24 Hour Buzz

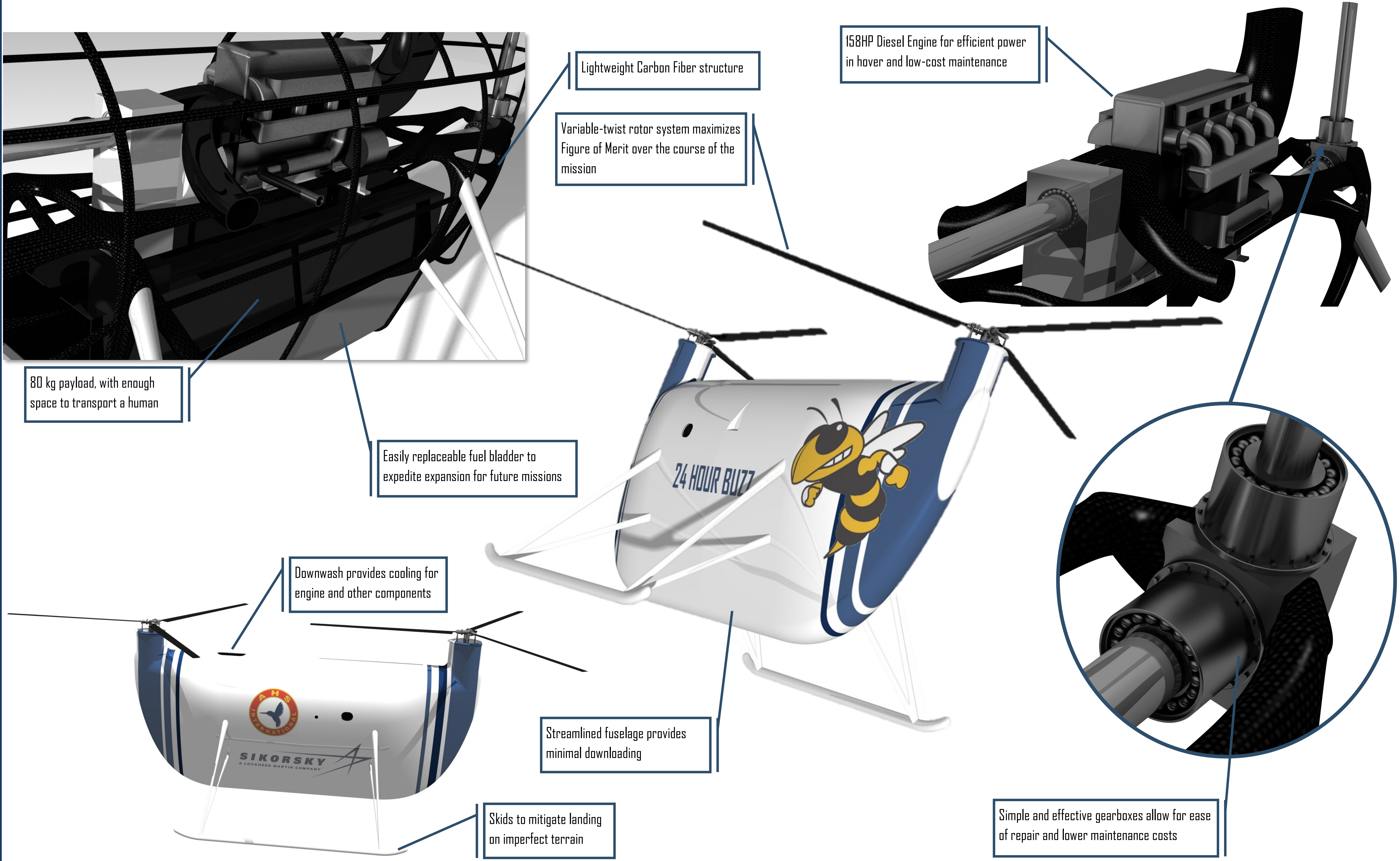
24 Hour Hovering Concept

34th Annual AHS Student Design Competition

Undergraduate Executive Summary

Daniel Guggenheim School of Aerospace Engineering

Georgia Institute of Technology

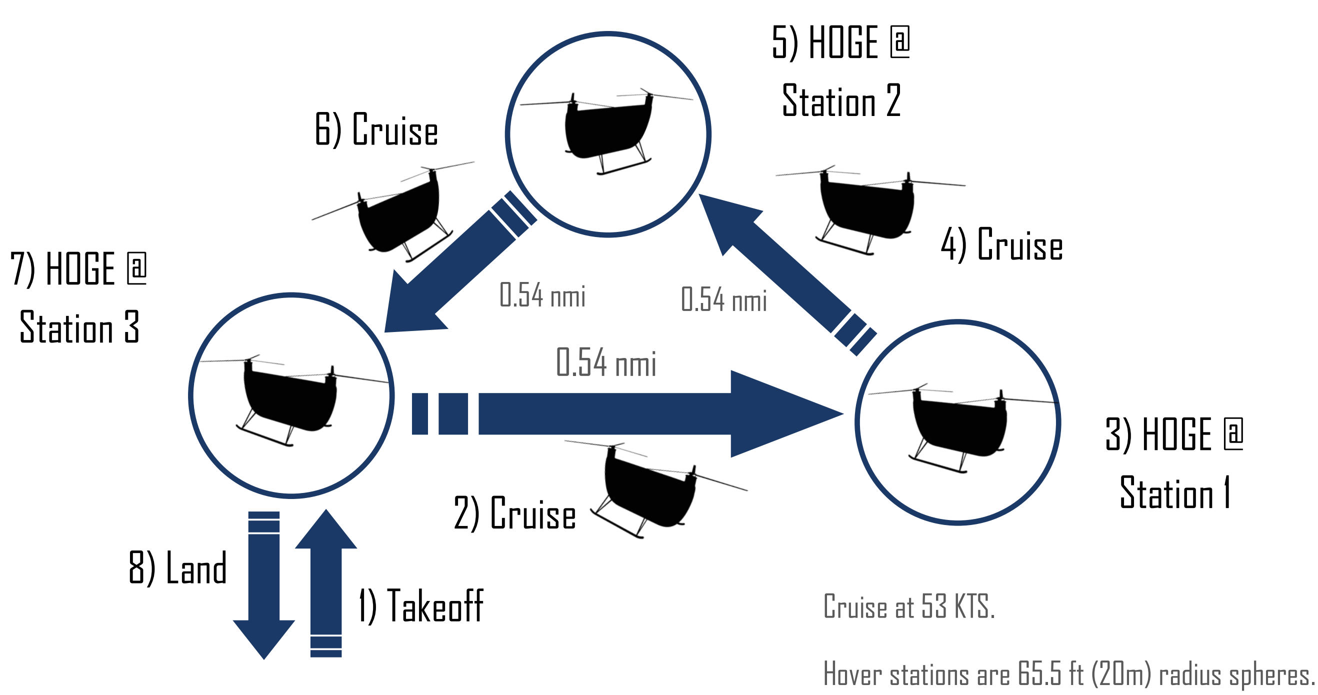

Lightweight Carbon Fiber structure
158HP Diesel Engine for efficient power in hover and low-cost maintenance
Variable-twist rotor system maximizes Figure of Merit over the course of the mission
80 kg payload, with enough space to transport a human
Easily replaceable fuel bladder to expedite expansion for future missions
24 HOUR BUZZ
Downwash provides cooling for engine and other components
SIKORSKY
Streamlined fuselage provides minimal downloading
Skids to mitigate landing on imperfect terrain
Simple and effective gearboxes allow for ease of repair and lower maintenance costs

The Mission

Sponsored by **Sikorsky, a Lockheed Martin Company** the 34th annual AHS design competition issued a unique challenge: the design of a heavier-than-air flying machine that can **hover for 24 hours** while still demonstrating other typical helicopter attributes. This design fulfills all requirements specified.

