VERDECOMMUTE

VERDEGO AERO

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

VerdeCommute

VC-1 "AMPED" CONFIGURATION EVALUTATION

An aircraft purpose built for the Regional Air Mobility Market, leveraging VerdeGo's hybrid powerplants.

Team Lead: Gabriel Rodriguez

Team Members: Gregory Callaghan, Daniel Rodriguez, Walker Wood, Holden Smith

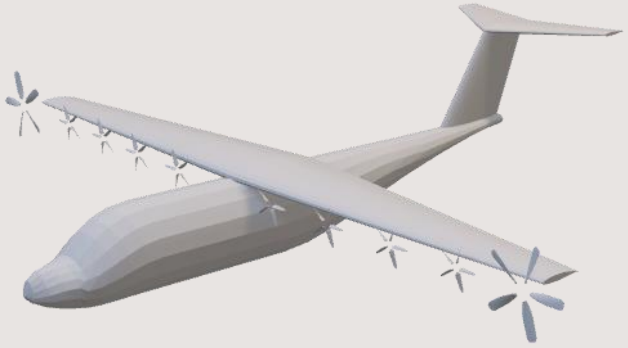
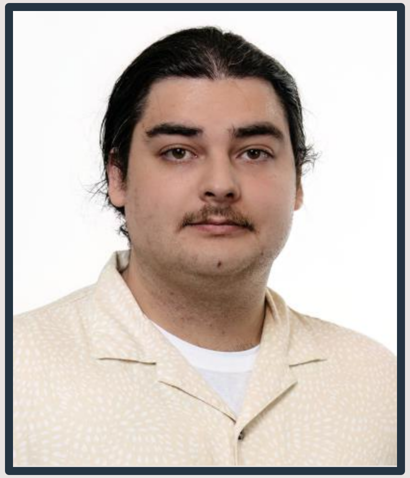


Figure 1: The VC-1 Aircraft Model

TEAM MEMBER INTRODUCTION

				
Gabriel Rodriguez	**Walker Wood**	**Holden Smith**	**Daniel Rodriguez**	**Gregory Callaghan**
Principal Investigator	Design Engineer	Structural Engineer	Performance Engineer	Controls Engineer
Detailed Weight Modeling, Cost Analysis, Systems Integration, Propulsion	*Solid Modeling, Systems Integration, Stability Analysis*	*Drag Modeling, Structural Analysis*	*Performance Analysis, Mission Analysis*	*Lift Modeling, Stability Analysis, Constraint Analysis*

PRESENTATION CONTENTS

PRIMARY MISSION AND STAKEHOLDERS

THE VC-1 "AMPED"

- Hybrid-Electric STOL (Short Take-Off and Landing)
- Designed for Regional Air Mobility
- Carries 7 passengers or 1,575 [*lbs*] payload over a 438 [*nm*] range

OUR PRIMARY MISSION

- Connect under-utilized regional airports, enabling faster travel between cities
- Increase sustainability and lower operating costs

OUR STAKEHOLDERS

Figure 2: VC-1 Stakeholders

VC-1 "AMPED" KEY FEATURES

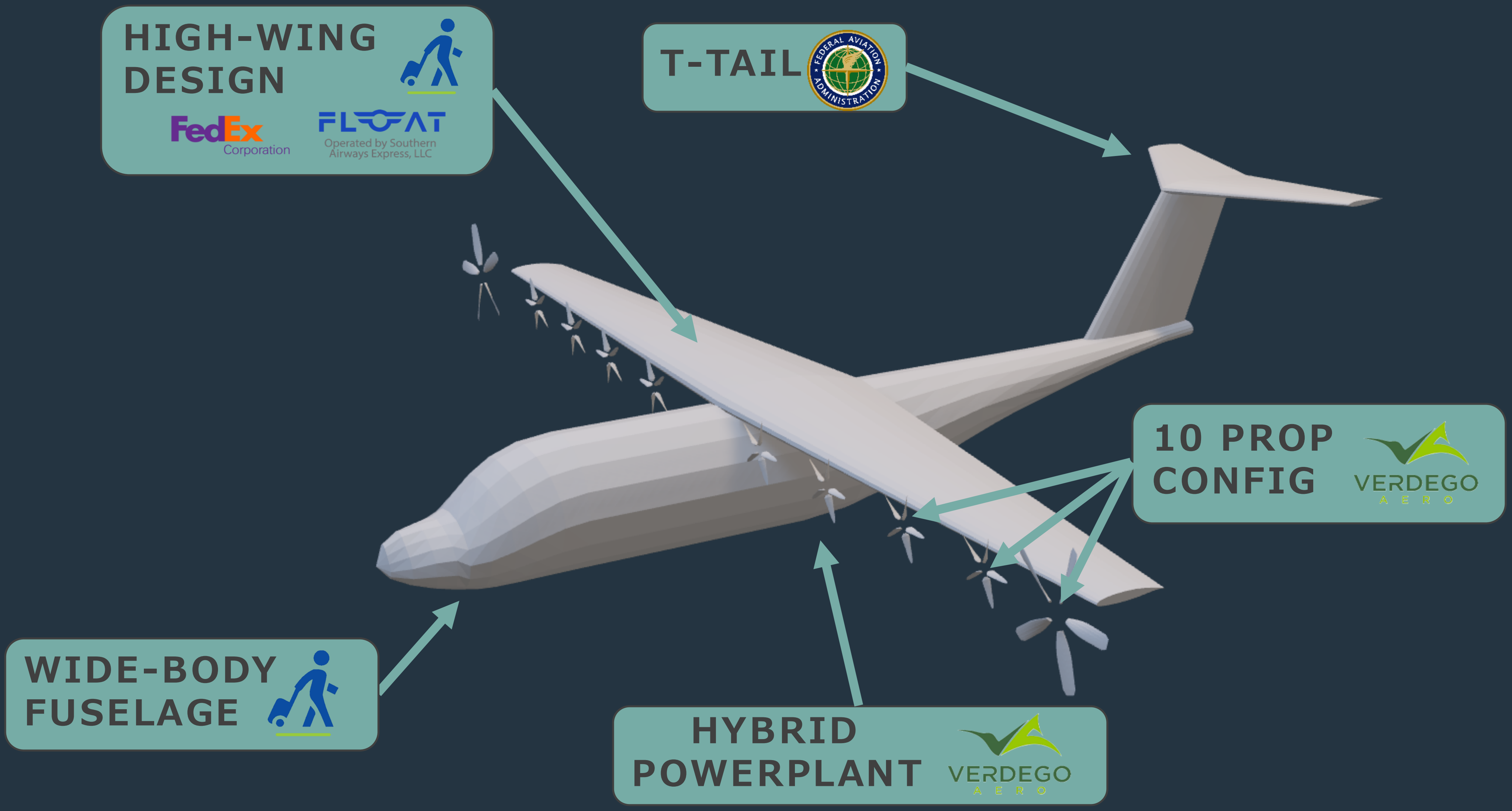


Figure 3: The VC-1 Aircraft Model, Key Features

PRESENTATION CONTENTS

DESIGN MISSION PROFILE

KEY CHARACTERISTICS

- *Distributed Electric Propulsion Enabled Short Take-Off*
- *Hybrid-Electric Powerplant*
- *Short Landing*

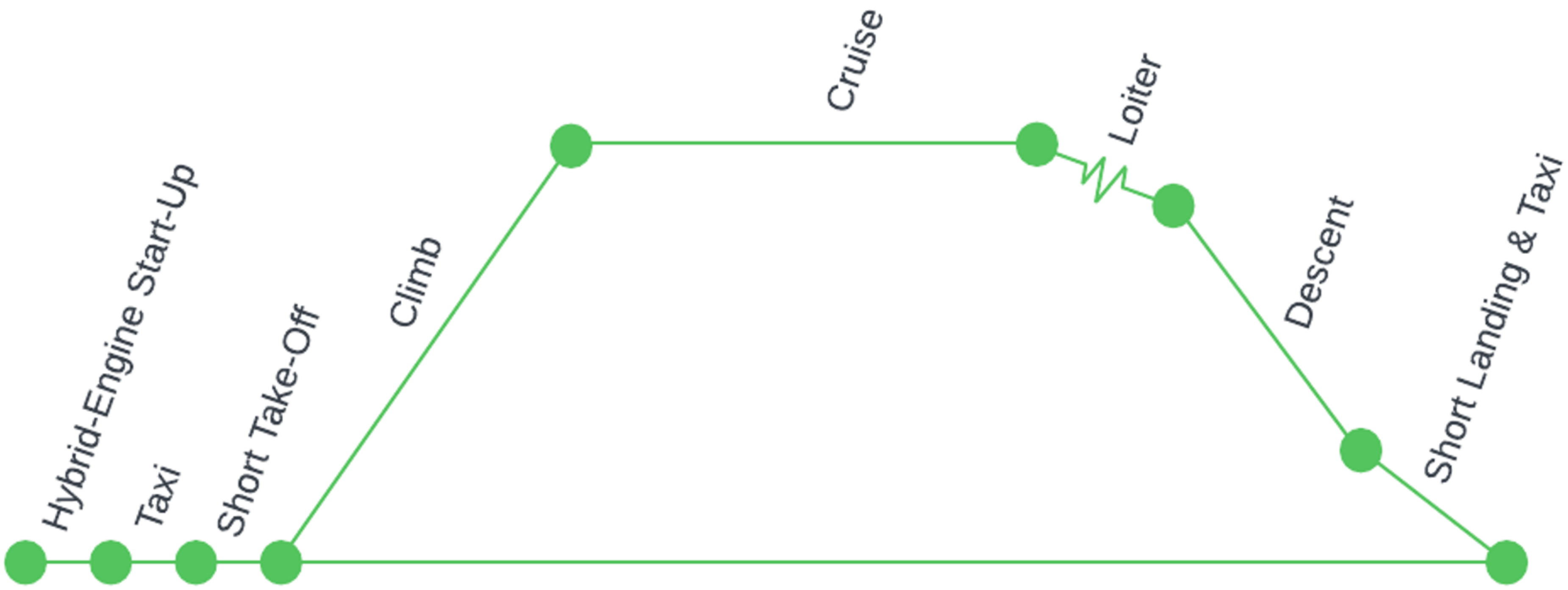


Figure 4: The VC-1 Design Mission Profile

MISSION REQUIREMENTS

REQUIREMENT	SOURCE	VALUE	STATUS
Number of Passengers + Crew	RFP	8 [*persons*]	✓
Range	RFP	275 [*nm*]	✓
Cruise Speed	RFP	150 [*KTAS*]	✓
Take-Off Ground Roll	RFP	500 [*ft*]	✓
Landing Ground Roll	RFP	500 [*ft*]	✓
Propulsion System	RFP	DEP, Hybrid	✓
Rate of Climb (ROC)	14 CFR	1,100 [*ft/s*]	✓
Service Ceiling	14 CFR	10,000 [*ft*]	✓
Cruise Altitude	VC	8,000 [*ft*]	✓

SIMILAR DEP AIRCRAFT

Basic Requirements	VC-1 "Amped"	Maxwell X-57	Electra Concept
Number of Passengers + Crew	8 [persons]	2 [persons]	9 [persons]
Range	438 [nm]	87 [nm]	1,100 [nm]
Cruise Speed	150 [KTAS]	150 [KTAS]	175 [KTAS]
Take-Off Ground Roll Distance	393 [ft]	1,600 [ft]	150 [ft]

Maxwell X-57

Figure 5: The X-57 (DEP configuration), sourced from nasa.gov

Electra Concept

Figure 6: The Electra concept, sourced from electra.aero

PRESENTATION CONTENTS

FISHBONE DIAGRAM

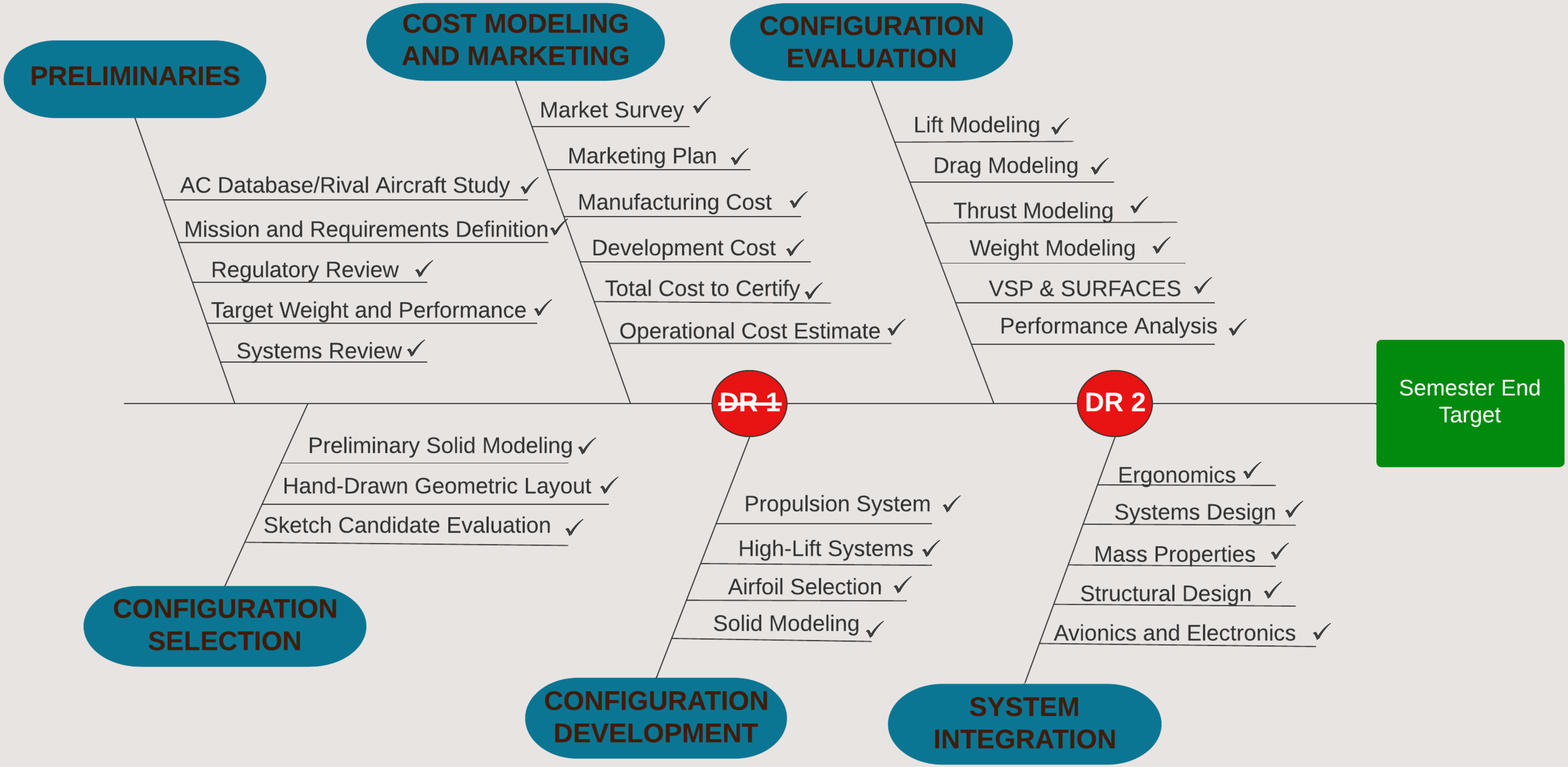


Figure 7: The Fishbone diagram, created using Lucid.

