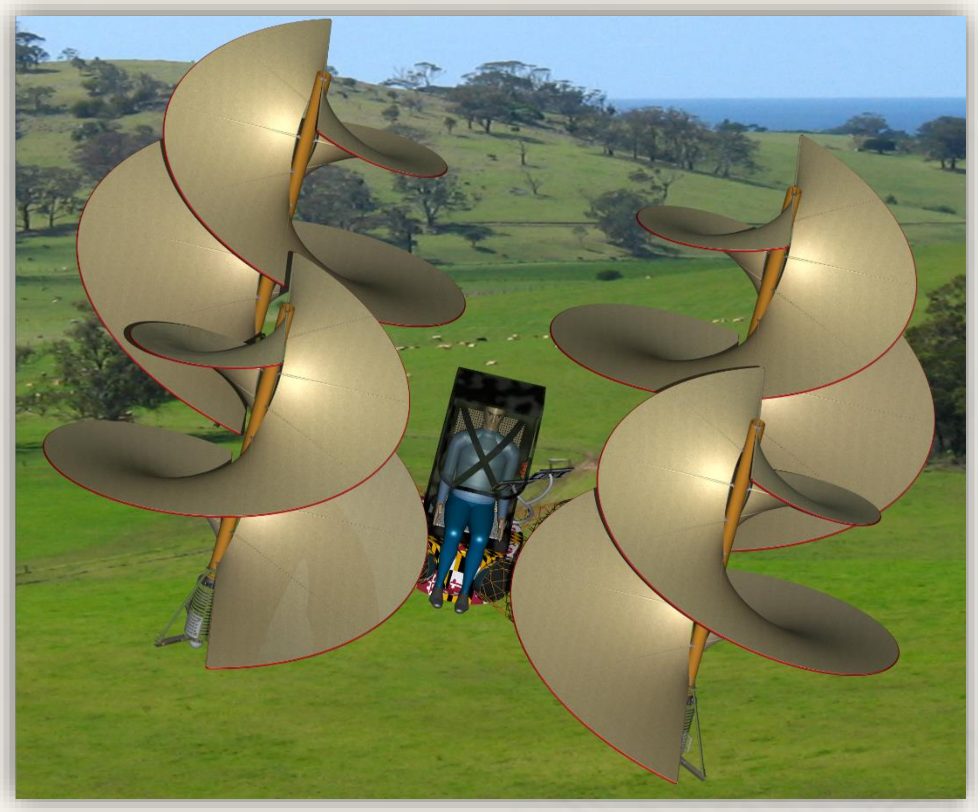
Samara



37th Annual VFS Student Design Competition

Leonardo's Aerial Screw: 500 Years Later

Sponsored by Leonardo Helicopters

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The students listed above will receive credit for the course ENAE 481 and ENAE 482: Helicopter Design.

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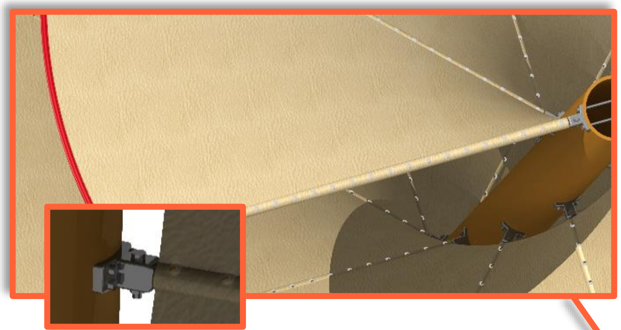
To Vertical Flight Society:

The members of the University of Maryland Undergraduate Student Design Team hereby grant VFS full permission to distribute the enclosed Executive Summary and Final Proposal for the 37th Annual Design Competition as they see fit.