- **Shall** hover out of ground effect for a total of 24 hours at 3 hover stations separated by 0.54 nm (3 km) ✓
- **Shall** carry 176 lb (80 kg) non-useful payload with a volume of a human ✓
- **Shall** be fully autonomous or remotely controlled ✓
- **Shall** be feasible with technology mature within the next 1-5 years ✓

- **Shall not** receive external chemical or electromagnetic energy (other than solar) in flight ✓
- **Shall not** capture lighter-than-air gases ✓
- **Shall not** jettison any part during flight ✓

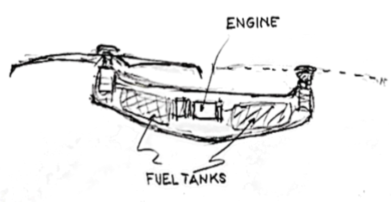


Concept Generation

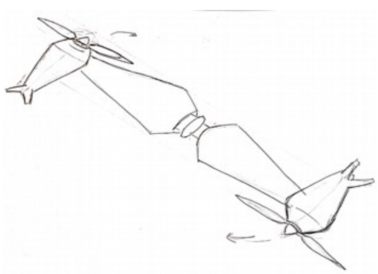
During initial ideation, many concepts were generated using a **morphological matrix**:

COMPONENT	1	2	3	4
Rotor	Single Main	Coaxial	Multicopter	Concentric Multi-Diameter
Rotor Enhancements	None	Ducted	Tip Device	Variable Twist
Power Generation	Turboshaft	Reciprocating	Hydrogen Fuel Cell	
Structure	Metallic	Composite		
Control	Collective/Cyclic	Vanes in Downwash	Gas thrusters	
Anti-Torque Device	Tail Rotor	NOTAR	Tip Jets/Propellers	
Drivetrain	Conventional Shaft	Chain Drive	Hybrid-Electric	

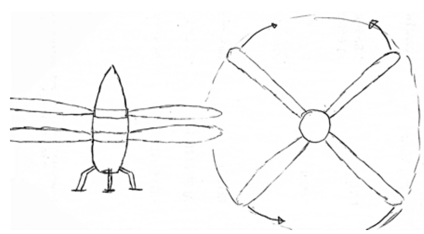
From these, **5** were selected for further study and comparison. These concepts were analyzed to find the design with the perfect balance in rotor efficiency, structural efficiency and power generation efficiency required to best complete the mission.



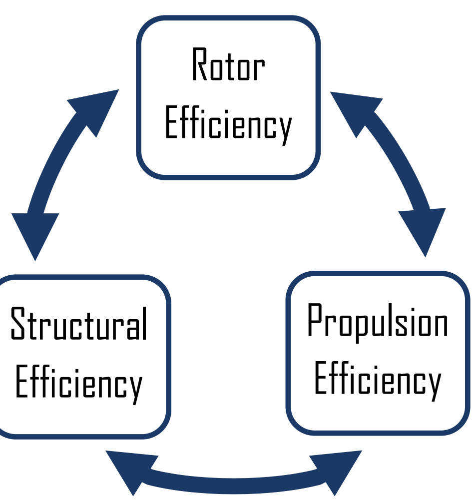
Tandem/Multicopter

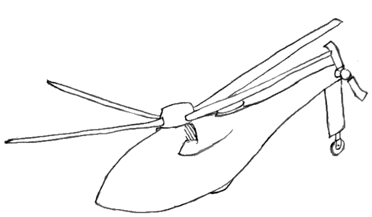


Tip-propelled Flying Rotor

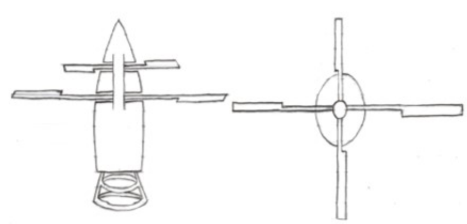


Coaxial Rotor





Single Main Rotor

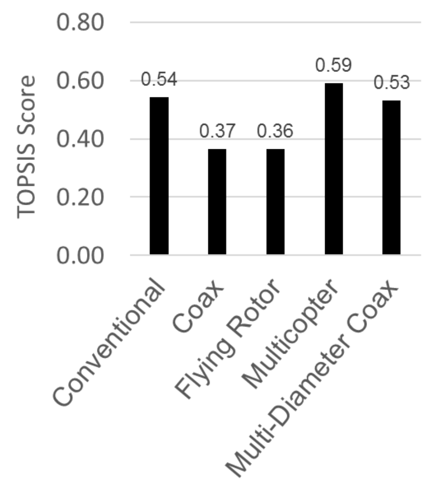


Multi-Diameter Coaxial Rotor

Concept Maturation

Quality Function Deployment (**QFD**) was used to rank the importance of the engineering metrics on the performance of the aircraft and the it's ability to complete the mission. The Technique for Order of Preference by Similarity to Ideal Solution (**TOPSIS**) was employed to score each concept according to its relative merits in these metrics.

Relative WEIGHT	9	7	8	6	5	3	3	3
METRICS / CONCEPTS	Empty Weight Fraction	Figure of Merit	Disk Loading	Controllability	Reliability	Flat Plate Area	Maintainability	Cost
Single Main Rotor	6	3	3	6	9	6	9	9
Coaxial	3	3	6	6	3	6	3	6
Flying Rotor	6	3	9	1	1	9	1	1
Multicopter	3	6	9	9	6	3	6	3
Multi-Diameter Coax	6	9	9	3	3	6	3	1



In the TOPSIS matrix, a score of 9 means that a concept has exceedingly beneficial properties in that metric, while a score of 1 represents an area where the concept is notably flawed. Metrics with a higher weighting were determined to have a greater impact on mission performance. The lowest score was the Flying Rotor (**0.36**) while the highest score, nearest the ideal solution, was the Multicopter (**0.59**).

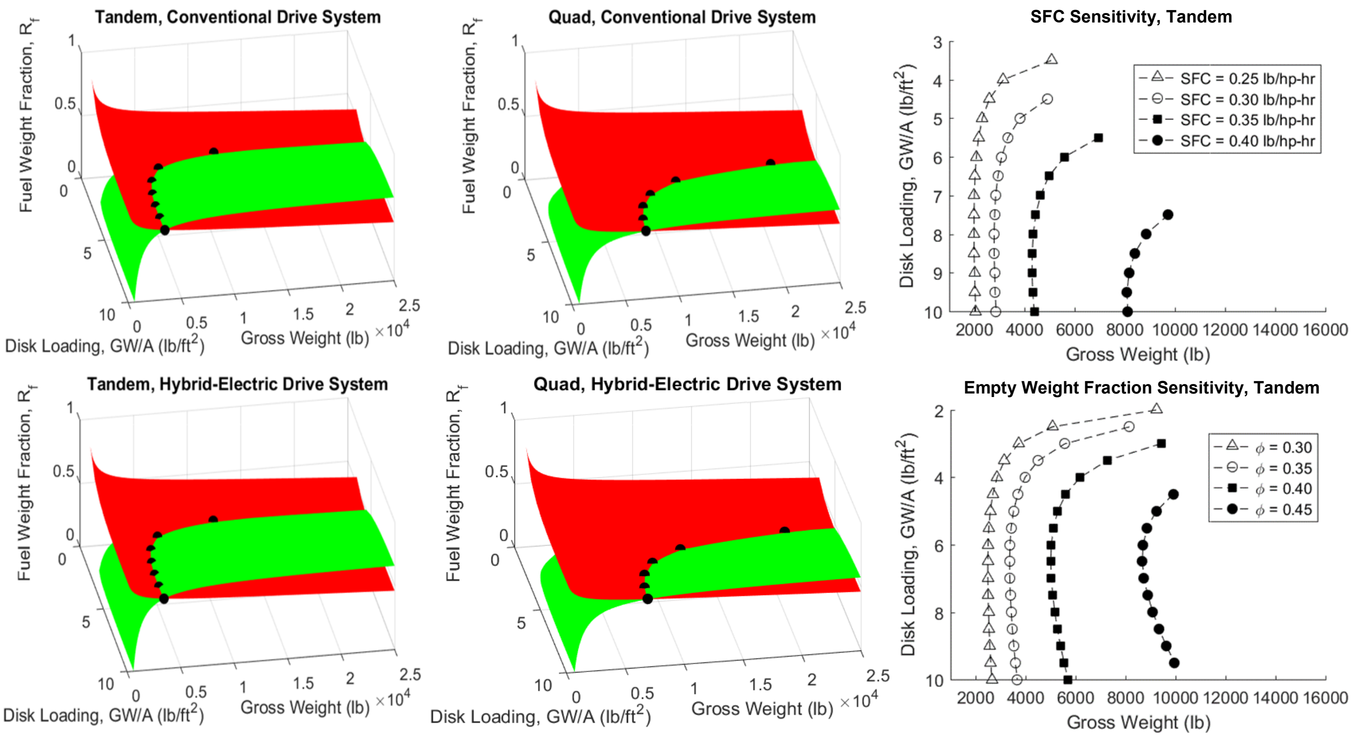
Based on the results of this analysis, the Tandem/Multicopter configuration was selected.