CONFIGURATION SELECTION

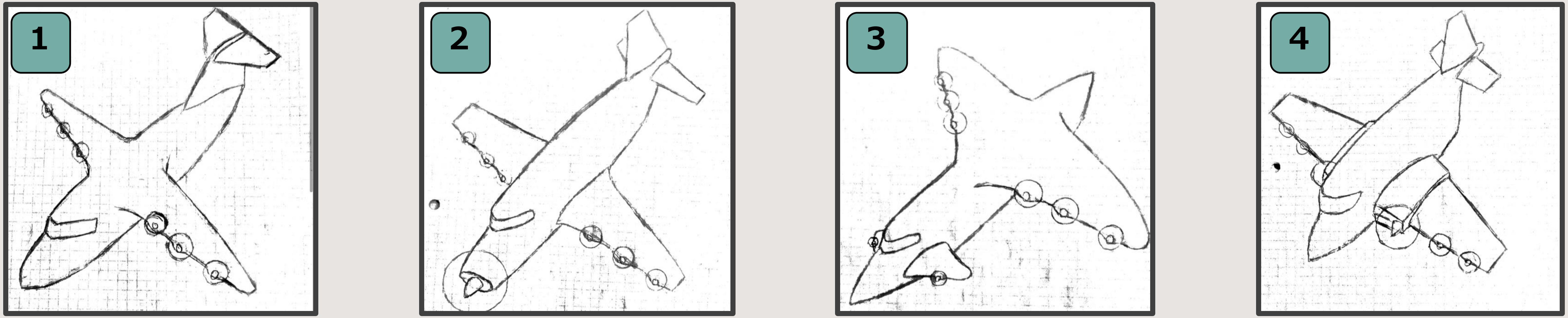


Figure 8: Initial configuration concepts.

MAIN CONSIDERATIONS:

- *Ground Roll Take-Off Distance*
- *Cost Estimation*
- *Payload Capacity*
- *Noise Minimization*

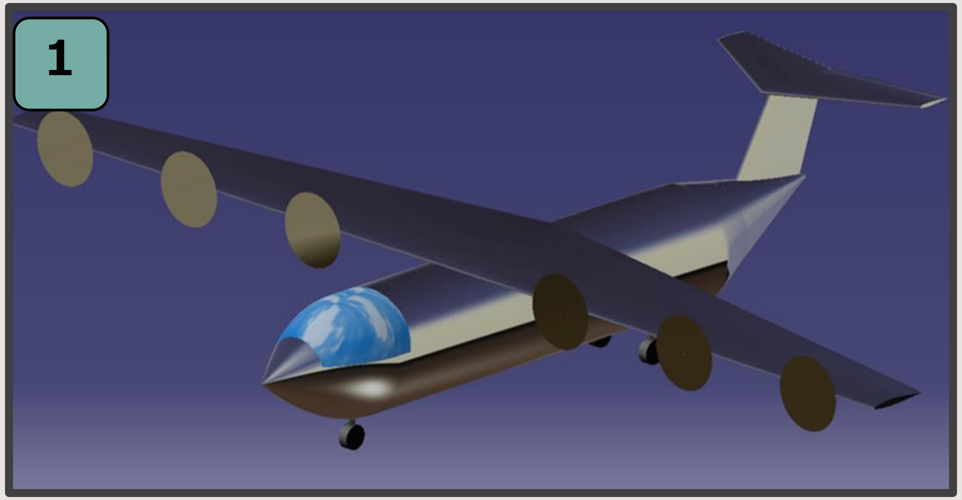


Figure 9: Preliminary solid model of selected configuration.

KEY CONFIGURATION CHANGES

Powerplant Selection

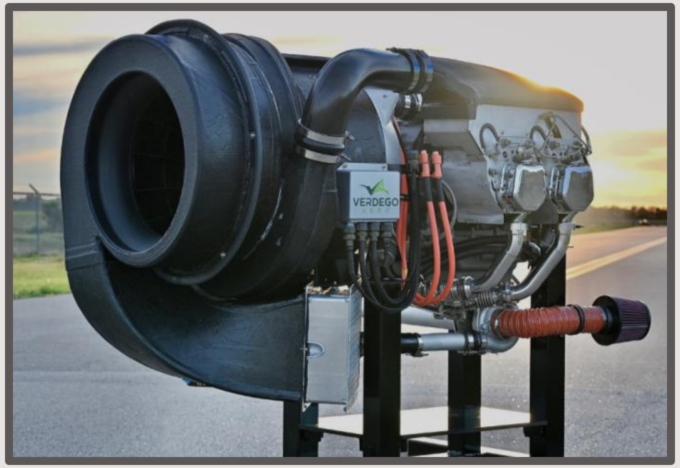


Figure 10: The VH-3 Engine, sourced from verdegoaero.com

Two VH-3's ⇒ One VH-4T

4920 [lbs] ⇒ 7200 [lbs]

Oct. 20th

Figure 11: The VH-4T Engine, sourced from verdegoaero.com

Distributed Electric Propulsion

6 Thrust Propellers ⇒ 2 Thrust Propellers + 8 High Lift Propellers

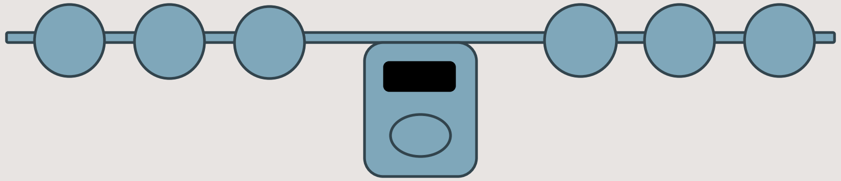


Figure 12: The initial DEP configuration.

Oct. 24th

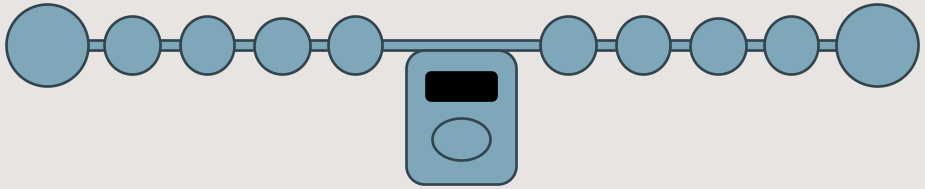


Figure 13: The final DEP configuration

PRESENTATION CONTENTS

CONSTRAINT ANALYSIS

Three Potential Design Points:

- *Wing loading 23 [lb/sf]*
    - *Prioritizes ground roll*
- *Wing loading 26 [lb/sf]*
    - *Closest to all constraints*
- *Wing loading 30 [lb/sf]*
    - *Prioritizes cruise*

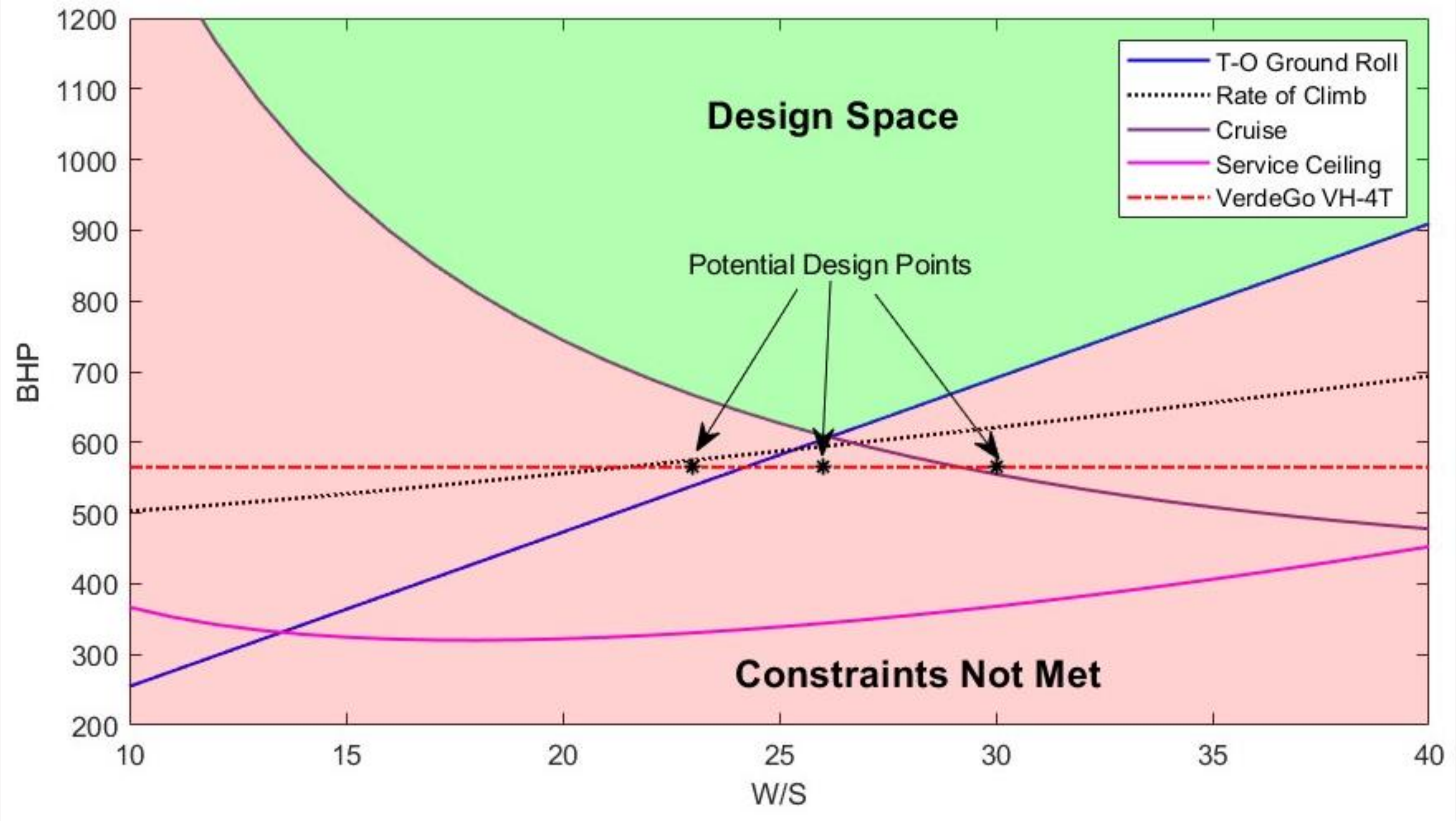


Figure 14: The VC-1's Constraint Analysis Map

CONSTRAINT ANALYSIS CONT.

Ground Roll Prioritized:

- *23 [lb/sf]*
- *Most important to regional air mobility mission*

VH-4T Max Power Output:

- *556 [hp]*
- *Battery usage avoided to reduce weight*

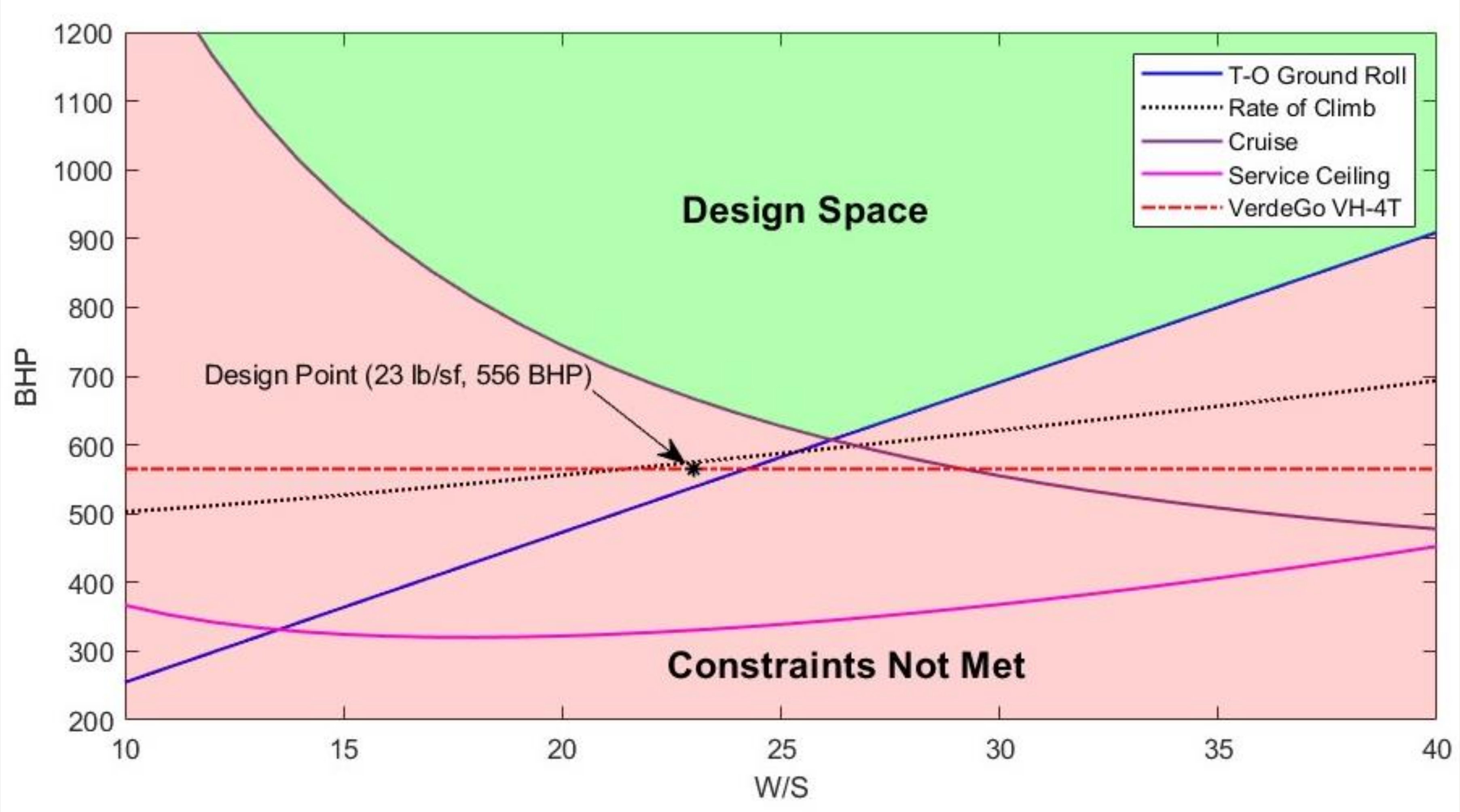


Figure 15: The VC-1's Constraint Analysis Map

PRESENTATION CONTENTS

CAD RENDERINGS

DR1

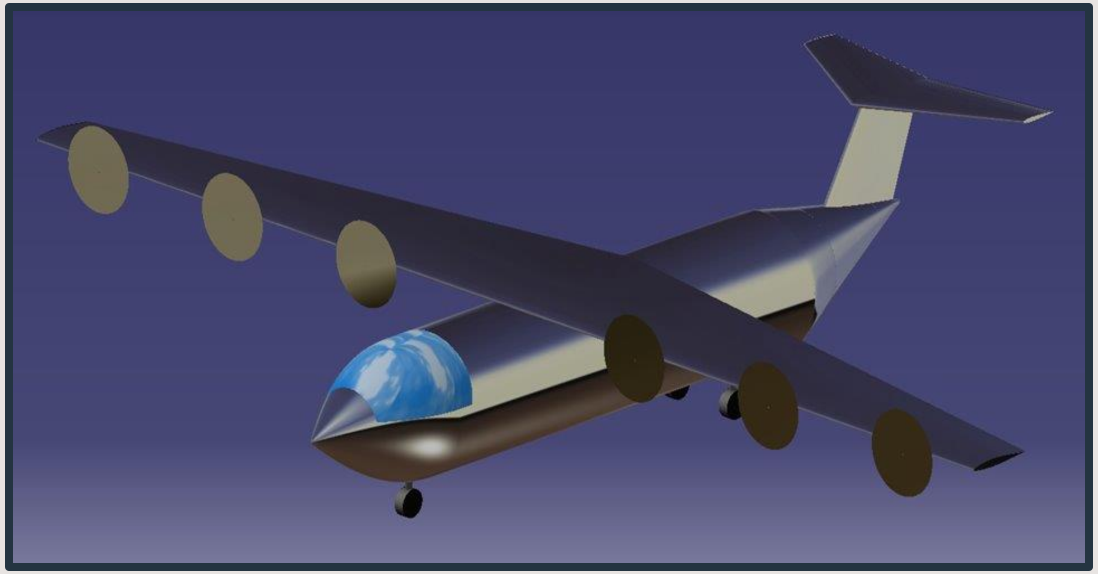


Figure 16: Preliminary CAD Model

DR2

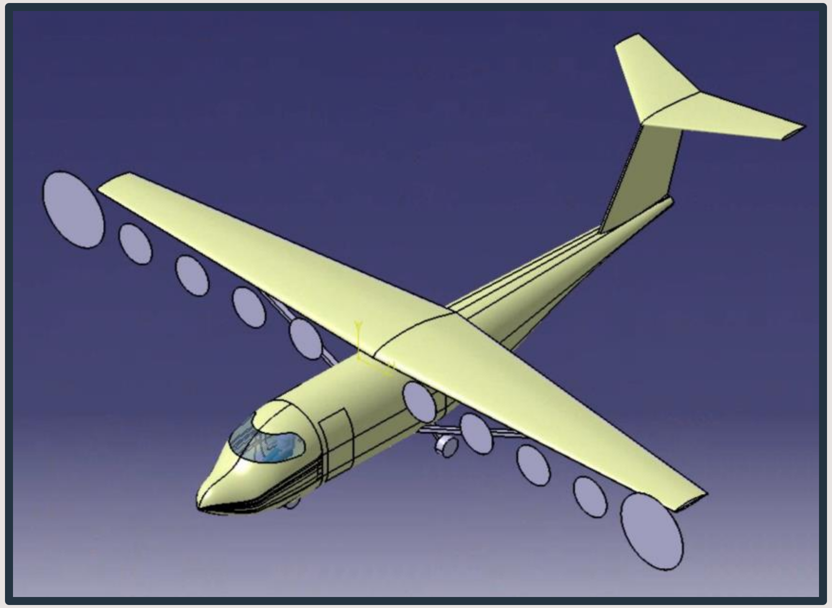
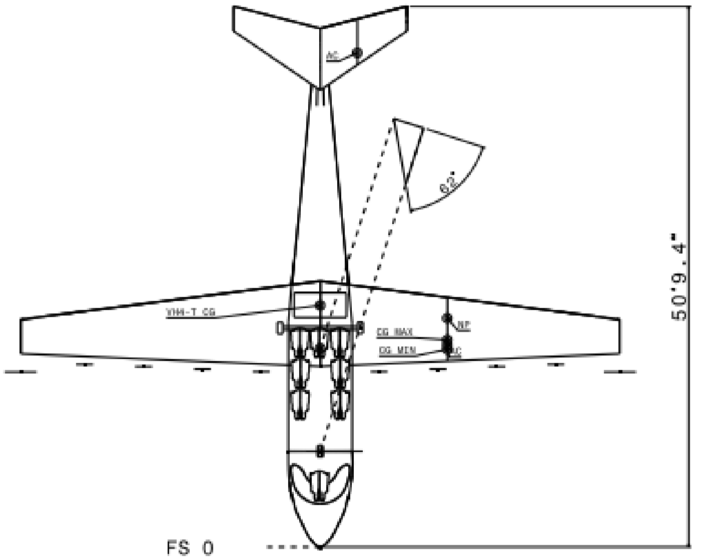
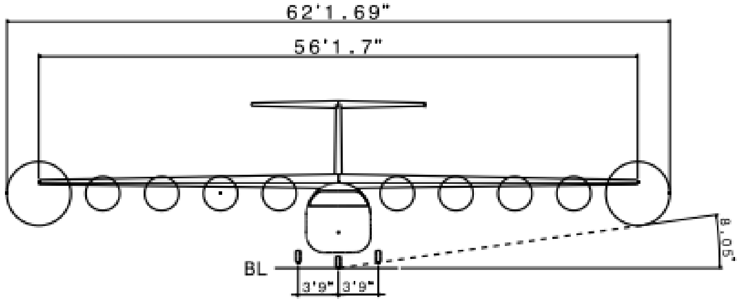


Figure 17: Current CAD Model

3-VIEW DRAWING



	Wing	HT	VT
SPAN (FT)	56.14	16.25	7.43
AREA (FT^2)	315.22	66.08	42.47
MGC (ft)	5.96	4.31	5.77
ASPECT RATIO	10	4	1.3
FS LE MGC	17.48	28.89	23.92
FS AC	18.97	29.97	25.36
BL MGC	12.03	3.48	3.5
ROOT AIRFOIL	NASA LS(1)-0417	NACA 0012	NACA 0014
TIP AIRFOIL	NASA LS(1)-0413	NACA 0012	NACA 0014
CL ALPHA	5.6148	3.6837	
CM ALPHA	-0.0634	-2.214	
CMCL	-0.0133	-0.601	