The UMD Undergraduate Design Team

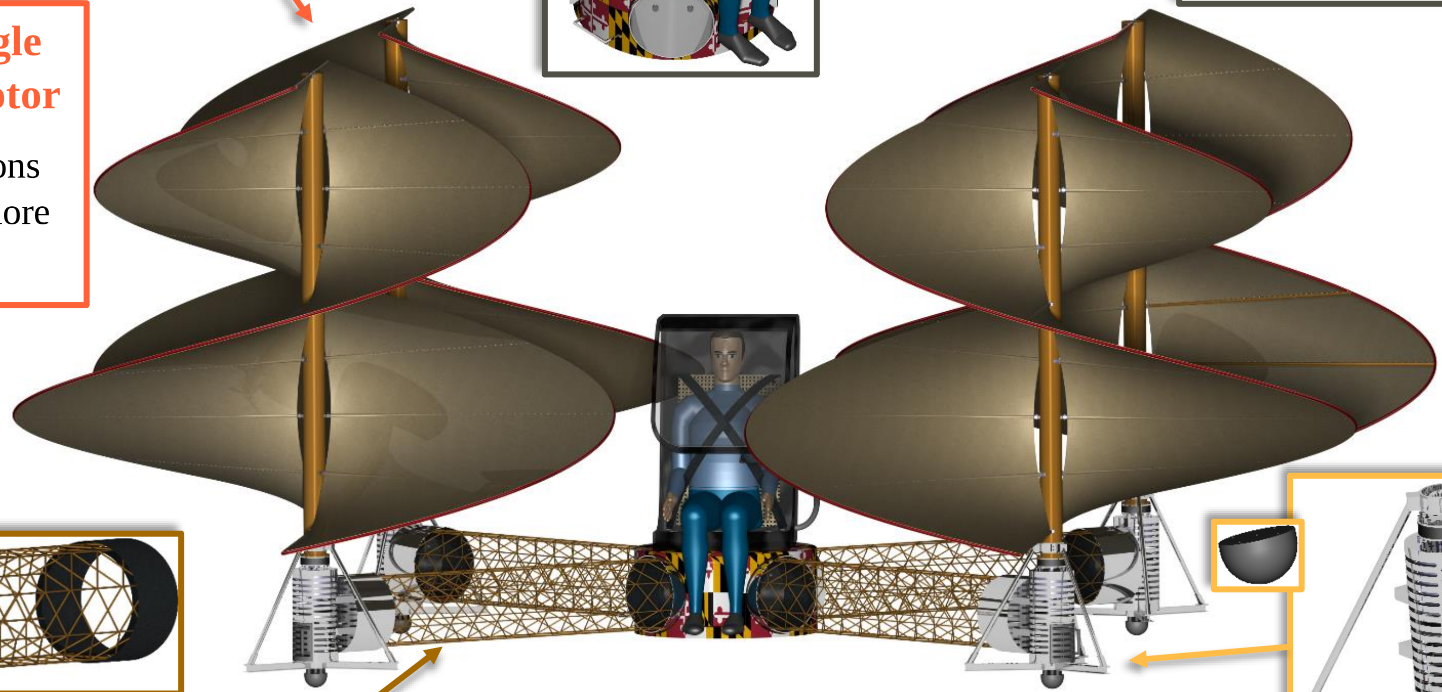


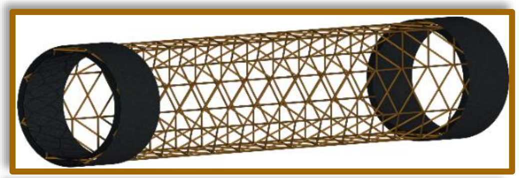
High Pitch Angle and Tapered Rotor

Decreases vibrations while producing more thrust

Autonomy and Low Pilot Workload Cockpit Display

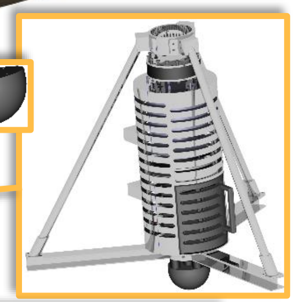
iPads allow for flight autonomously or under pilot control