This configuration has a number of benefits:

- Large rotor area **decreases induced power required** for hover
- Non-overlapping rotors **minimize interference losses**
- Reduced complexity **enables better analysis**
- Fuselage provides ample **space for systems and fuel**

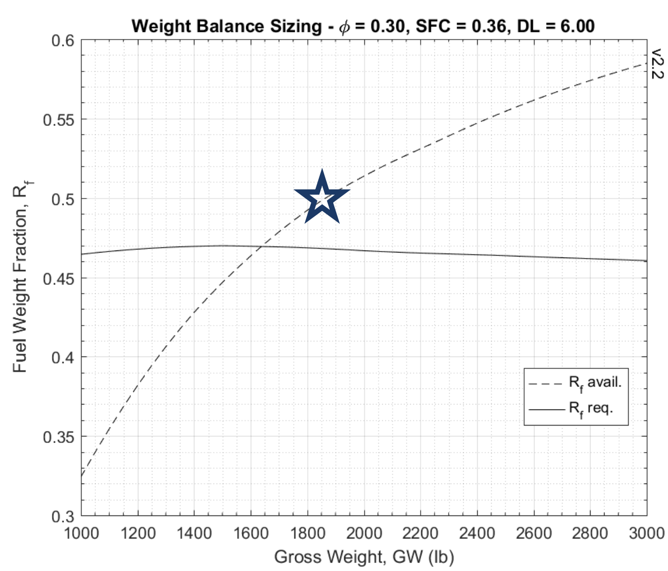
Design Space Exploration

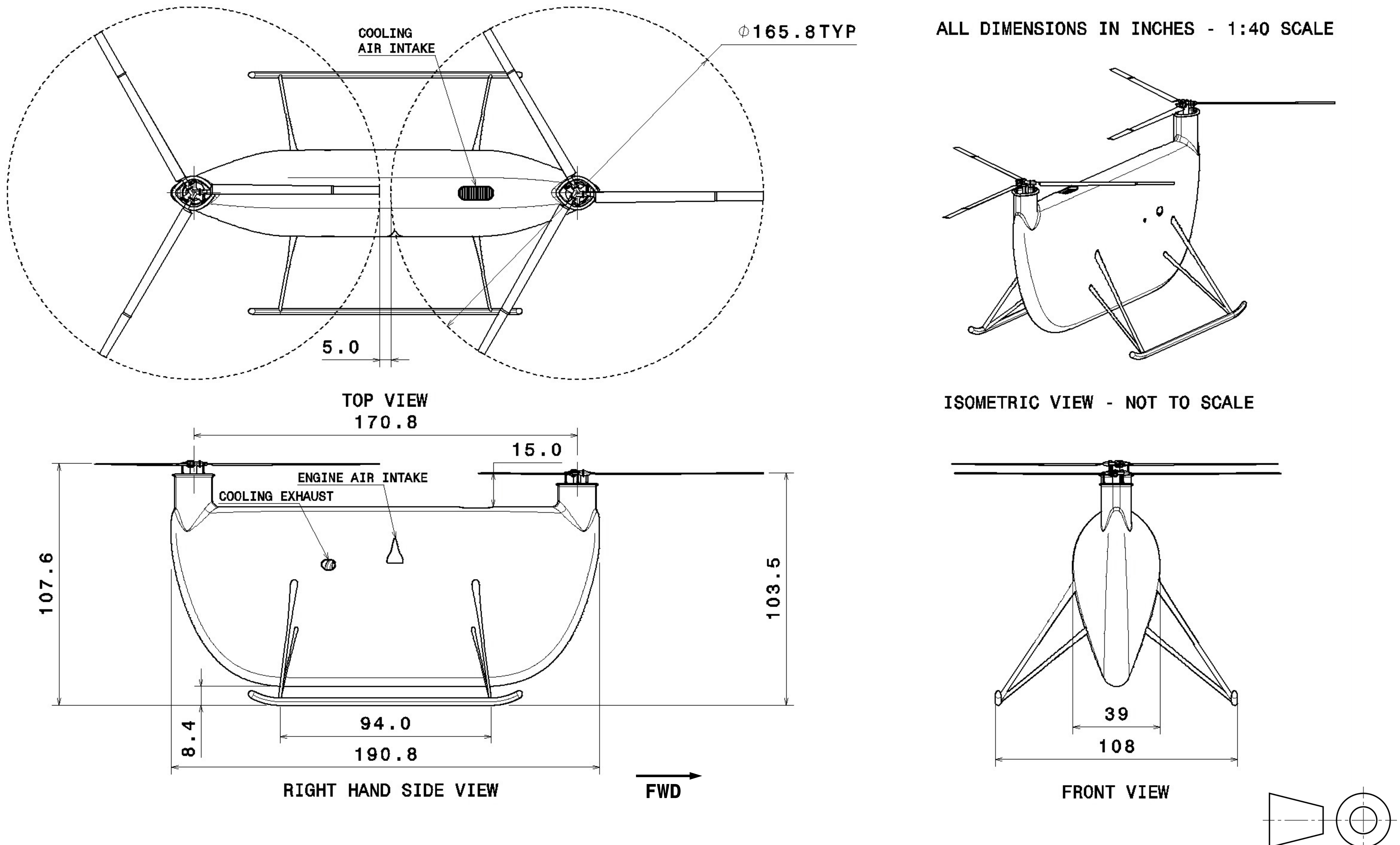
The primary method of air vehicle sizing was the **fuel weight fraction balance** (R_f) technique. A gross weight is a feasible design if it can carry enough fuel to complete the mission.



This analysis revealed that for this mission, a **tandem configuration is preferable** to a quadcopter, and because the hybrid electric drivetrain does not provide significant benefits to gross weight, a simpler **conventional shaft drivetrain is selected.**

Additionally, the same tools showed that the feasible gross weight is sensitive to three design drivers: **specific fuel consumption** (SFC), **empty weight fraction** (Φ), and **disk loading** (DL). These factors are optimized during the subsystem selection and design. Applying technology factors and a higher fidelity **combined blade element momentum theory** (CBEMT), a feasible gross weight of 1650 lb can be found. To allow for some margin, a **design gross weight** of **1800 lb** is selected for this design.

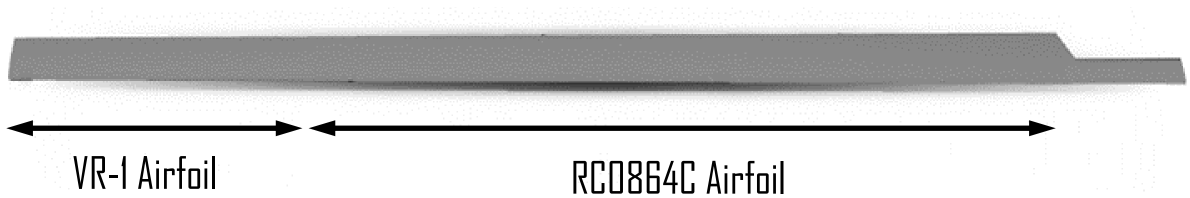




ALL DIMENSIONS IN INCHES - 1:40 SCALE
COOLING
AIR INTAKE
Φ165.8TYP
5.0
TOP VIEW
170.8
15.0
ENGINE AIR INTAKE
COOLING EXHAUST
107.6
103.5
8.4
94.0
190.8
RIGHT HAND SIDE VIEW
FWD
ISOMETRIC VIEW - NOT TO SCALE
39
108
FRONT VIEW

Optimized Rotors

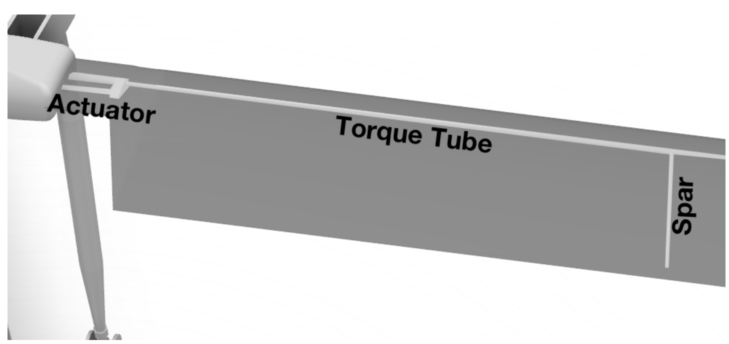
The rotor blade geometry, including profile, twist, and taper, are optimized for the thrust range required during the mission through the use of Dassault Systèmes® Isight optimization software and a custom **Combined Blade Element Momentum Theory** (CBEMT) code with nonlinear inflow and tip loss models.