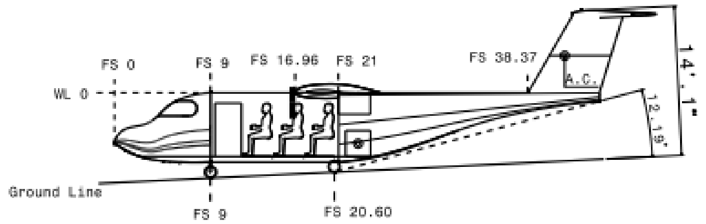


Figure 18: VC-1 3-View Drawing

FRONT VIEW KEY FEATURES

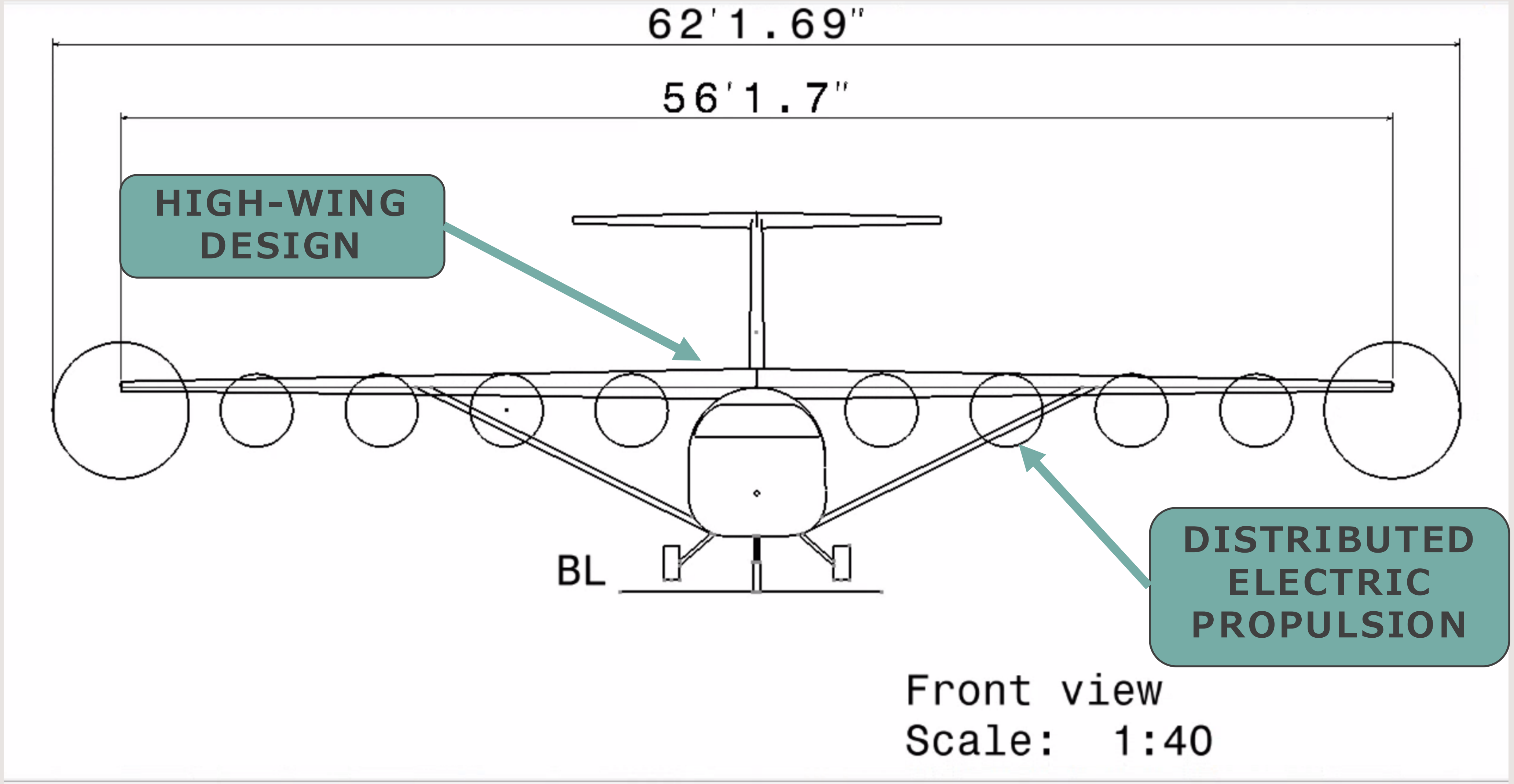


Figure 19: VC-1 Front View and Key Features

RIGHT VIEW KEY FEATURES

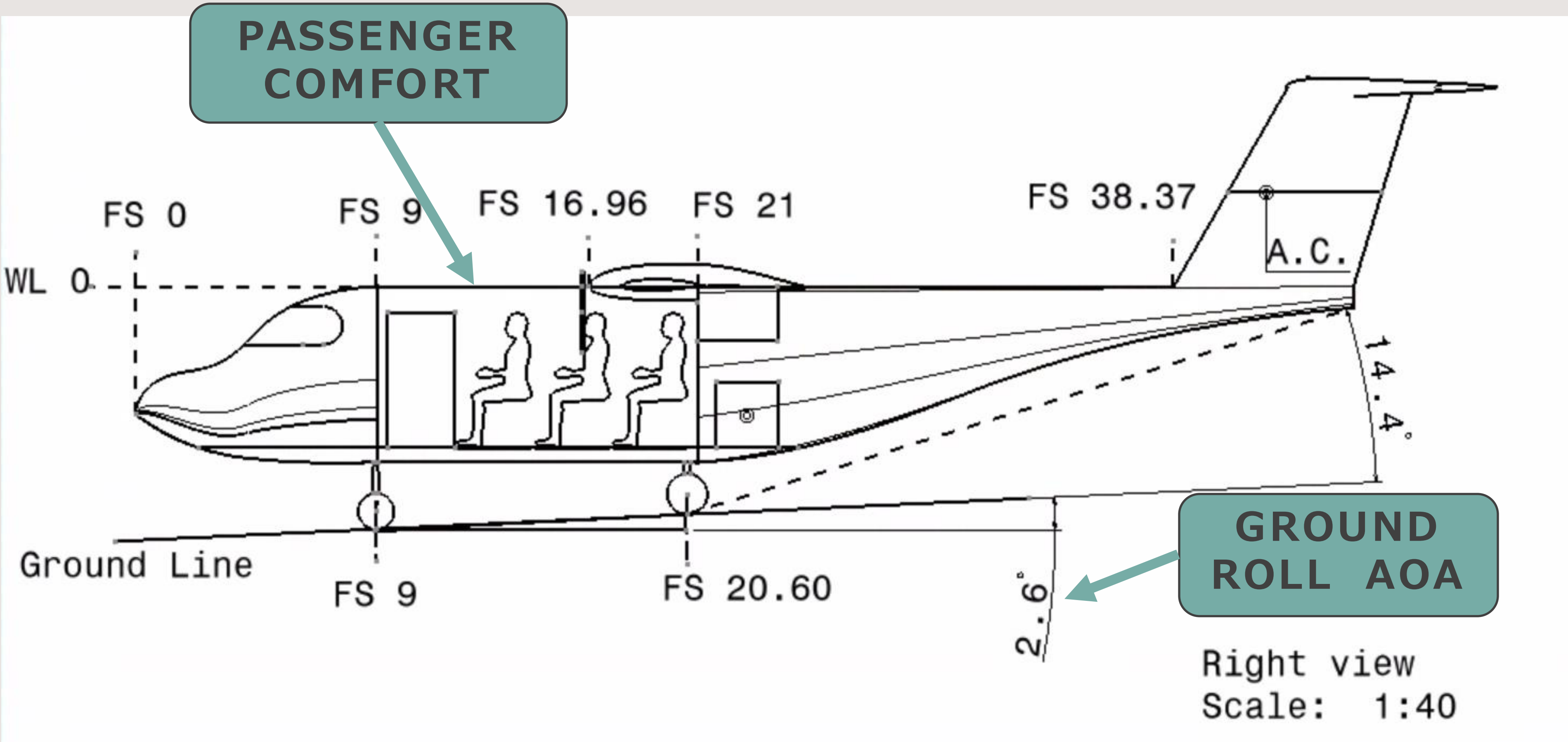


Figure 20: VC-1 Right View and Key Features

CROSS-SECTIONAL VIEW

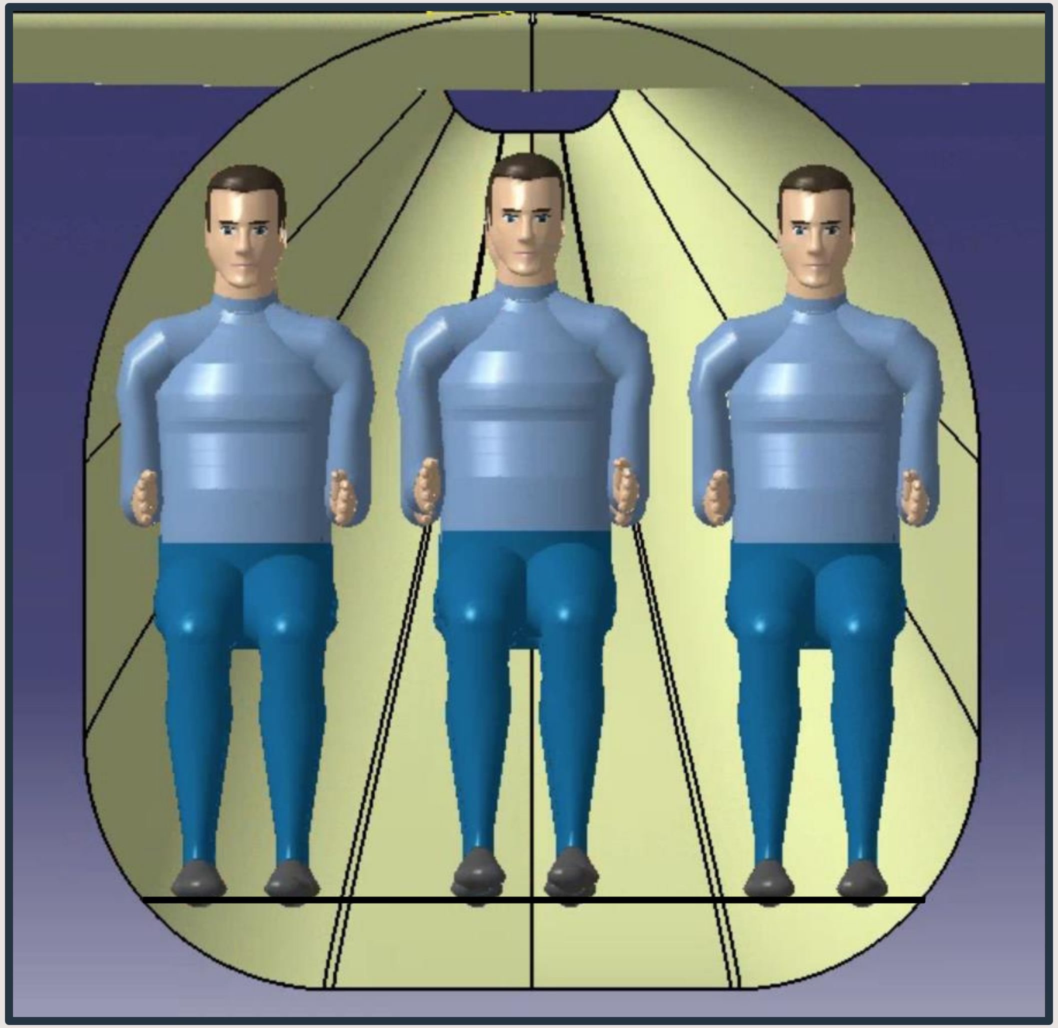


Figure 21: VC-1 Cross-Sectional View

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1. ~~AIRCRAFT AND STAKEHOLDER INTRODUCTION~~
2. ~~DESIGN MISSION AND REQUIREMENTS~~
3. ~~DEVELOPMENT SUMMARY~~
4. ~~CONSTRAINT ANALYSIS AND TRADE STUDIES~~
5. ~~CONFIGURATION SELECTION AND LAYOUT~~
6. **WEIGHT MODELING AND MASS PROPERTIES**
7. AERODYNAMICS AND SENSITIVITY ANALYSIS
8. PROPULSION AND THRUST GENERATION
9. PERFORMANCE
10. STABILITY & CONTROL
11. COST ANALYSIS
12. CONCLUSION
13. REFERENCES

WEIGHT COMPONENTS

KEY CHARACTERISTICS

- *Sized Batteries to Smooth Power from the Powerplant*
- *Weight ∝ Ground Roll*

GROUND ROLL TRADE STUDY	
5500 [*lbs*]	**268 [*ft*]**
6500 [*lbs*]	**352 [*ft*]**
7200 [*lbs*]	**393 [*ft*]**

AIRCRAFT COMPONENT	WEIGHT (*lbs*)
Structural	2311
Engine Installation + Cowling	809
Electric Propulsion Systems	441
Other Systems	811
Fuel	1000
Payload (*7 Passengers*) and Pilot	1800
Maximum Take-Off Weight	**7172**

MASS PROPERTIES

KEY CHARACTERISTICS

- *Seating will start from the rear, and progress forward*
- *Limits taken from S&C analysis, further constrained based on desirable conditions and similar aircraft*

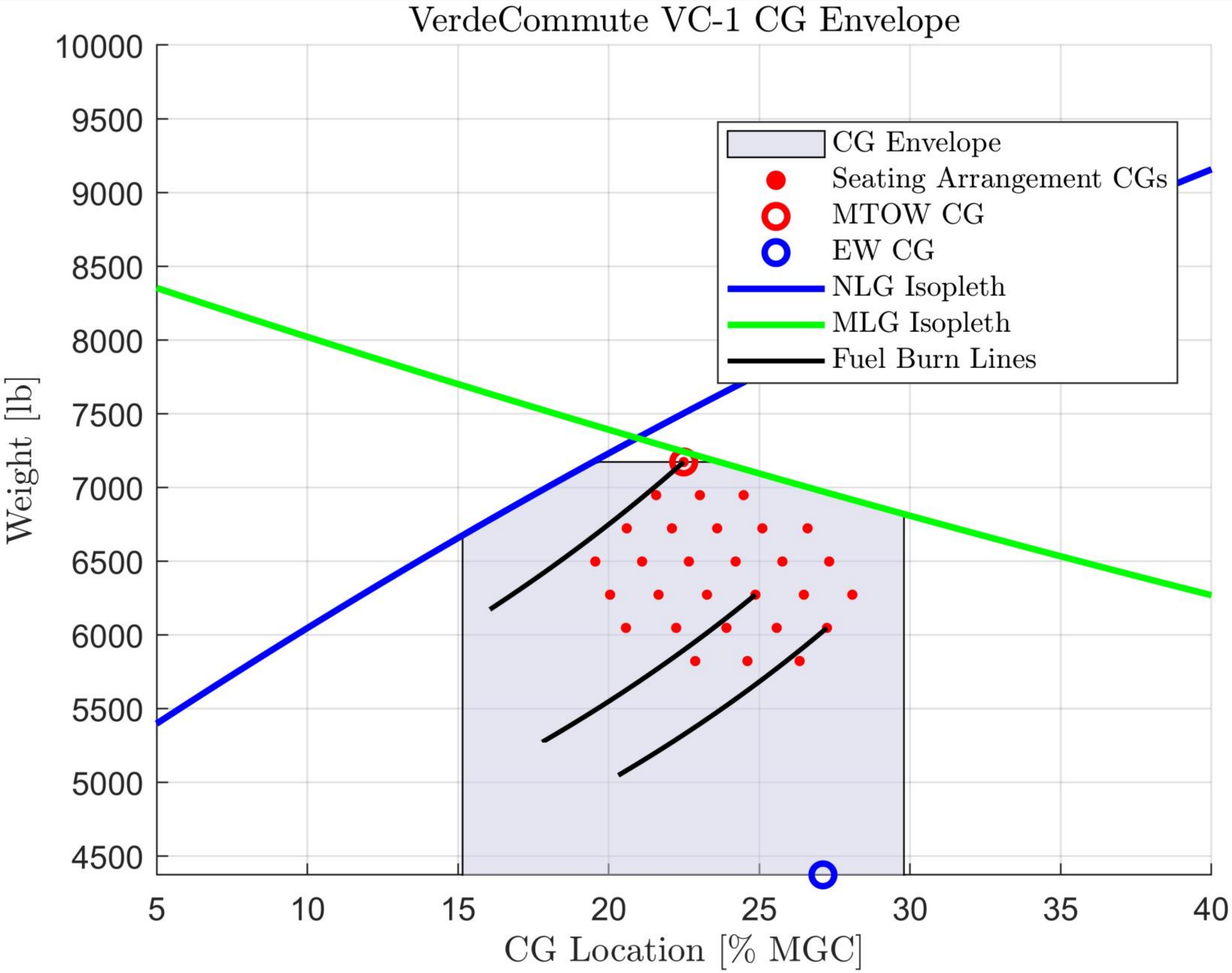


Figure 22: VC-1 CG Envelope Plot

PRESENTATION CONTENTS

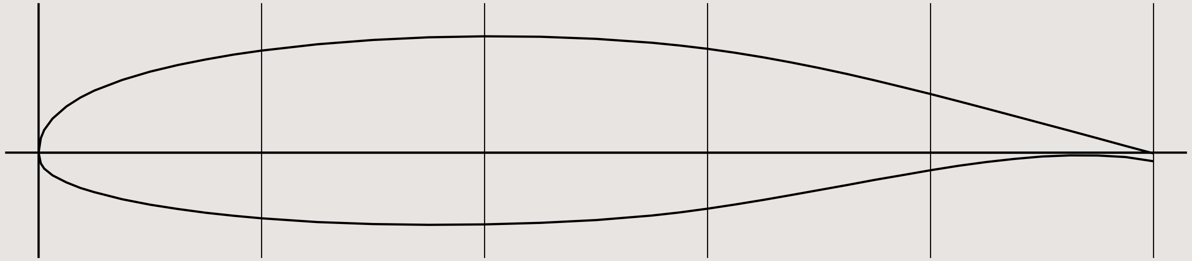
AIRFOIL SELECTION

DESIRED CHARACTERISTICS:

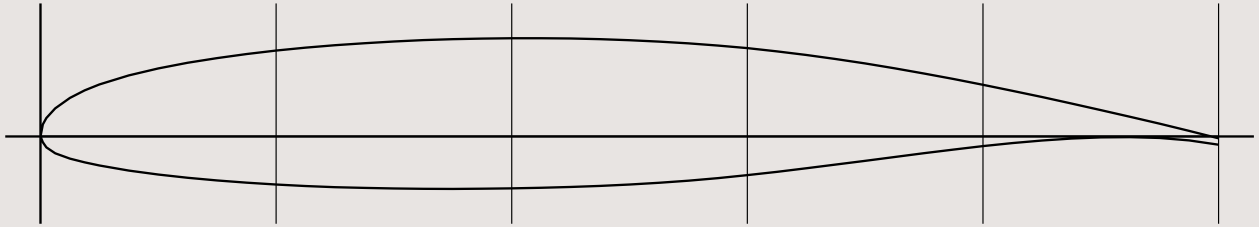
- *High L/D*
- *High $C_{L,MAX}$*
- *Drag Bucket around C_L of 0.4*
- *Benign Stall*
- *Natural Laminar Flow (NLF)*

Airfoil	Ideal C_L	Max L/D	NLF	$C_{L,MAX}$	Benign Stall	t/c
Clark Y	0.55	111	N	1.56	N	0.117
NACA 23112	0.2	98	N	1.55	N	0.12
NACA 4412	0.6	97	N	1.51	N	0.12
NACA 63-415	0.4	96	Y	1.26	Y	0.15
NASA LS(1)-0417	0.5	112	Y	1.75	Y	0.17
NASA LS(1)-0413	0.5	115	Y	1.75	Y	0.13

ROOT: NASA LS(1)-0417 (GA(W)-1)