OctaTruss

Unique carbon fiber truss provides lightweight structural rigidity



Integrated Powertrain

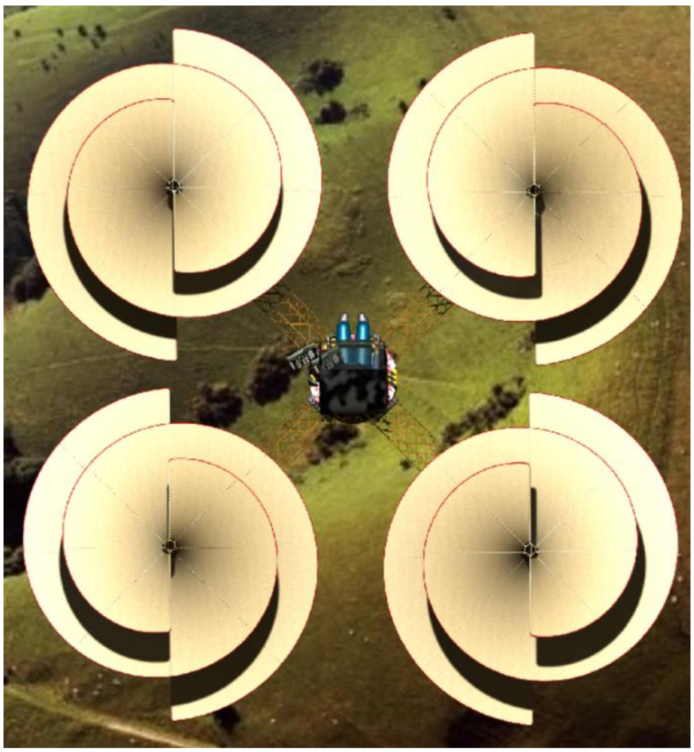
Motor, gearbox, batteries are easily accessible. All-weather landing gear and rotor support attached

GTOW	290 kg
Rotor Radius	1.5 m (max)
Installed Power	60 kW
Disk Loading	10.8 kg/m^2
Figure of Merit	0.38

Vehicle Overview

Samara: A Modern Take on da Vinci's Aerial Screw

It is believed that Leonardo da Vinci wondered, while watching a maple seed (a samara) spin rapidly as it fell to the ground, if the seed could also rise while spinning through the air. This idea inspired da Vinci to sketch the Aerial Screw.



Five centuries later the University of Maryland Undergraduate Design Team closes the gap in the technical understanding of the Aerial Screw. ***Samara*** is an autonomous, ultralight, and electric quadcopter with rotors inspired by da Vinci's Aerial Screw. ***Samara*** brings Leonardo da Vinci's concept to life through extensive testing and design.

Through small scale testing and CFD analysis, the University of Maryland Undergraduate Design Team developed a single-bladed, concentric rotor that does not suffer from inertial or aerodynamic imbalances. ***Samara's*** design offers a smooth and safe ride. It not only achieves a VTOL vehicle based on the Aerial Screw merited with physics, but also brings da Vinci's design into the twenty-first century with modern technology allowing the vehicle to fly autonomously or under pilot control.

The Aerial Screw – 500 Years Later

Samara is a reimagining of da Vinci's Aerial Screw concept that uses modern aerodynamic research to understand and build upon the original design.

Da Vinci's Aerial Screw

Excellent Performance

Figure of Merit of 0.38 shows the design is efficient and capable of powering a VTOL vehicle

Single Continuous Surface

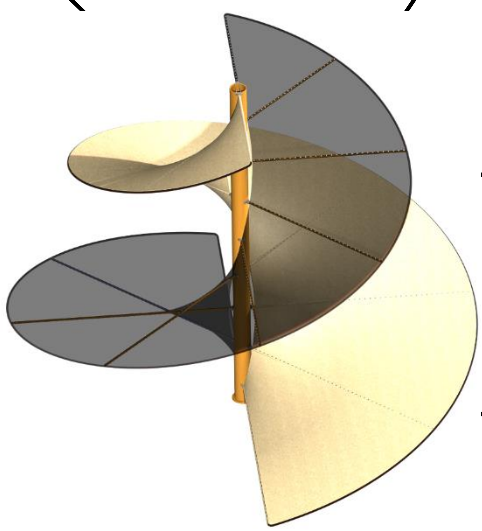
No gaps, holes, or slots in the blade surface

Solidity Greater than 1

Calculated as Projected Area / Disk Area
Samara's rotor solidity > 1.0

Increased Pitch Angle

Samara's rotor features a large pitch angle at the root for increased lift



Single Blade Design

A concentric single blade significantly reduces inertial and aerodynamic imbalances

No Buoyancy Needed

100% of *Samara's* lift and thrust is produced by the rotors

***Samara's* Tapered Aerial Screw Rotor**

Design Summary:

Samara's rotor design is heavily inspired by da Vinci's Aerial Screw and maximizes performance, efficiency and durability.