ROTOR CHARACTERISTICS

Radius (ft)	6.91	**Twist (deg/ft)**	-0.71 to -1.92	**Tip Speed (ft/s)**	700
Number of Blades	3	**Taper**	0.777	**RPM**	967
Average Chord (ft)	.346	**Airfoil Transition (%R)**	75	**Hub Type**	Hingeless

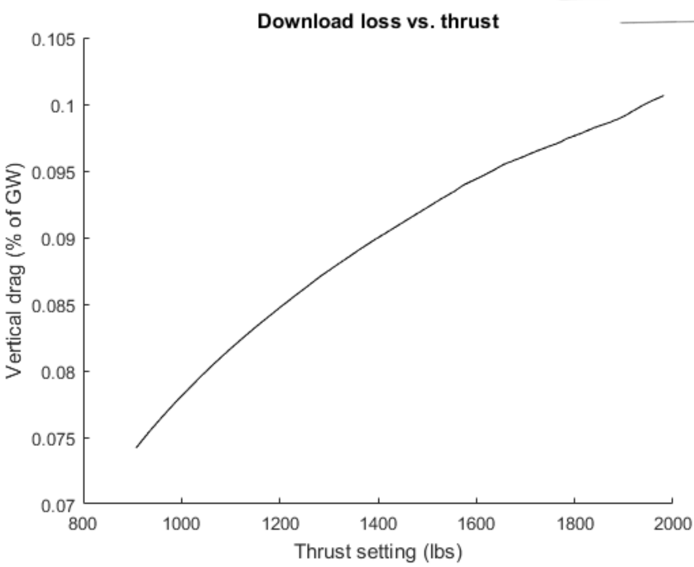
A design tip speed of 700 ft/s and rotor speed of 967 RPM allows for auto-rotation in the case of an emergency loss of power. The hub is **hingeless**, utilizing advanced composite blades designed to incorporate structural flapping hinges and be **stiff in plane** to mitigate lead-lag vibrations and ground resonance. Novel **variable twist** technology allows for the rotor twist to change over the course of the mission, modifying the inflow and providing more efficient lift generation at the thrust setting required.

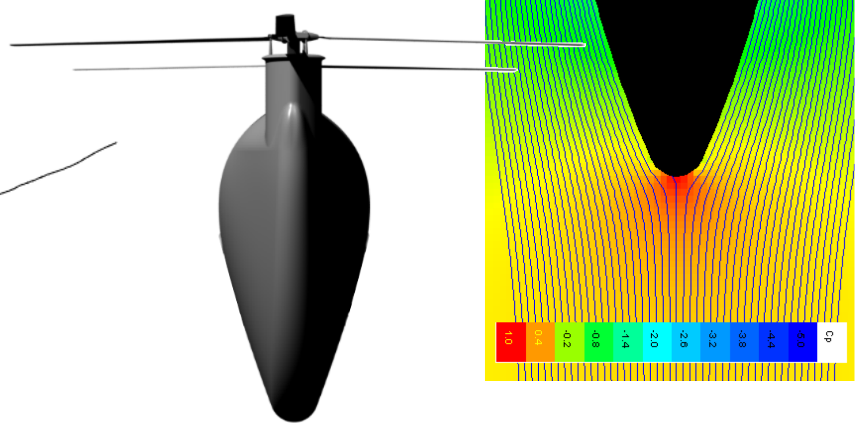


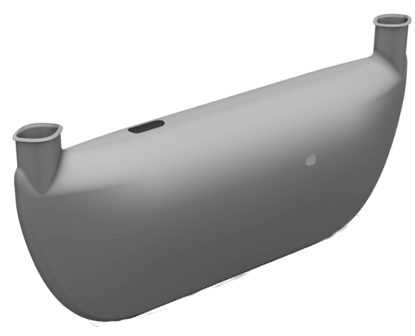
Variable Twist Internal Structure

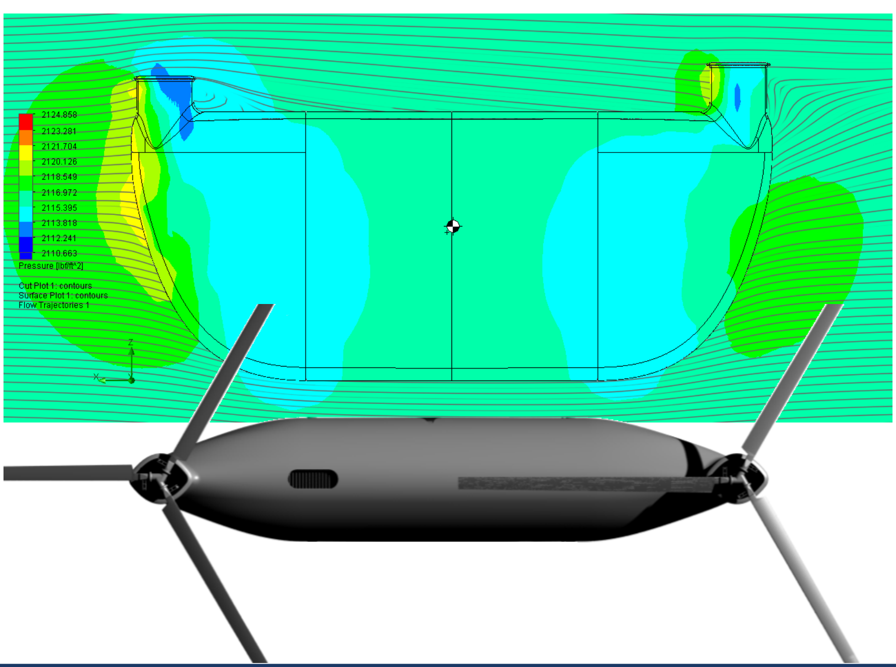
Fuselage Aerodynamics

Download, the force of the rotor wash on the fuselage, is an important consideration in hover, especially over the course of this 24 hour mission. To mitigate the power lost to download, the fuselage is aerodynamically shaped. Analyzing the central cross section in Javafoil and combining it with the non-uniform inflow model of the blade element code, the **download losses** across the whole range of operation can be seen to be at **most 0.1% of the gross weight**.





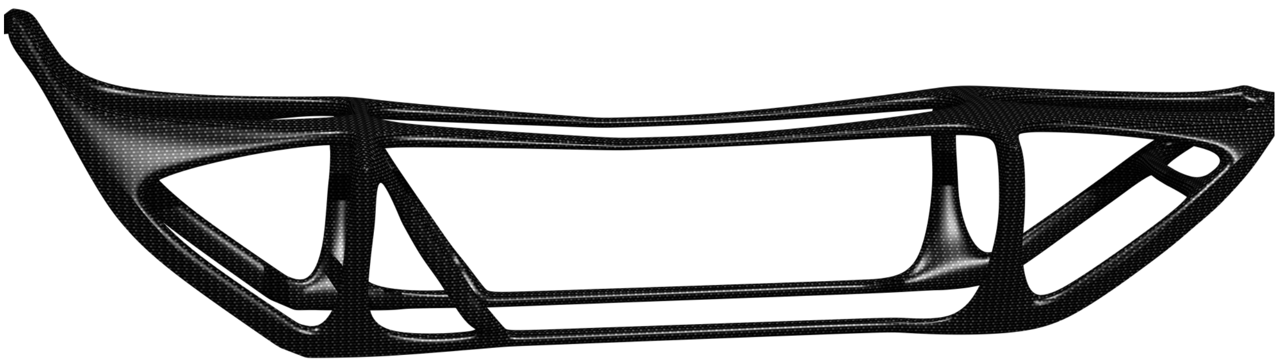




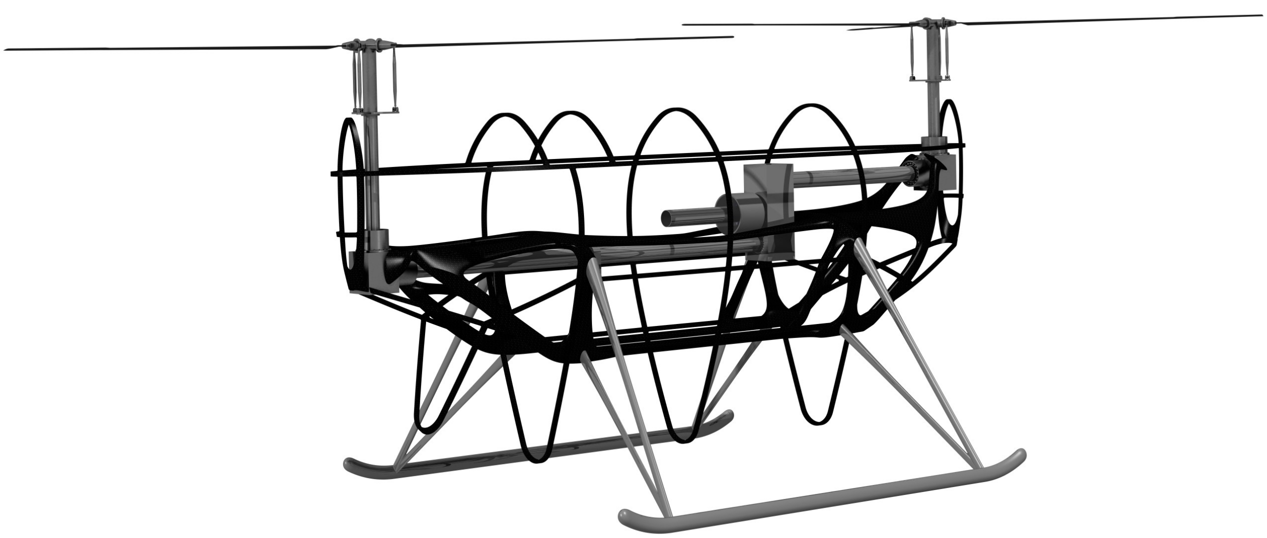
While forward flight is only a small portion of the mission, the fuselage also has a streamlined profile in the longitudinal direction.