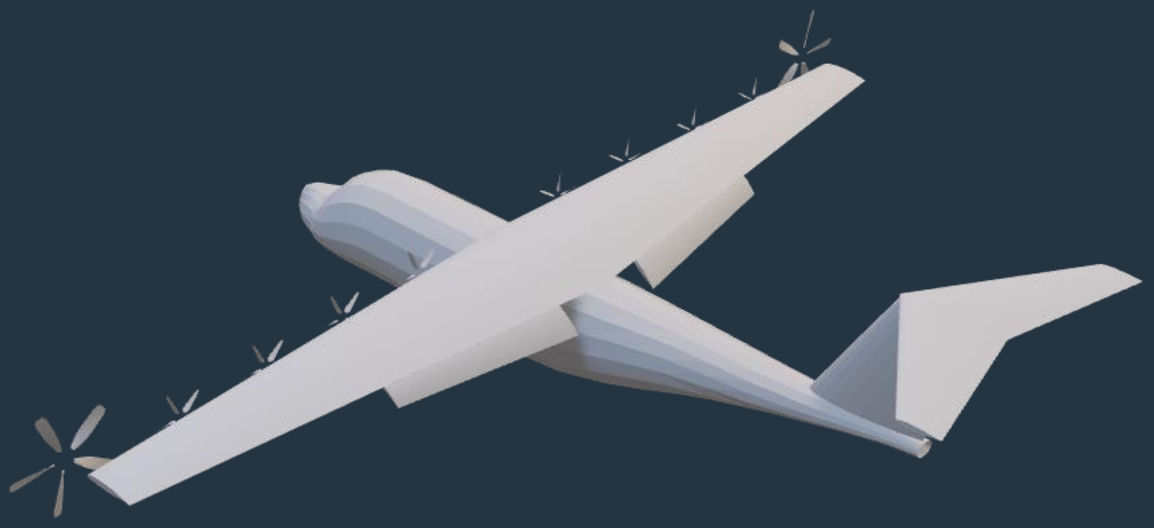
TIP: NASA LS(1)-0413



FLIGHT CONFIGURATIONS

Cruise

Figure 23: VC-1 Cruise Configuration



Take-off and Landing

Figure 24: VC-1 Cruise Configuration

FLIGHT CONFIGURATIONS

CRUISE

- *Propellers cause minimal lift augmentation*
- *Tail trimmed for no control deflection*
- *Cruise C_L in drag bucket*

TAKE-OFF & LANDING

- *Single slotted fowler flaps*
    - *40 degree deflection*
    - *Half exposed span*
- *HLPs increase lift by 25%*

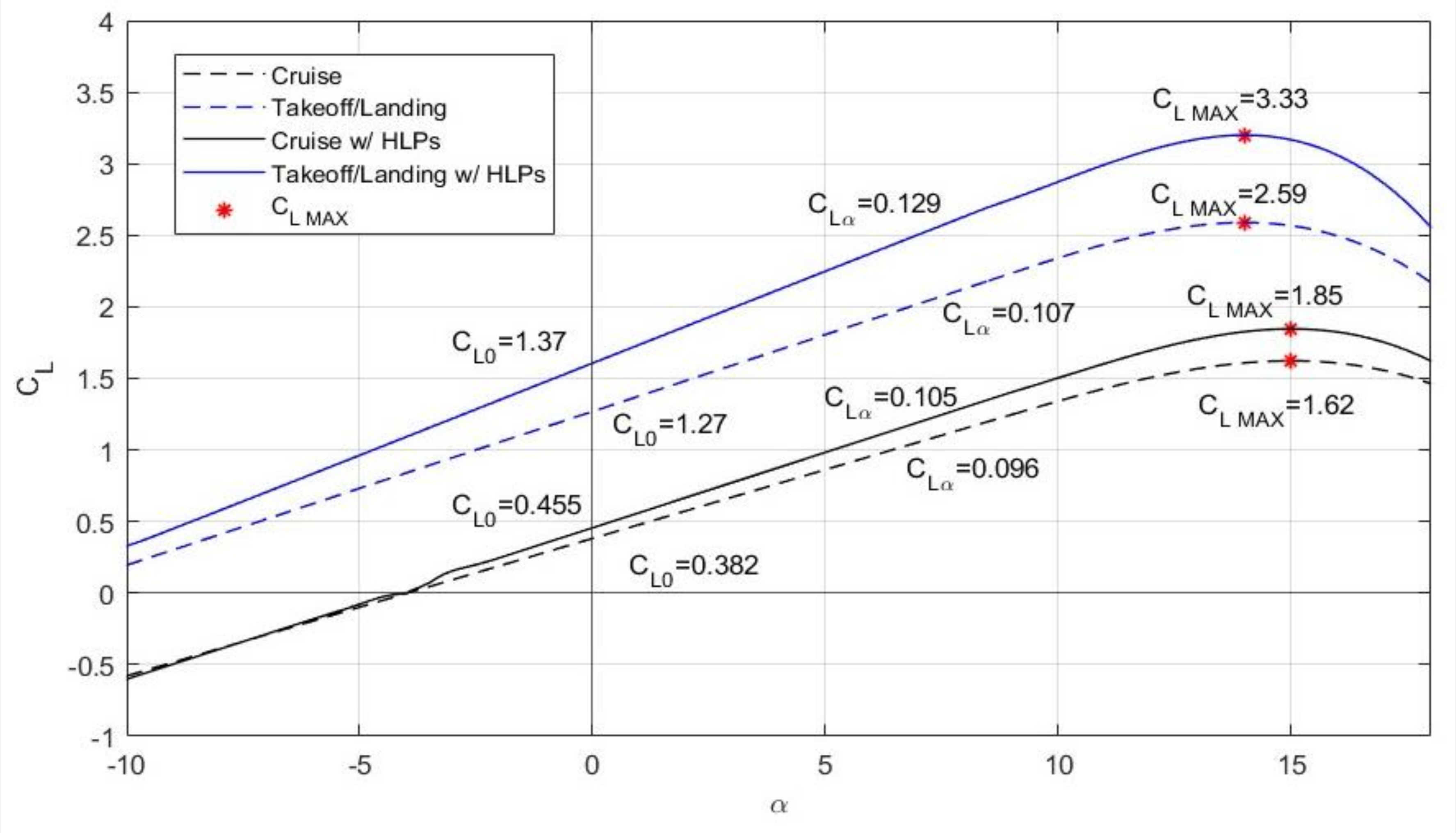


Figure 25: VC-1 Lift Modeling

DRAG CONFIGURATIONS

CRUISE

- *Trimming for stability results in minor drag*
- *High aspect ratio reduces induced drag for efficient cruise*

TAKE-OFF & LANDING

- *Fowler flaps and HLPs increase C_{D_i}*
- *Similar drag for both*

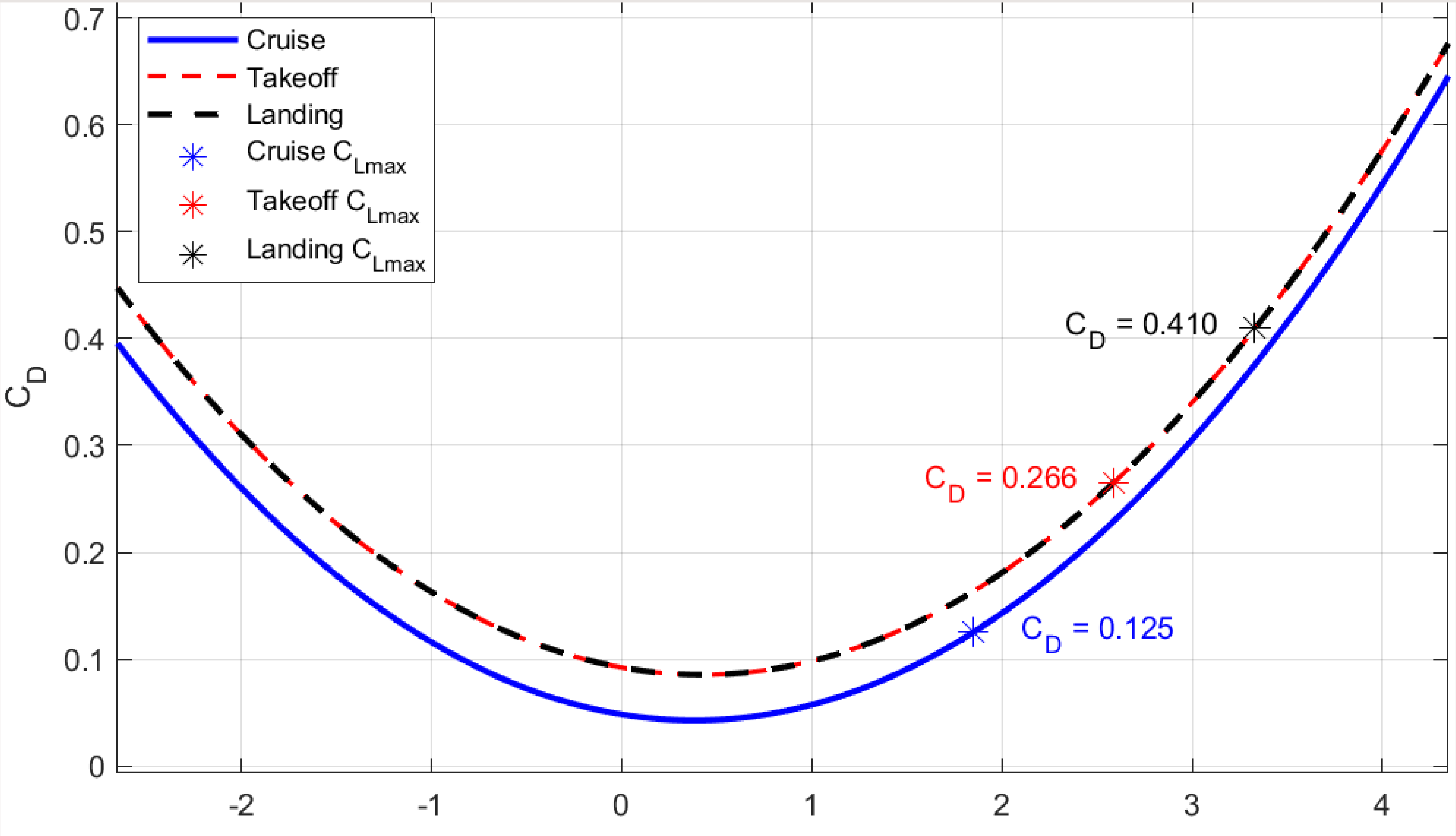


Figure 26: VC-1 Drag Modeling

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POWERPLANT SELECTION

TWO VH3-185 KW

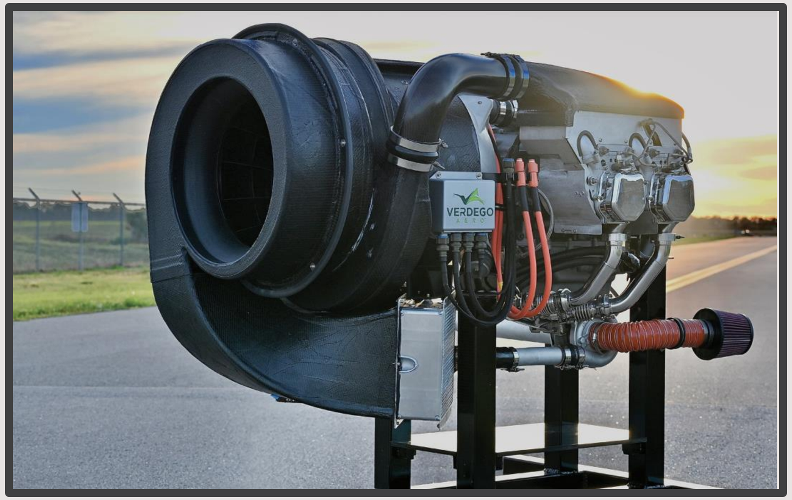


Figure 27: Sourced from VerdeGo Aero Website verdegoaero.com/

MTOW: 7930 [*lbs*]
Battery Weight: 450 [*lbs*]
Less Desirable

ONE VH4T-400 KW

Figure 28: Sourced from VerdeGo Aero Website verdegoaero.com/

MTOW: 6570 [*lbs*]
Battery Weight: 150 [*lbs*]
Maximum Efficiency

RESULTING THRUST MODEL

KEY CHARACTERISTICS

- *Maximizing Thrust at Take-off*
- *Stopped High Lift Propellers at 90 KTAS*
- *74% Power Usage at Cruise*

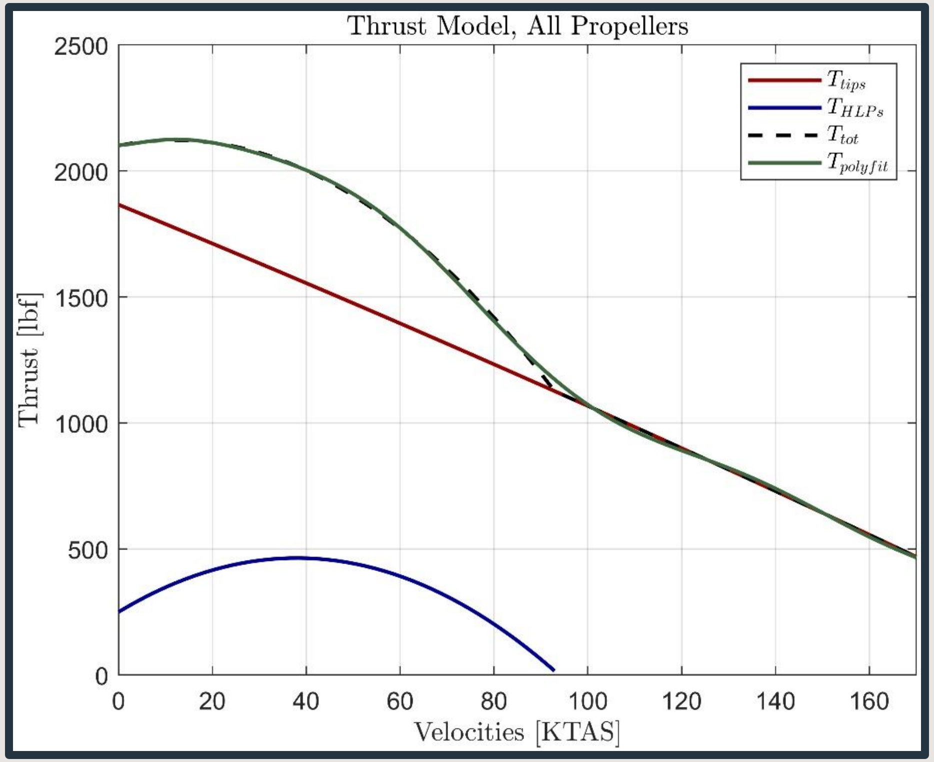


Figure 29: Thrust model across velocities, sea-level.