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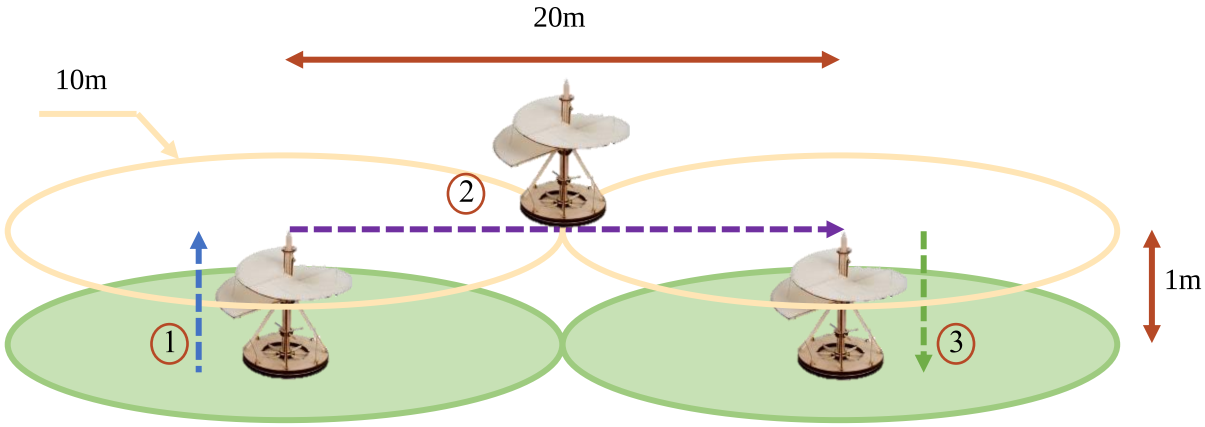
Mission Profile

Leg 2

- Fly for at least 60 sec for a minimum distance of 20 m (66 ft) at an altitude of at least 1 m (3.3 ft)
- Hold position at an altitude of at least 1 m (3.3 ft) for a minimum of 5 sec within a 10 m (33 ft) radius from take-off spot



Leg 1

- Take-off vertically carrying at least a 60 kg (132 lb) person
- Climb to altitude of at least 1 m (3.3 ft)
- Hold position for at least 5 sec within a 10 m (33 ft) radius from take-off spot

Leg 3

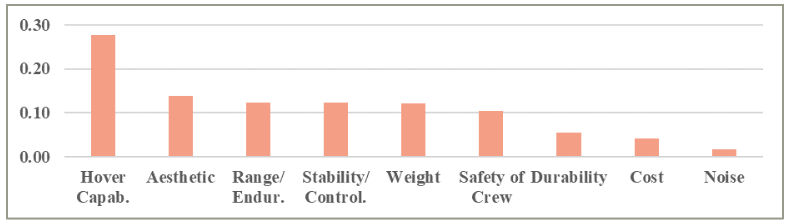
- Land vertically within a 10 m (33 ft) radius from the landing spot

	RFP Requirement	*Samara* Mission Capability
Mission Time	70 sec	70 sec
Range	20 m	20 m
Hover	5 sec within a 10 m radius	183 sec within a 10 m radius
Payload	60 kg (pilot)	60 kg