Structural Design

The structure is designed to support the weight of itself and the required payload, fuel, and powertrain in two conditions: flight and on the ground. While keeping a high level of rigidity and maintaining a high factor of safety, the mass of the structure was minimized to 109 pounds using solidThinking® Inspire **topology optimization** software. This hollow frame structure bears the major loads of the aircraft in both conditions.

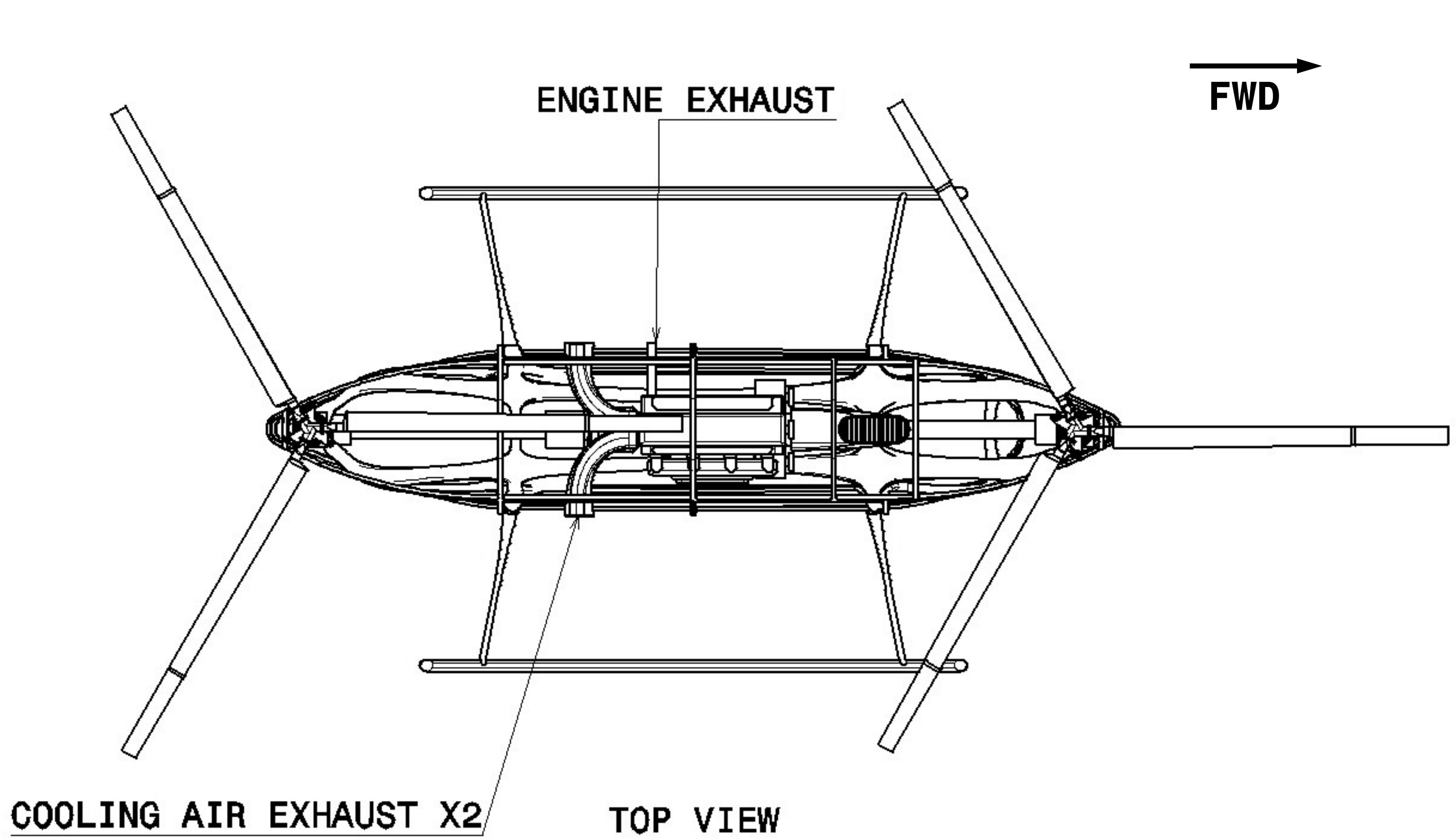


A secondary structure consisting of spars and ribs adds holds and supports the outer shell of the helicopter. The entirety of the structural aspects of this design are constructed of **carbon fiber-epoxy composites** to minimize the weight of the structure, while maintaining strength.

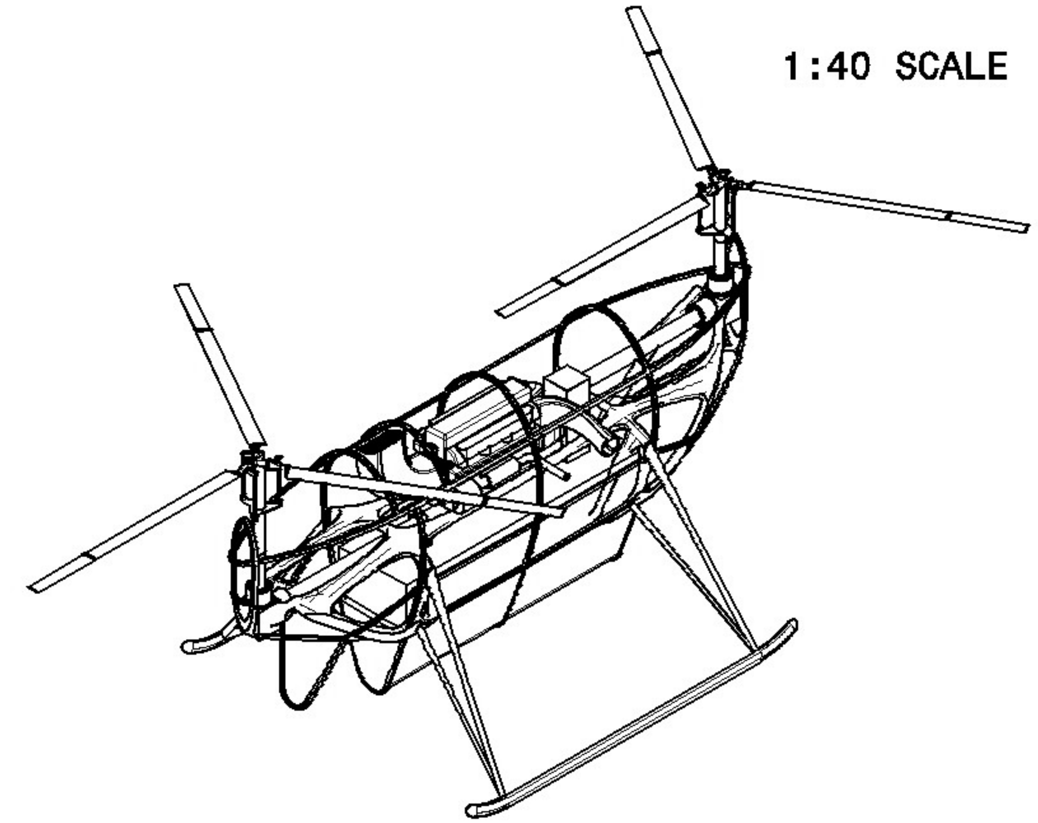


Advanced materials enables the **very low empty weight fraction** crucial for 24 hour hover.