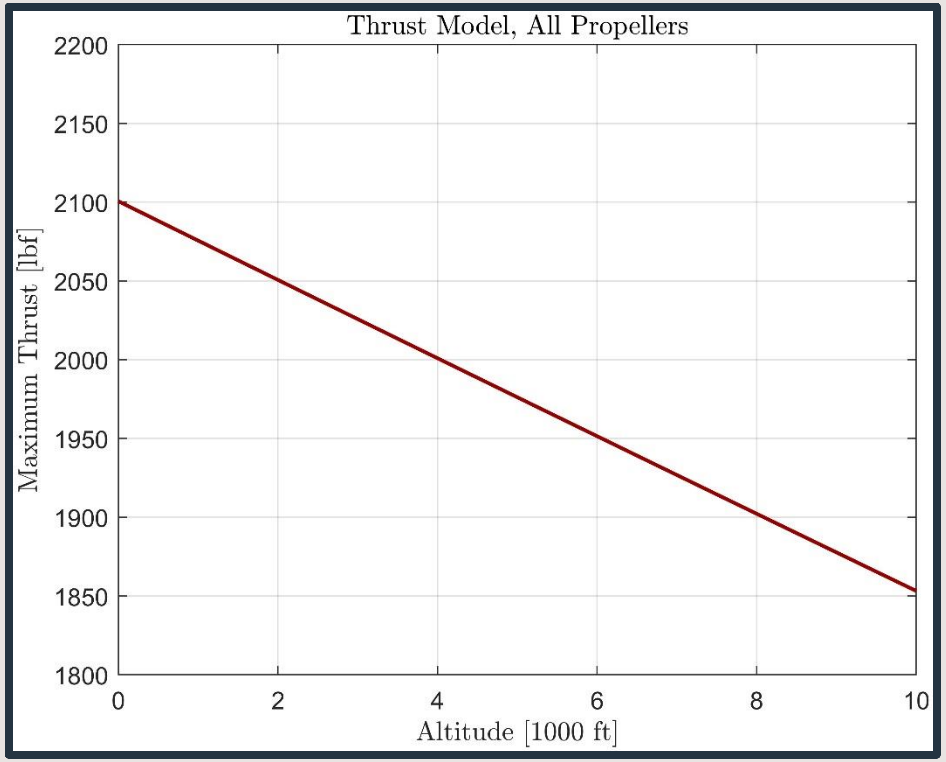


Figure 30: Maximum thrust across operating altitudes.

PRESENTATION CONTENTS

PERFORMANCE

KEY PERFORMANCE DATA

- *Maximum Range Target Cruise: 438 [nm]*

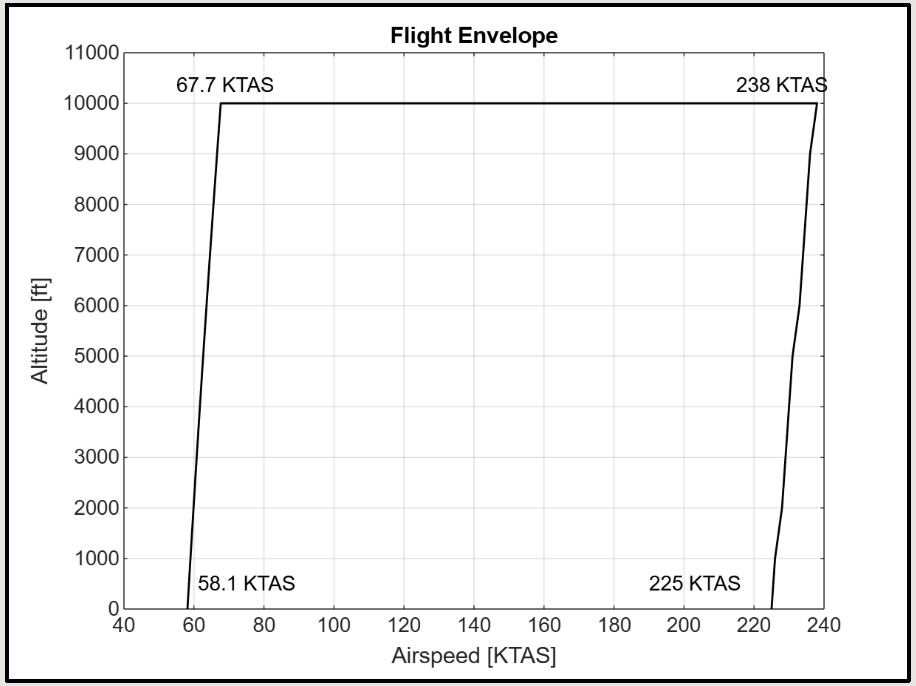


Figure 31: VC-1 Flight Envelope

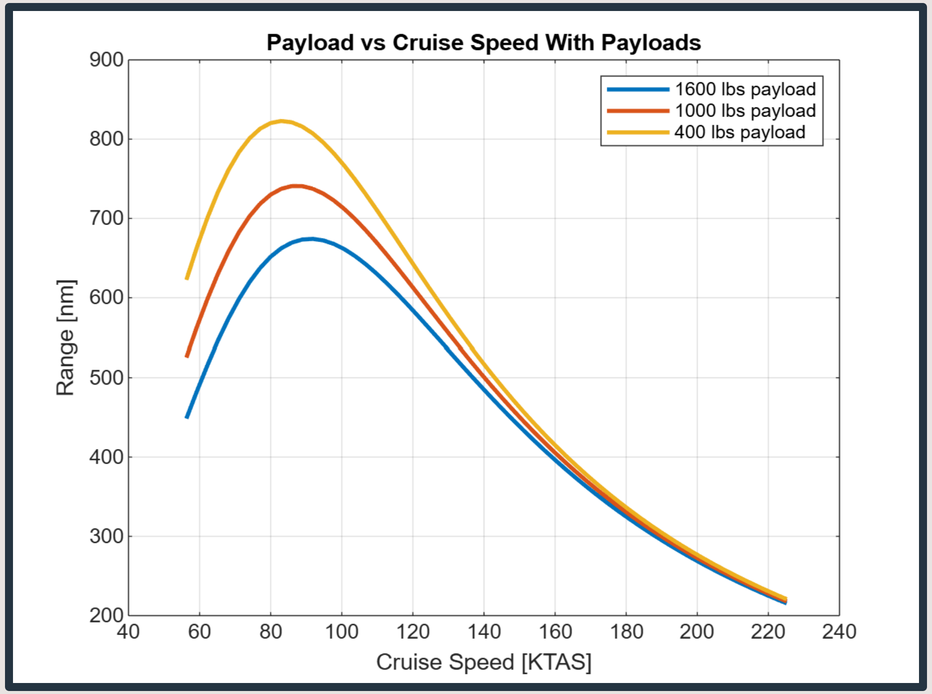


Figure 32: Range vs Airspeed for Payloads

PERFORMANCE CONT.

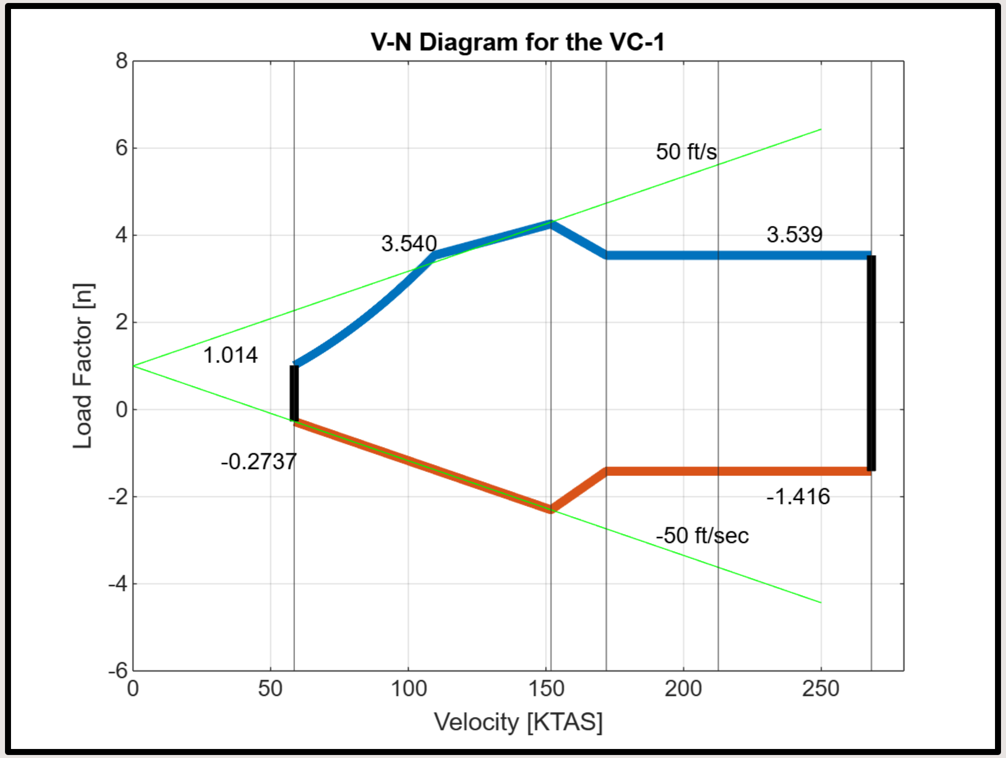


Figure 33: V-N diagram for the VC-1

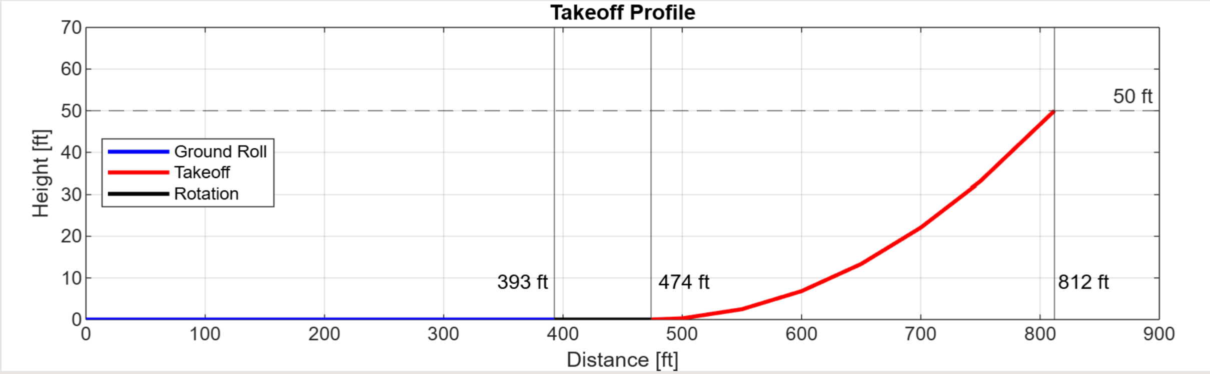


Figure 34: Takeoff profile of the VC-1

Take-off Performance Compared w/ Rivals

Aircraft	VC-1 "Amped"	Pilatus PC-6 STOL	Electra Concept
Ground Roll (ft)	393 [ft]	646 [ft]	150 [ft]

PRESENTATION CONTENTS

STATIC STABILITY

KEY CHARACTERISTICS:

- Tail and fuselage sizes increased since DR1
- Directional and lateral stability remain low
  - Fuselage increase opposes tail increase
  - Handles neutrally for a passenger aircraft
  - Active control systems improve handling, safety, and comfort
- Opportunities for improvement
  - Increase vertical tail size
  - Introduce dihedral

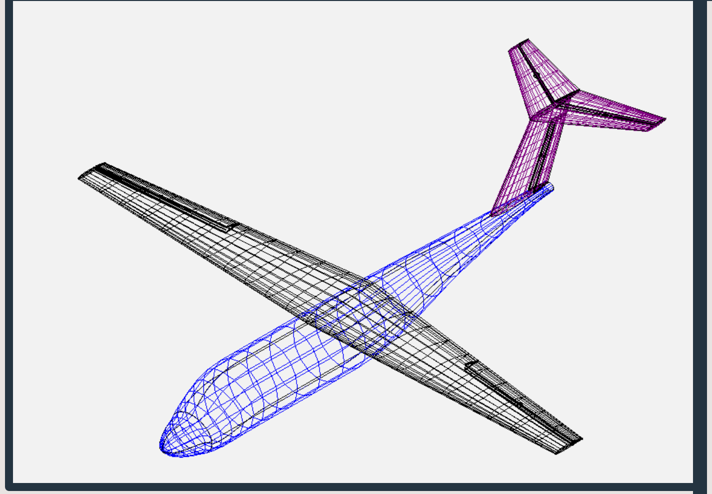
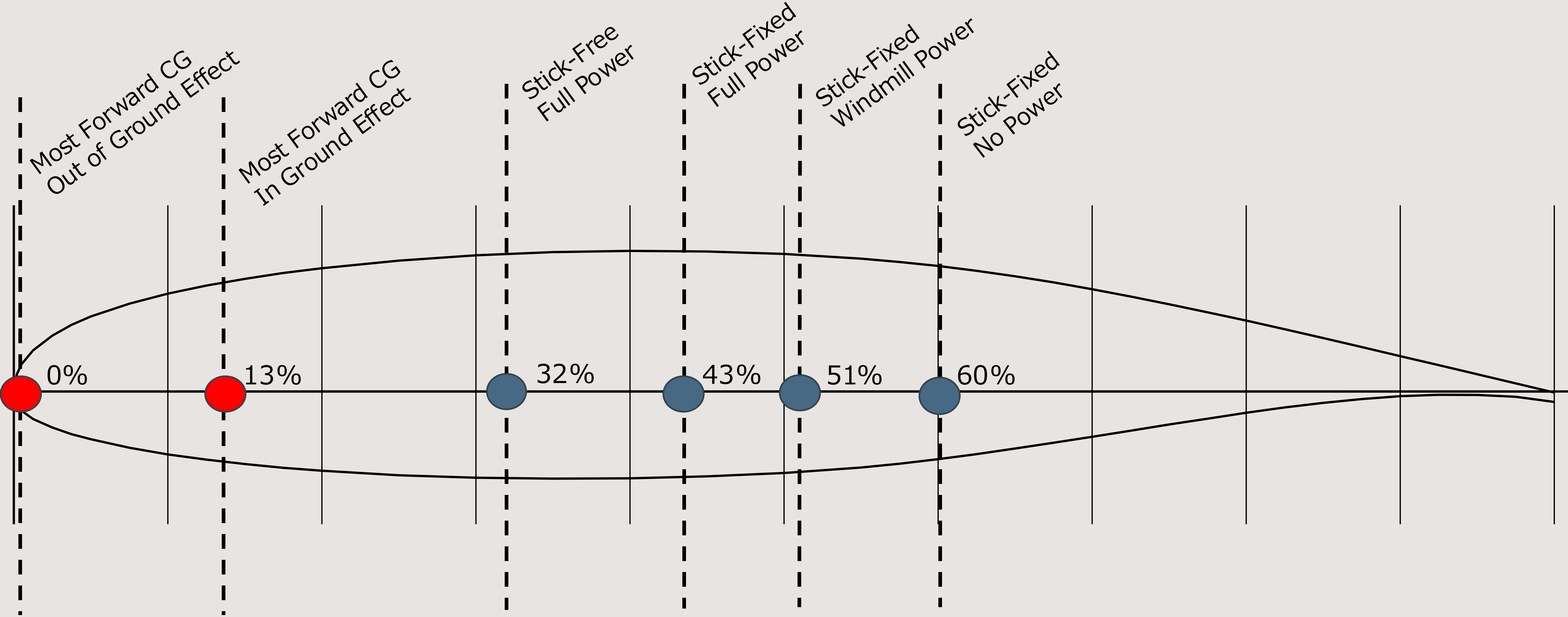