Vehicle Configuration

Configurations Considered

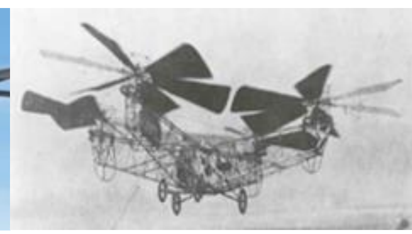
Design Drivers



Down Selection

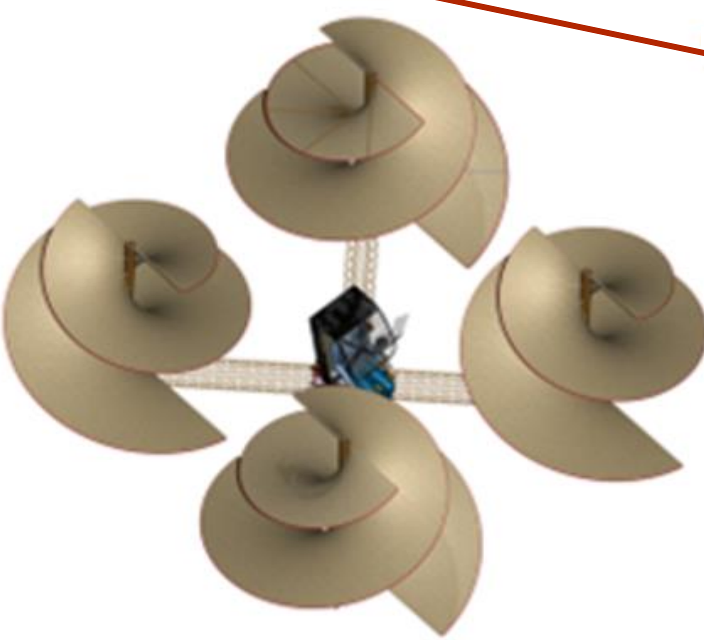
Tandem

Quadcopter



Coaxial

Further Down Selection



<u>Quadcopter Configuration</u>

- Good Maneuverability at Low Speeds
- No Anti-Torque Required
- No Swashplate Needed (RPM Control)
- High Flight Stability

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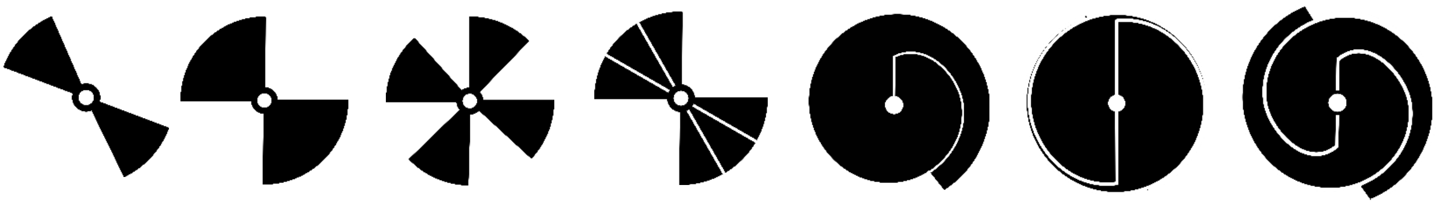
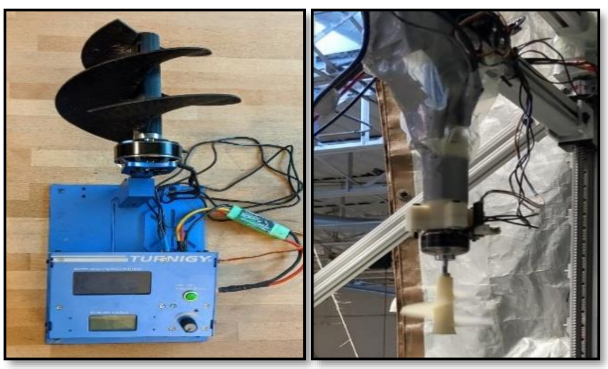
Scale Model Testing

The final rotor configuration was determined through a series of systematic, small-scale tests. 3D printed rotors were tested on a small scale thrust stand measuring thrust, torque, and power. Nondimensional metrics allowed the performance and efficiency of the design iterations to be compared.

Initial Tests → Final Design



Quarter Solidity	Half Solidity	Half Solidity	Slotted Blade	Single Turn Screw	Concentric Screw	Tapered Screw