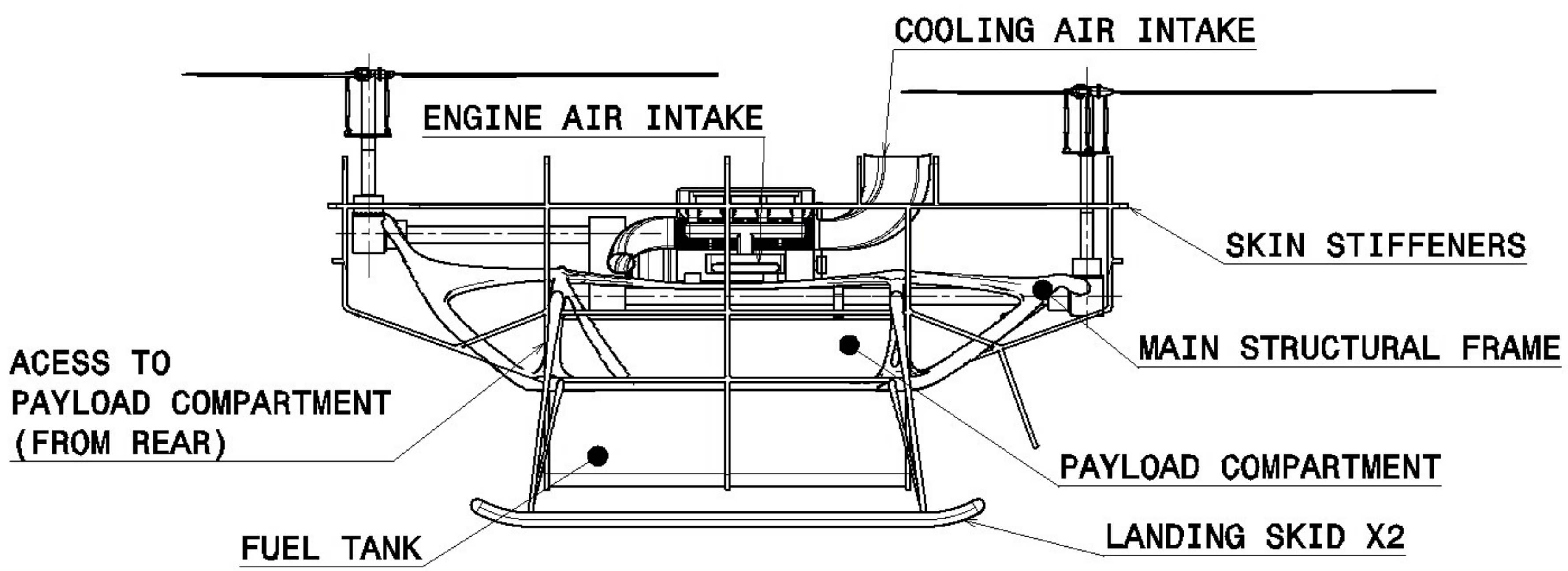
1:40 SCALE



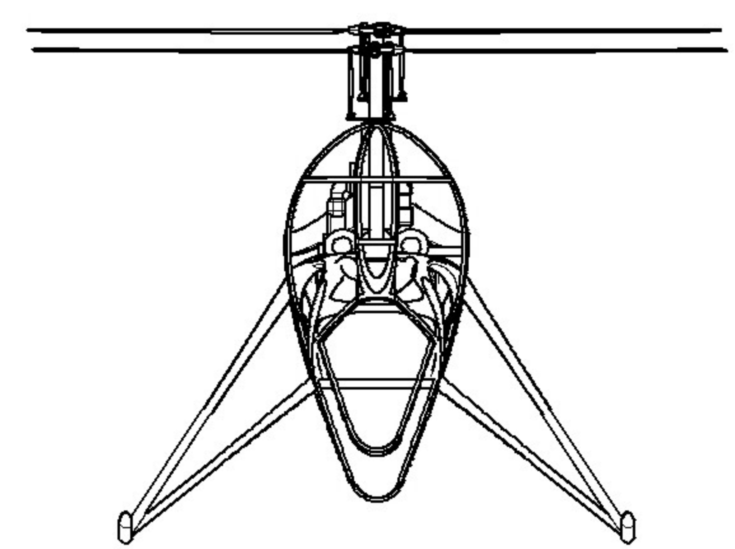
TOP VIEW



ISOMETRIC VIEW - NOT TO SCALE



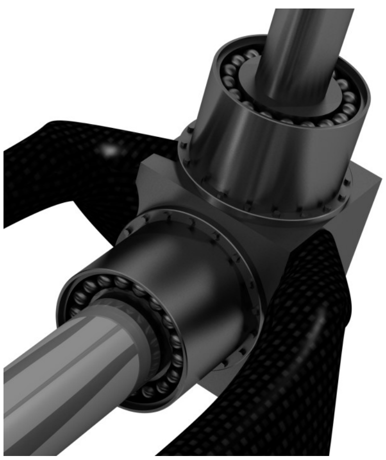
RIGHT HAND SIDE VIEW



FRONT VIEW

Propulsion System

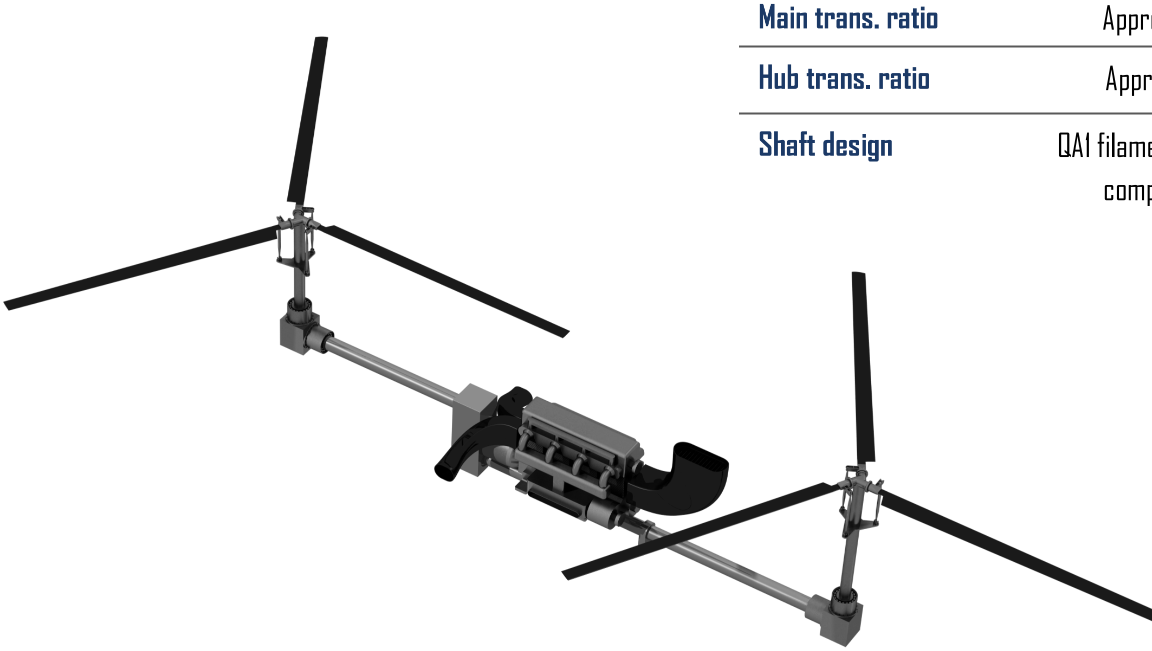
For a 24 hour mission, fuel efficiency is paramount. A state of the art **reciprocating diesel engine** provides enough power to maintain hover using only a fraction of the fuel a turboshaft engine would require. While hydrogen fuel cells are highly efficient, carrying a heavy pressurized tank is not. Diesel on the vehicle is stored in a light weight fuel bag at the bottom of the fuselage. An **air-cooled** configuration makes use of the downwash to carry away heat.



Due to a **low reduction ratio** of the system, another benefit of the diesel engine, the main transmission utilizes a single stage planetary gearbox coupled with a splitter gearbox to transmit power to the forward and aft drive shafts. Carbon fiber winding is used instead of a traditional driveshaft to reduce the weight and increase durability.

DRIVETRAIN CHARACTERISTICS

Engine type	Air-cooled diesel
Piston arrangement	Inline four cylinder
MCP	169 HP (126.0 kW)
Operating RPM	4000
SFC @ MCP	0.358 lb/hr-HP
Main trans. ratio	Approx. 4:1
Hub trans. ratio	Approx. 1:1
Shaft design	QA1 filament-wound composite