Figure 35: VC-1 OpenVSP Model

Method	$C_{M,\alpha}$	$C_{N,\beta}$	$C_{L,\beta}$
OpenVSP	-2.05	0.054	-0.058
Calculated	-1.44	0.025	-0.097
Status	Stable	Stable	Stable

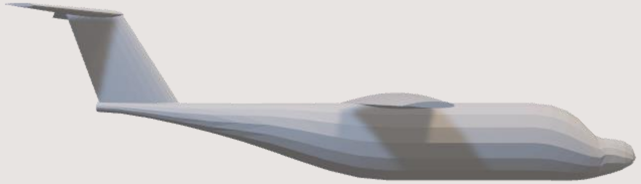
NEUTRAL POINTS AND FORWARD CG LOCATIONS



DYNAMIC STABILITY

PHUGOID MODE

- Lightly Damped
- Active control systems for passenger comfort
- Opportunities for improvement
  - Increase tail volume further



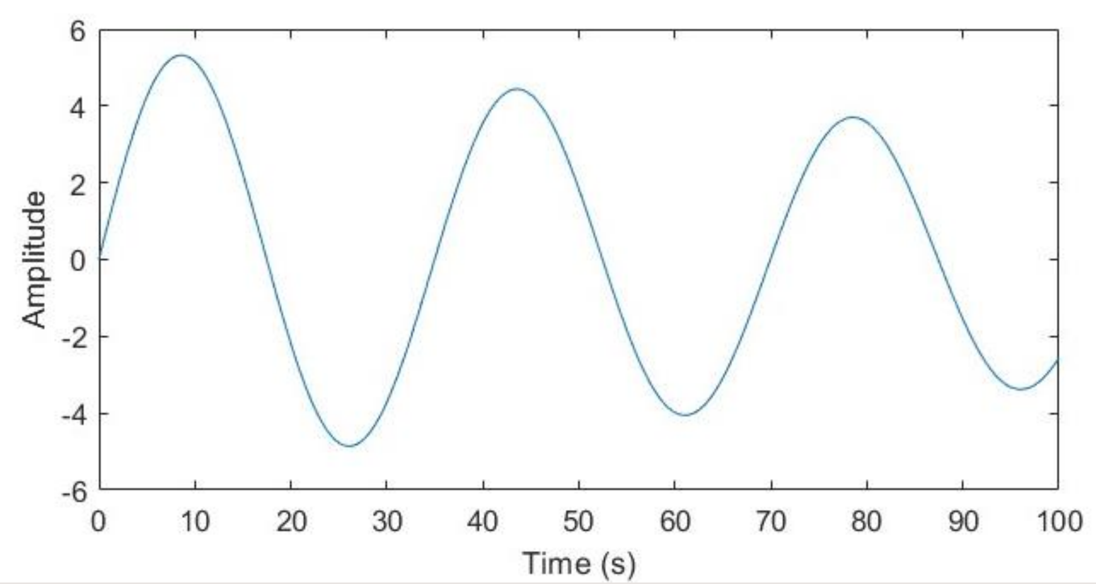
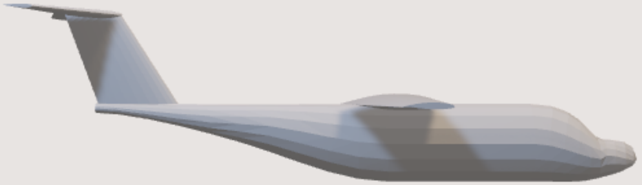


Figure 36: Phugoid Mode Plot

SHORT PERIOD

- Small oscillation damped out within 5 seconds
- Little affect on passenger comfort
- Further increases in tail volume would provide even more damping



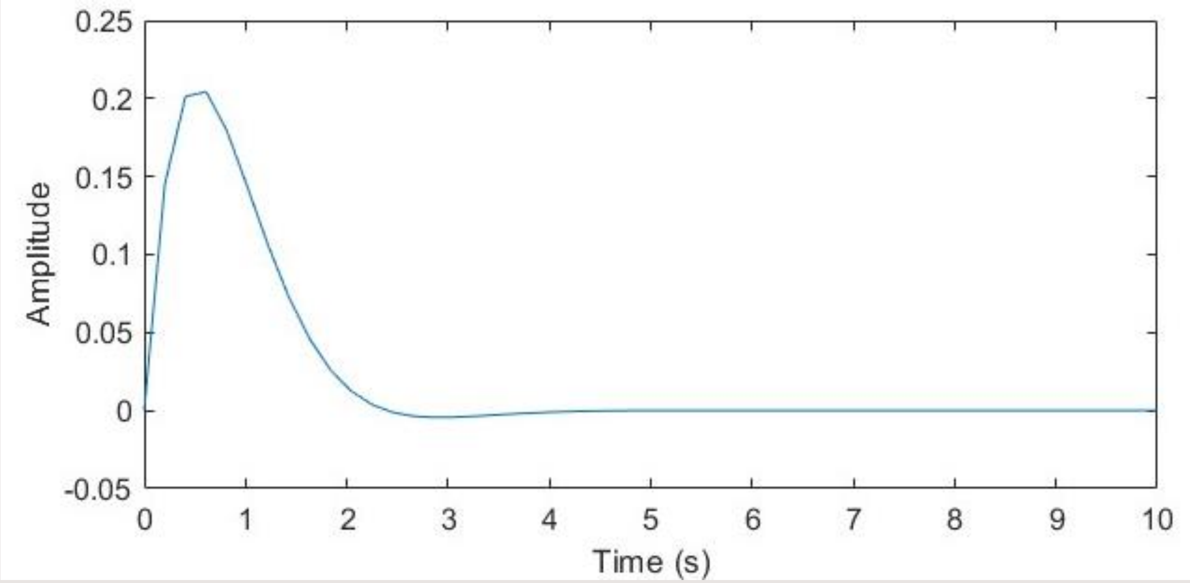


Figure 37: Short Period Plot

PRESENTATION CONTENTS

COST ANALYSIS

	Cost Estimates [$]
Total Development Cost	1,119,571,479
Variable Cost	2,155,900
Variable Cost with QDF	1,985,460
Yearly Operational Cost	2,803,560
Hourly Operational Cost	1121.42
Price	2,750,000

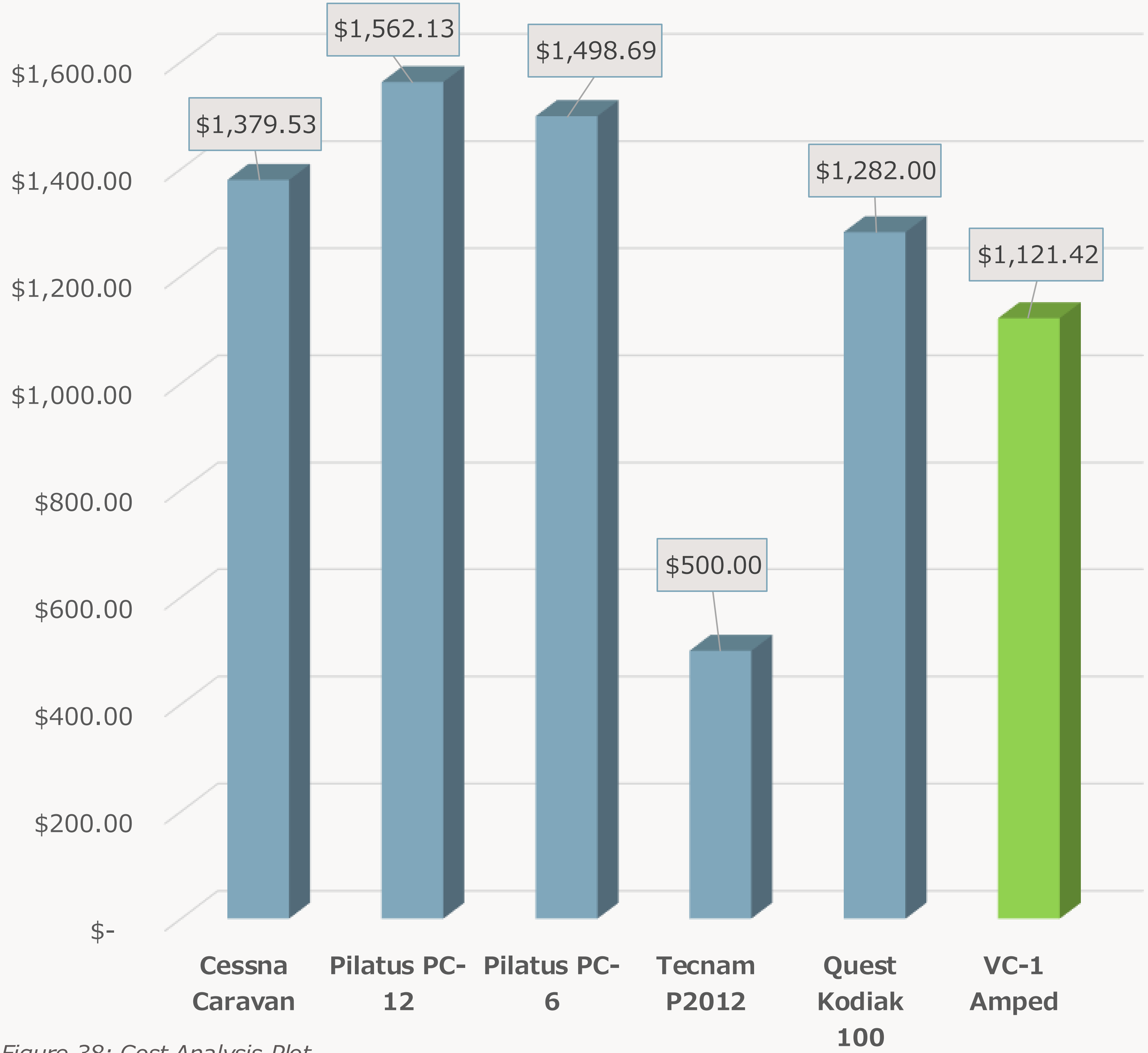


Figure 38: Cost Analysis Plot

PRESENTATION CONTENTS

CONCLUSION

The VC-1 is...

- Built for Regional Air Mobility
- Excelling in Take-Off Distance, Operating Cost, and Range
- Utilizing VerdeGo and NASA technologies
- Ready for detailed design
- **QUESTIONS?**

