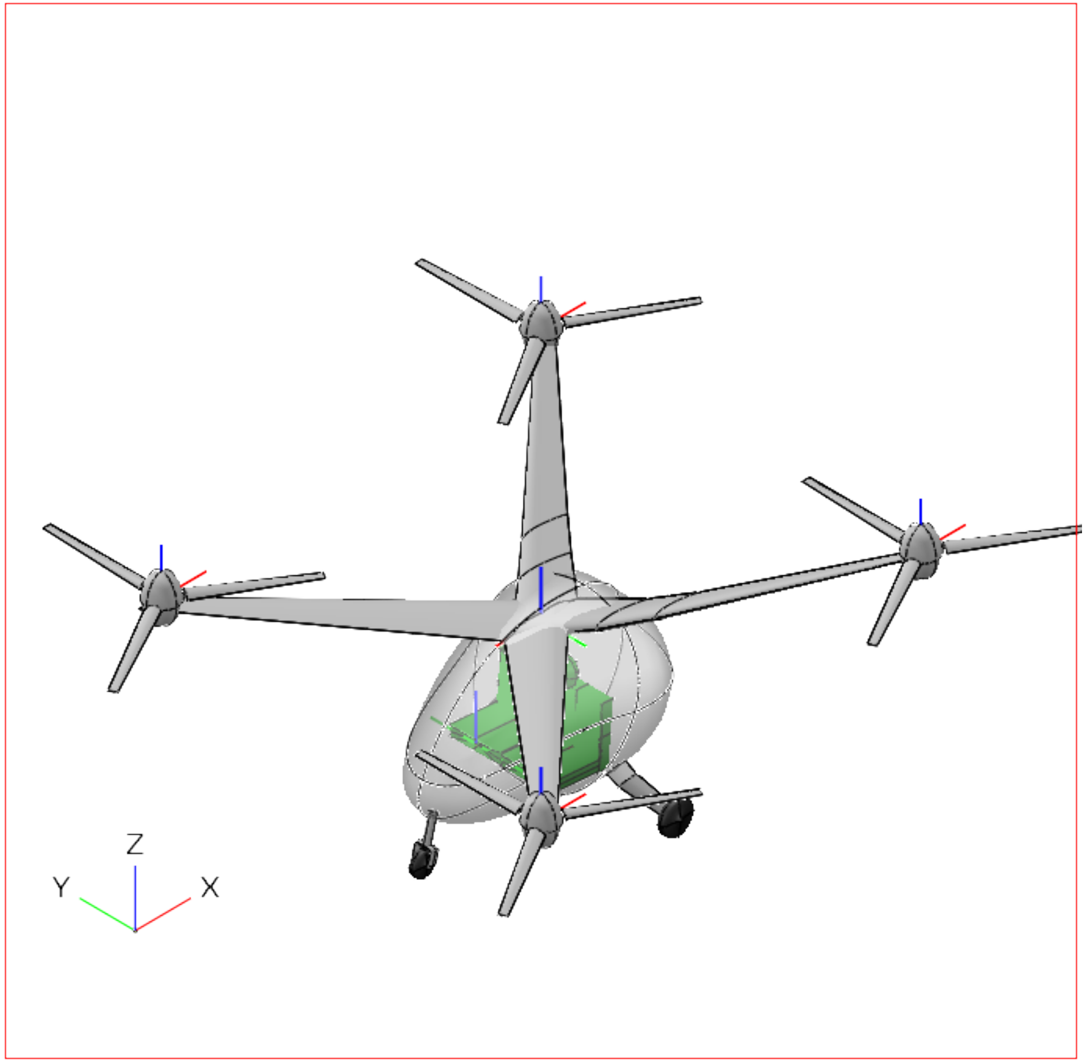
Sets
Set_0
Show Only
Show
NoShow
Select

Final eVTOL



Side



Isometric

Summary

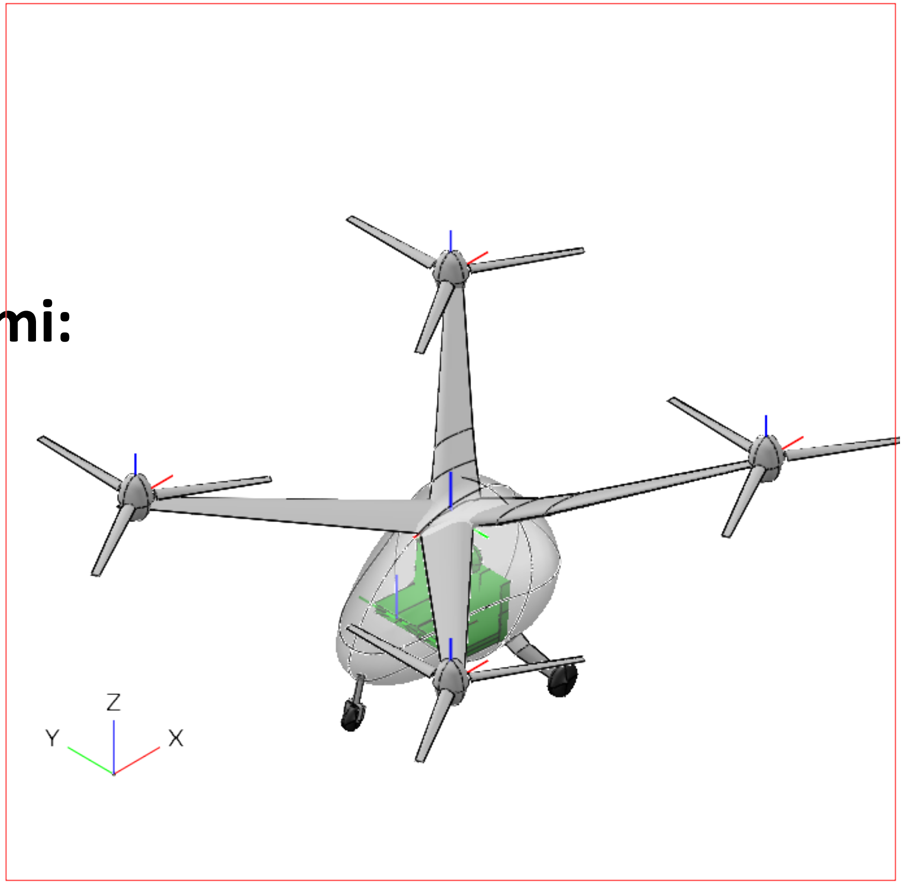
- Learned about aircrafts & how to calculate lift, drag, and power
- Learned how to design an evtol
- Designed an evtol that can carry 2 passengers to and from UMD campus and my house
- Visually rendered design using Nasa Langley OpenVSP software

Lessons Learned

- **Important Lessons:**
  - **Engineering requires iteration**
  - **Ask questions**
  - **Break difficult tasks into small steps**
  - **Pay attention to units!!!**

Conclusion

- **Yes, it is possible to design an evtol aircraft with a payload of 400 lbs and mission of 25 miles**
- **It is important to include the proper drag calculations**
- **Feasible designs have a DL in the range 2-10 lbs/ft^2**
- **Optimum design for payload = 400 lbs and range = 25mi:**
  - **DL = 6 lb/ft^2**
  - **W_{gto} ≈ 1987 lbs**
  - **Radius ≈ 2.25 ft**



Acknowledgements

A special thank you to:

- **Dr. Datta**
- **Dr. Krug**

Thanks for listening!
Questions?