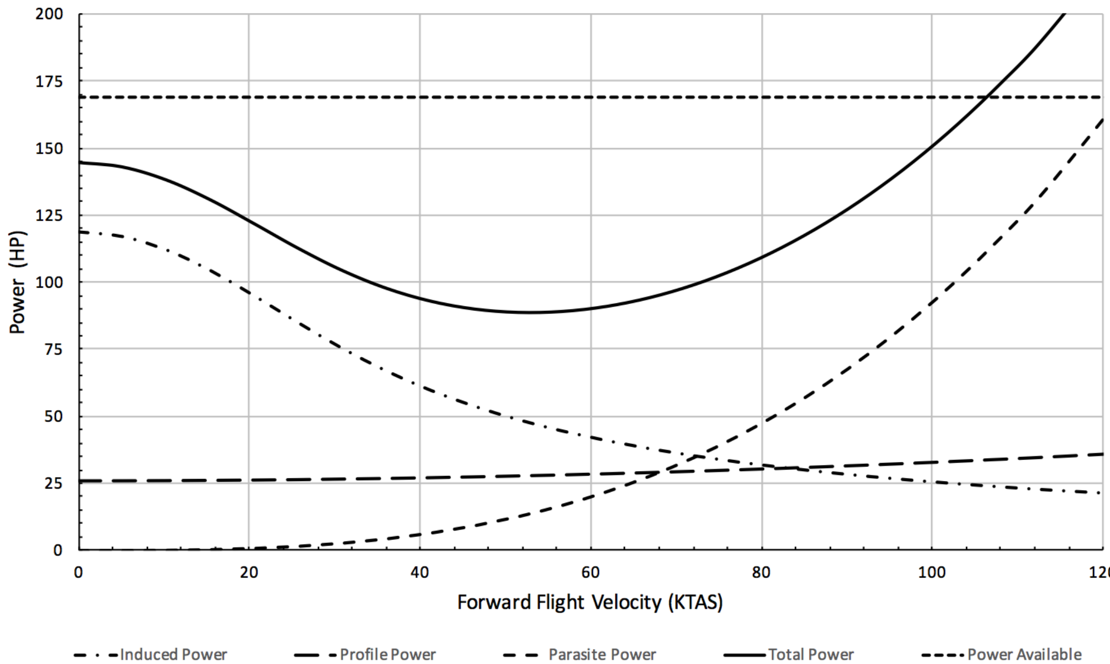
Vehicle Performance

Although the purpose of this mission was mainly to be performed in hover, the design has forward flight capability. High efficiency propulsion, light structural weight, and variable rotor twist make it more than a pure hovering machine. The large fuel tank allows for a long range.

Gross Weight:
1800 lb

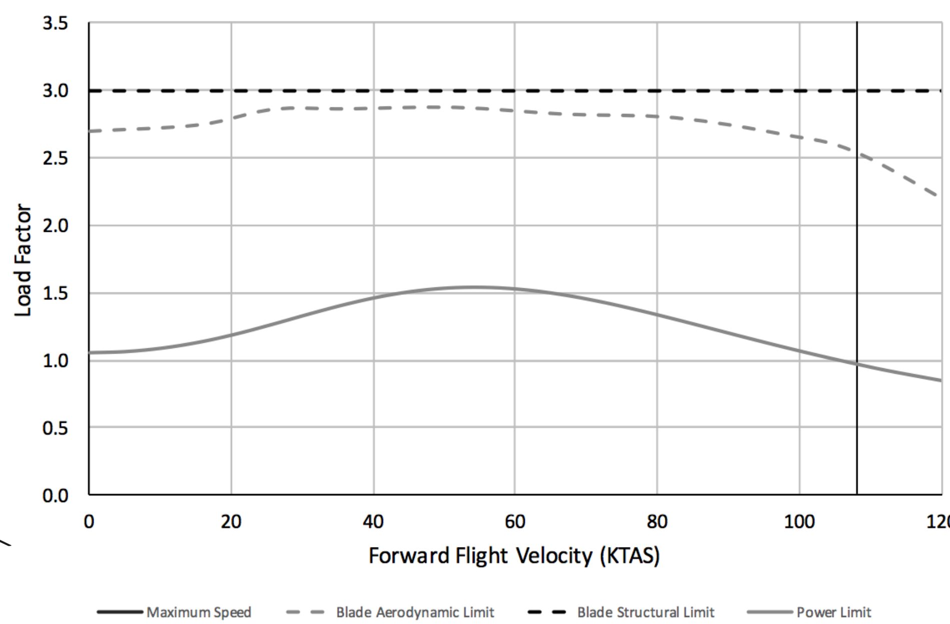
Max Speed:
110 Knots

Cruise Speed:
53 knots at 90 HP



Structural and aerodynamic limits exceed the mission flight condition requirements. Excess power and flight performance increase with fuel burn over the course of the mission.

The potential for power plant upgrades offers an opportunity for expanded capabilities beyond the 24 Hour Hover mission.



Weight Buildup & CG Analysis

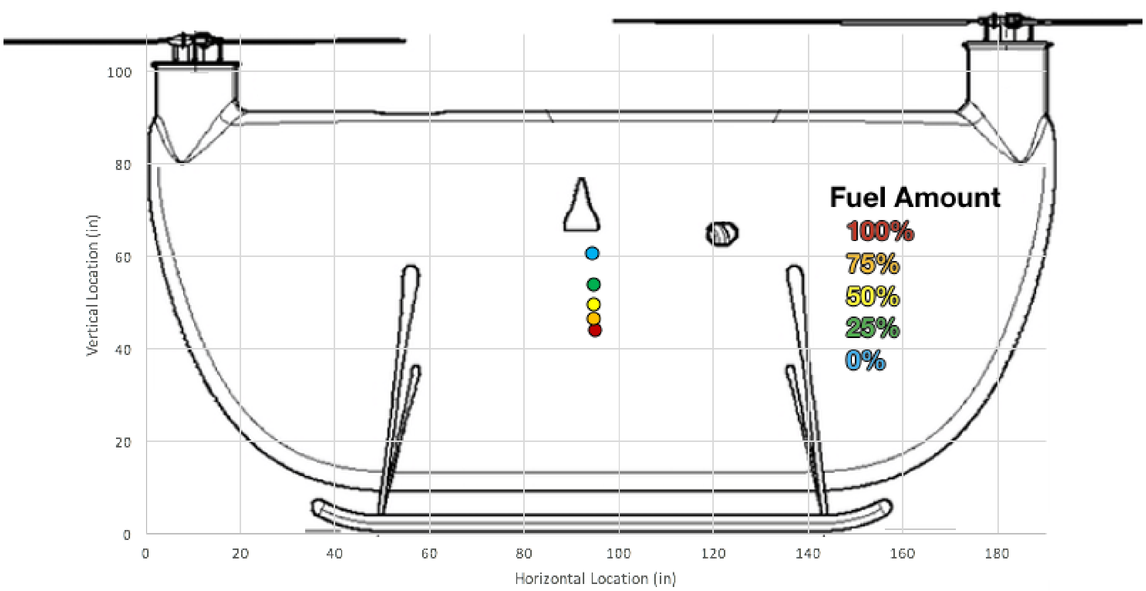
The vehicle is designed to be largely **symmetric in** both the **lateral and longitudinal directions**. This aids in keeping the center of gravity towards the centroid of the vehicle, an important consideration for controllability.

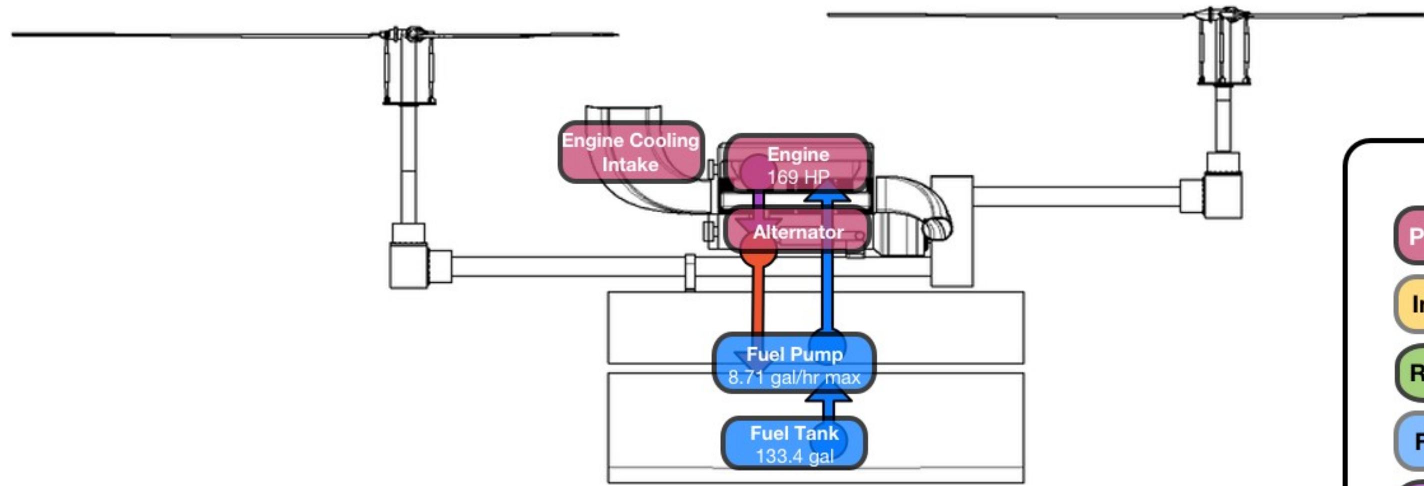
The center of thrust of the vehicle is located at FS 95.12. The center of gravity analysis indicates that the CG begins at FS 94.78 and drifts to FS 94.40 over the course of the mission. This minor discrepancy will create a very minor pitch down moment which can easily be corrected for with the cyclic.