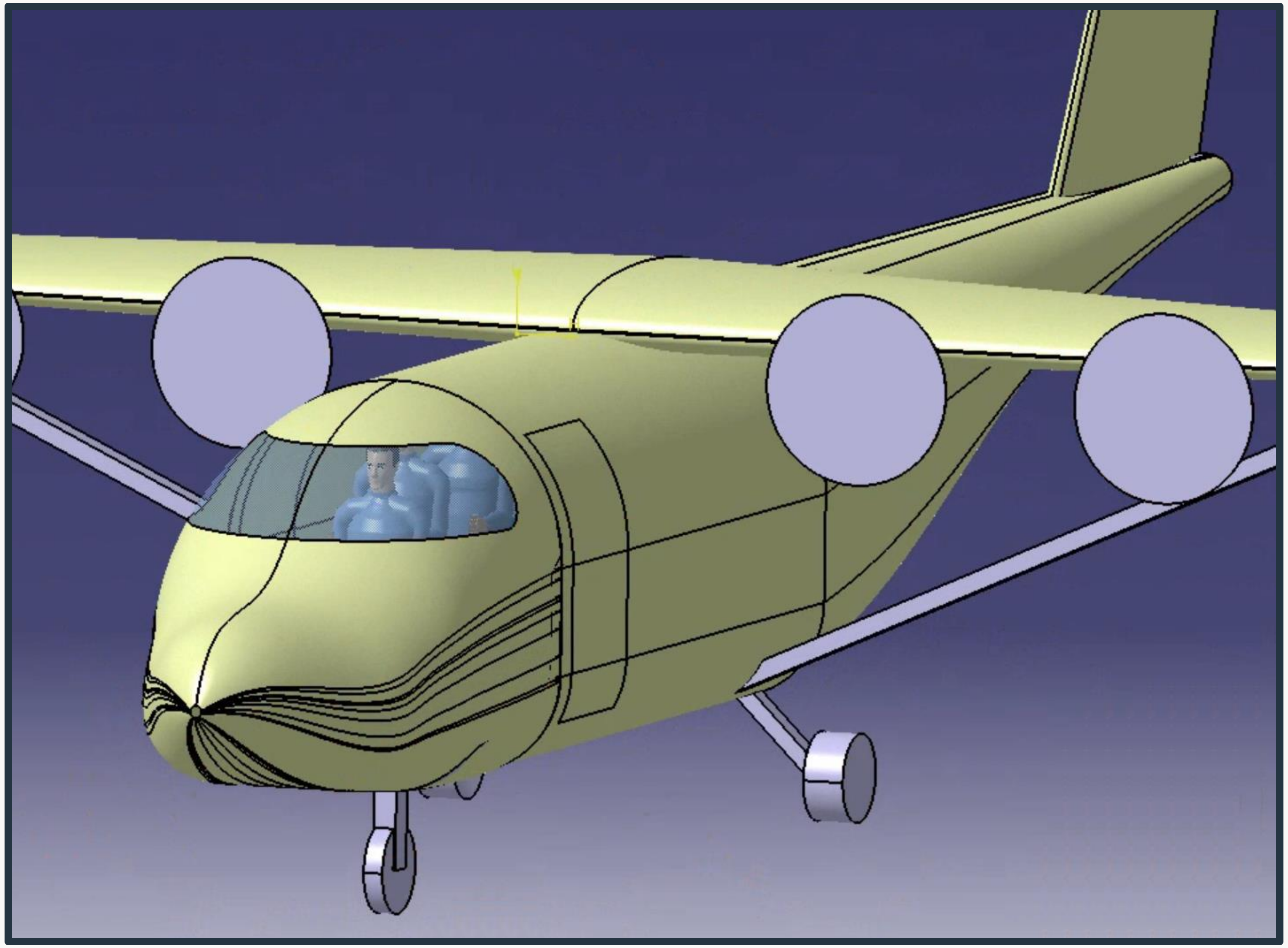


Figure 39: VC-1 CAD Model, with Pilot and Passengers

PRESENTATION CONTENTS

REFERENCES SLIDE

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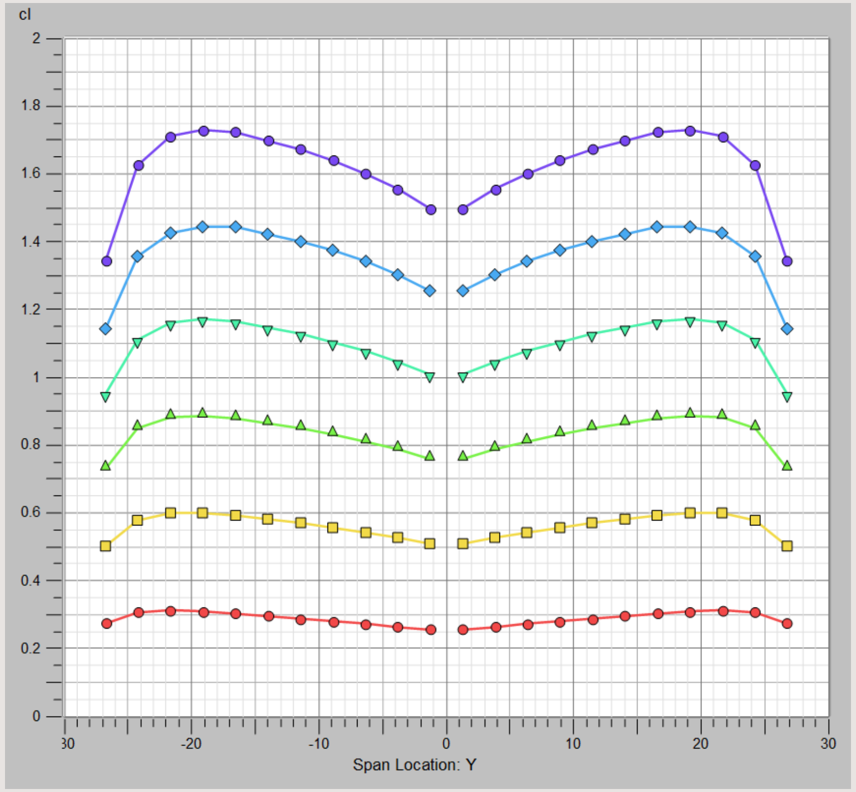
[7] M. D. Patterson, *Conceptual Design of High-Lift Propeller Systems for Small Electric Aircraft*, Ph.D. dissertation, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, 2016.

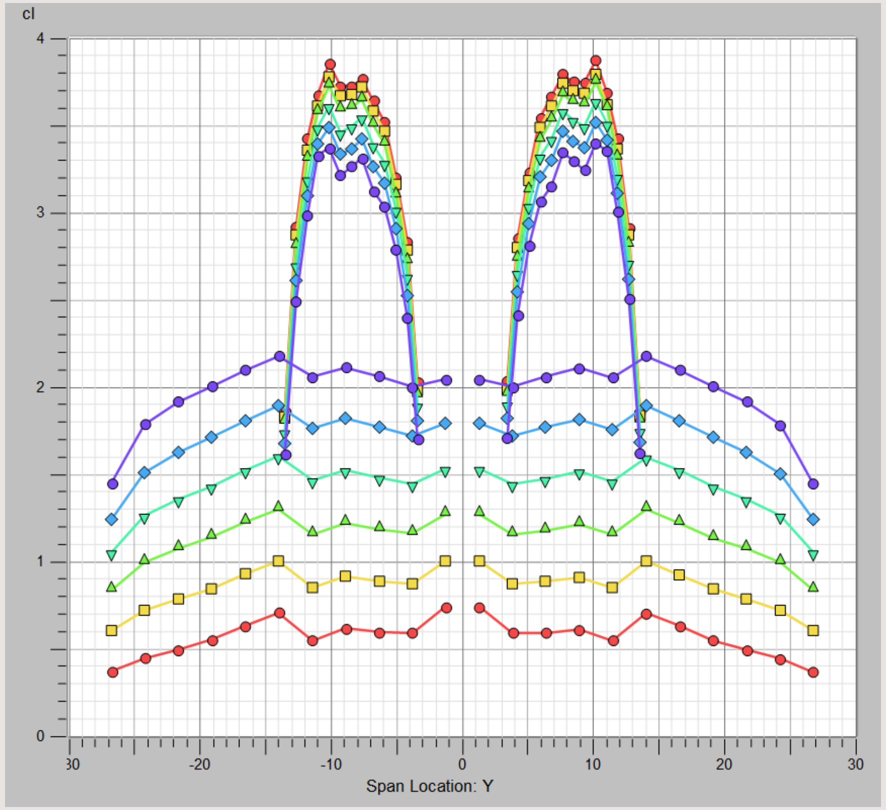
[8] M. D. Patterson, N. K. Borer, and B. J. German, "A Simple Method for High-Lift Propeller Conceptual Design," in *54th AIAA Aerospace Sciences Meeting*, San Diego, CA, USA, Jan. 4-8, 2016. [Online]. Available: https://doi.org/10.2514/6.2016-0770.

[9] R. Anderson, R. Roiati, T. Rice, and B. Steinfeldt, "Performance Study of a VH-3 Hybrid-Electric eCRM-002 Aircraft Comparing Reserve Energy and Range to Fully Electric and Conventional Propulsion Alternatives," in *VFS 6th Decennial Aeromechanics Specialists’ Conference*, Santa Clara, CA, USA, Feb. 6-8, 2024.

LIFT DISTRIBUTION AND STALL

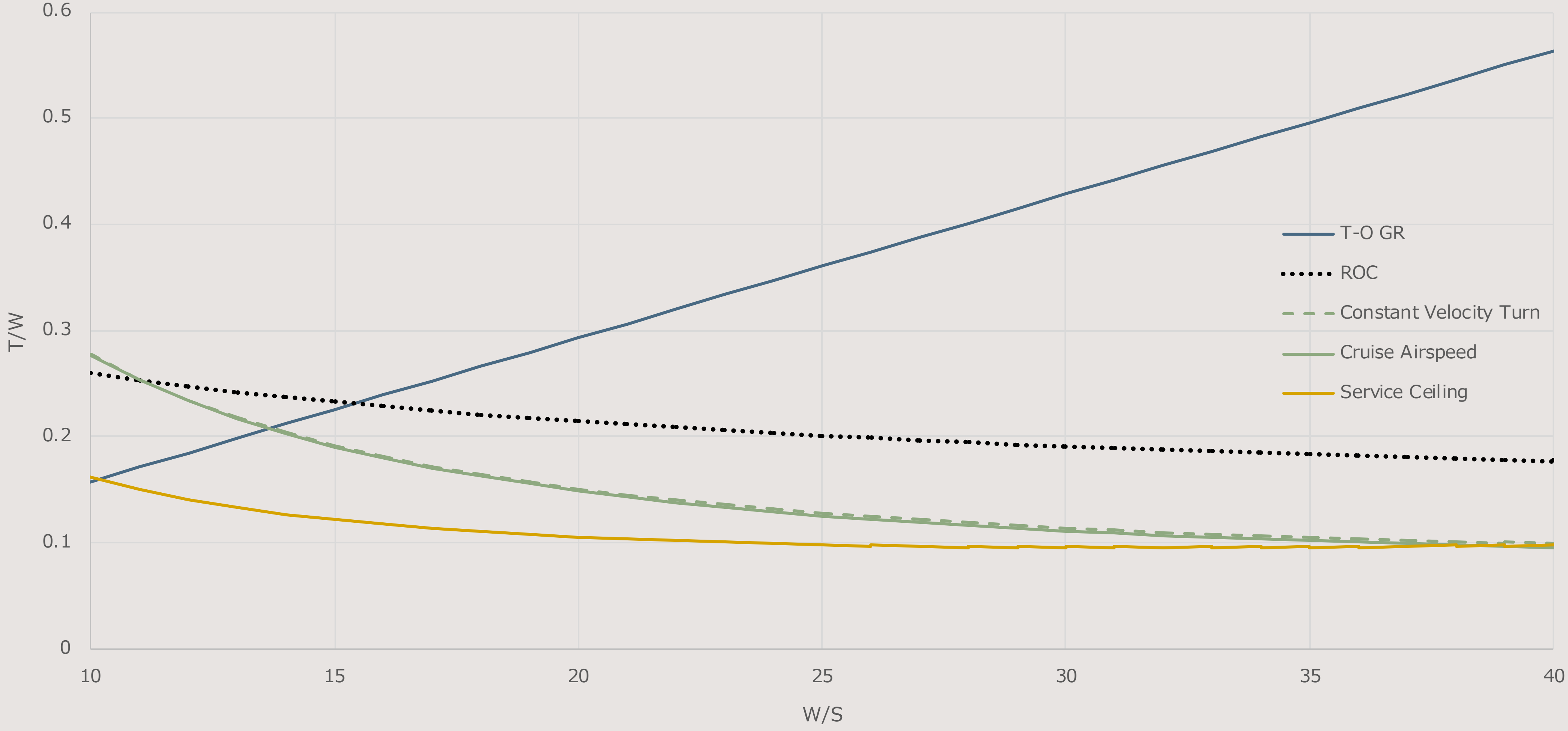


Cruise



Flaps Down

T/W CONSTRAINT GRAPH



STABILITY DERIVATIVES

- VC-1 remains statically stable across flight conditions
- Pitch is lightly damped
- Roll is well damped
- Yaw is aptly damped

Takeoff Roll	Derivatives	Stable
Pitch	-0.173	Stable
Roll	-0.076	Stable
Yaw	0.177	Stable

Damping	Derivatives
Pitch Damping	-32
Roll Damping	-0.80
Yaw Damping	-0.122

Max AoA	Derivatives	Stable
Pitch	-5.95	Stable
Roll	-0.171	Stable
Yaw	0.213	Stable

CONTROL SURFACES

Elevator:

- 50% chord
- Full span of HT
- Authority to reach CLMAX in takeoff configuration at takeoff speed
- Most forward CG at 13% MGC

Ailerons:

- Half exposed span
- 25% chord
- 9 degree deflection
- Roll helix of 0.088 radians
- High roll performance for authority at low speed

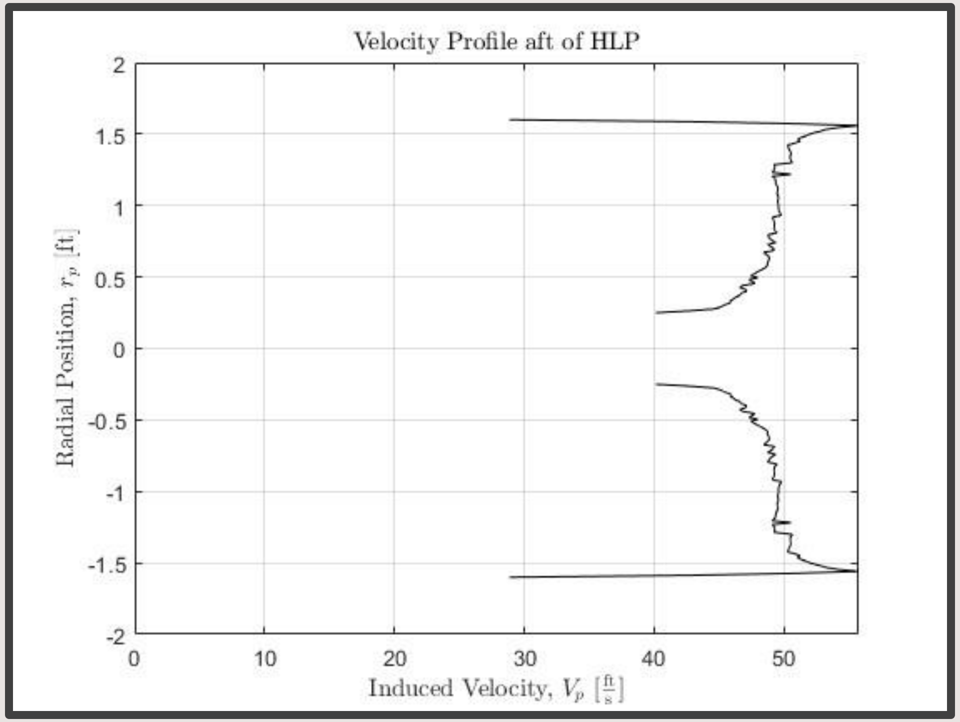
Rudder:

- Nearly full span of VT
- 50% chord
- Worst power case
  - Half total takeoff thrust on one tip propeller
  - Rudder cancels moment at 30 KTAS

HIGH LIFT PROPELLER DESIGN

Why HLP's?

- Minimize Excess Thrust
- Induce a Constant Velocity Profile
- Maximize Lift Augmentation



Designed Using BEMT:

$$dT = 4\pi r \rho V_\infty^2 (1+a) a dr$$

$$dT = Bc\frac{1}{2}\rho W^2 (c_l \cos(\phi) - c_d \sin(\phi)) dr$$