The CG does move upwards significantly over the course of the mission, as the fuel tank is located in the very bottom of the fuselage and the fuel makes up a large fraction of the gross weight. This shift is upwards and symmetric with respect to the rotors and does not pose a control issue.

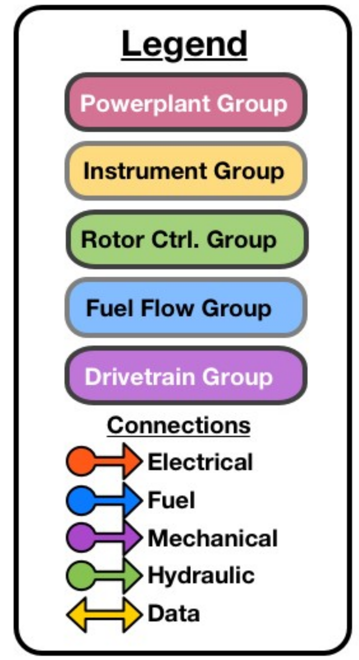
EMPTY WEIGHT BUILDUP

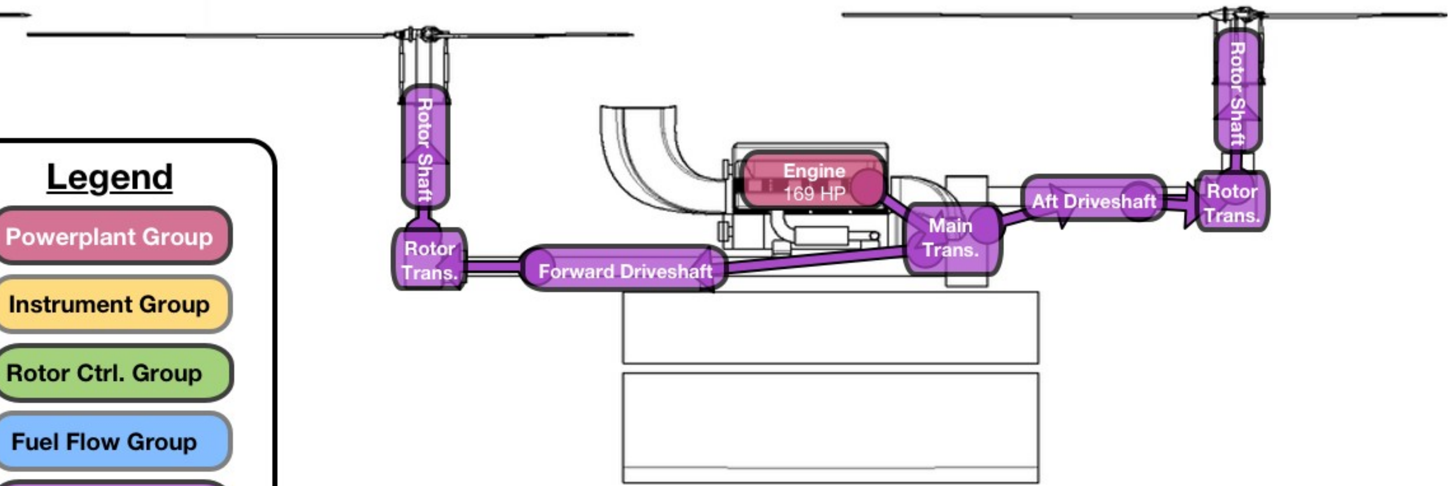
Component	Weight - lb (kg)
Main structure	109 (49.5)
Fuselage skin	20 (9.1)
Rotors	60 (27.2)
Engine	300 (136.2)
Avionics	21.3 (9.7)
Drivetrain	92 (41.8)
Landing Gear	10 (4.5)
Empty Weight	649.8 (278)
MISSION LOADOUT	
Diesel fuel	947 (430)
Payload	176.5 (80)
GROSS WEIGHT	1772.8 (804.2)



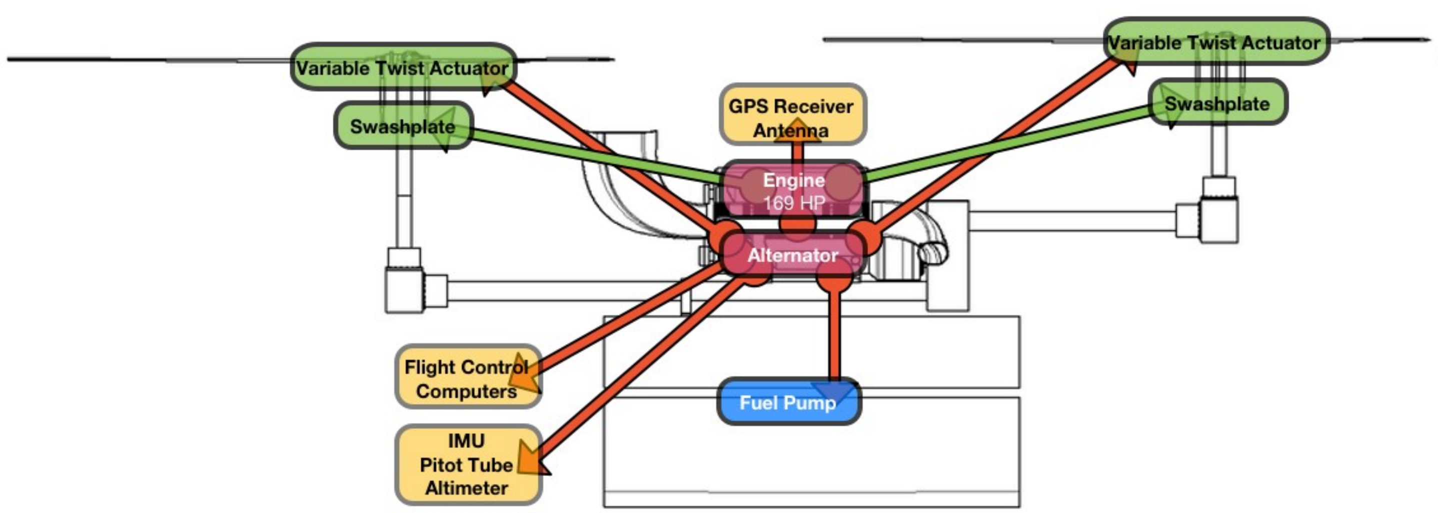


Powerplant Subsystem

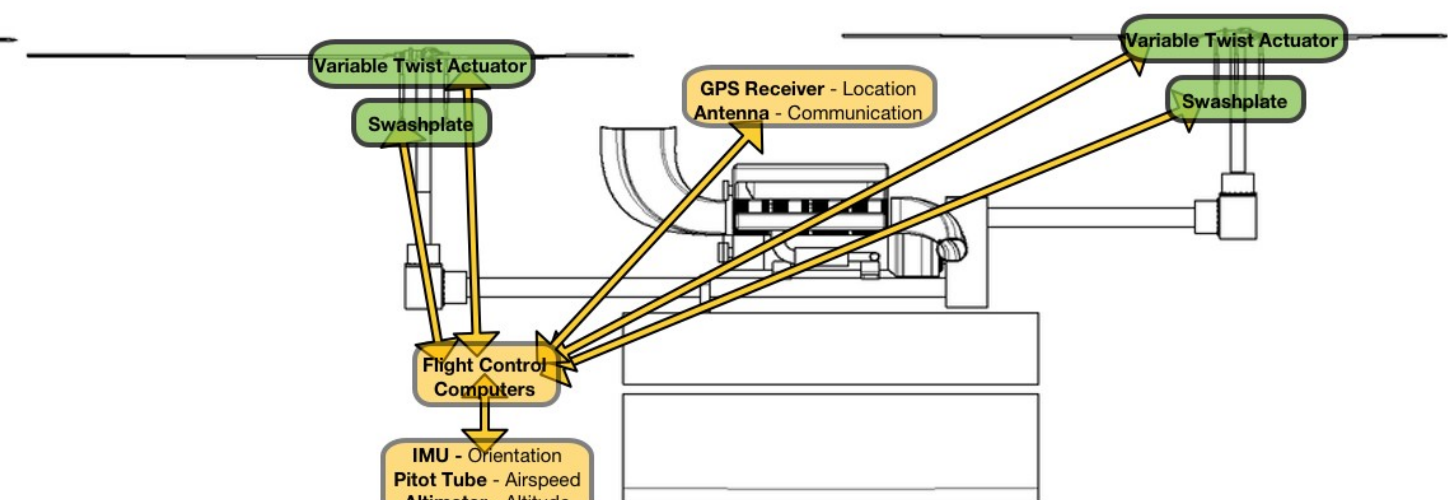




Drivetrain Subsystem



Electrical/Hydraulic Subsystem



Flight Control Subystem