Two test stands used to measure RPM, thrust, torque, power

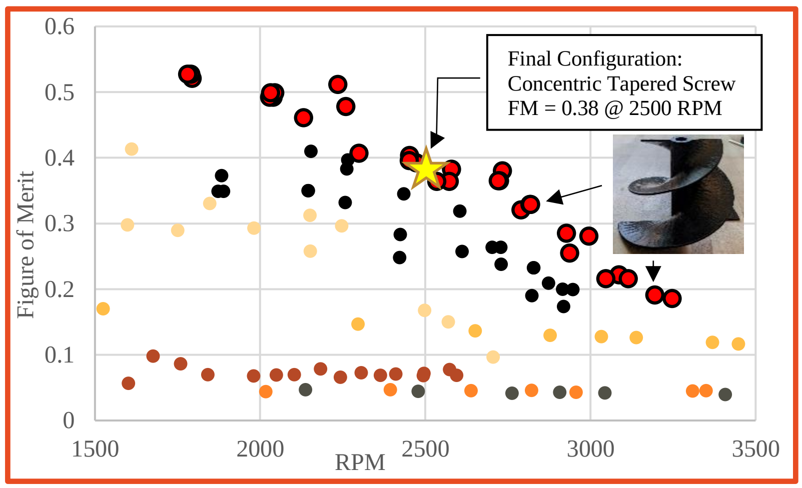


Figure of Merit vs RPM comparing efficiency of the final rotor configuration to previous design iterations

Flow Visualization

A smoke generator was used to create flow visualizations for each of the rotors tested. These visualizations helped verify and explain the test results, and directly influenced the iterative design process.

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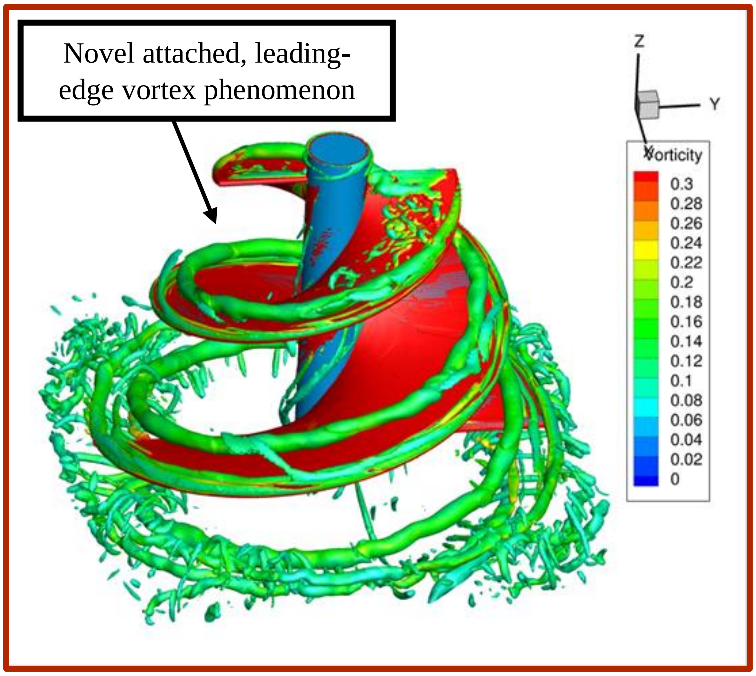
Computational Fluid Dynamics

These simulations applied three-dimensional, unsteady Reynolds-Averaged Navier-Stokes equations. They employed a fifth order WENO scheme, a second order dual-time stepping, a Medida-Baeder transition model, and a hybrid Spalart-Allmaras-Delayed Detached Eddy Simulation turbulence model. A total of 171,674 surface elements were used.

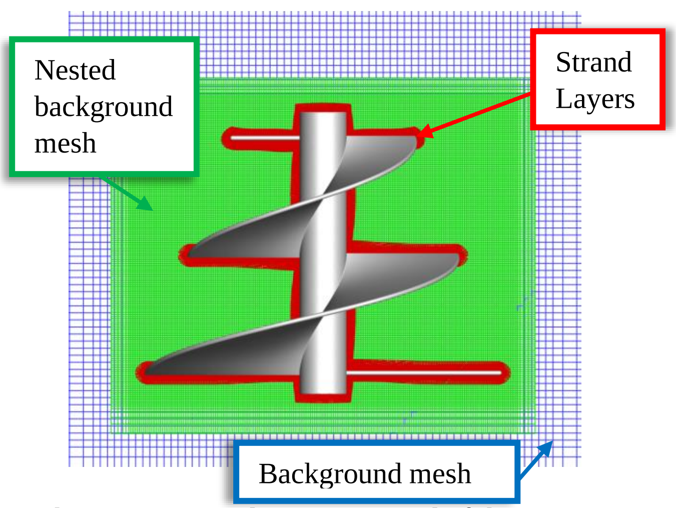


Visualization of vorticity on rotor with R_{max} = 1.518m

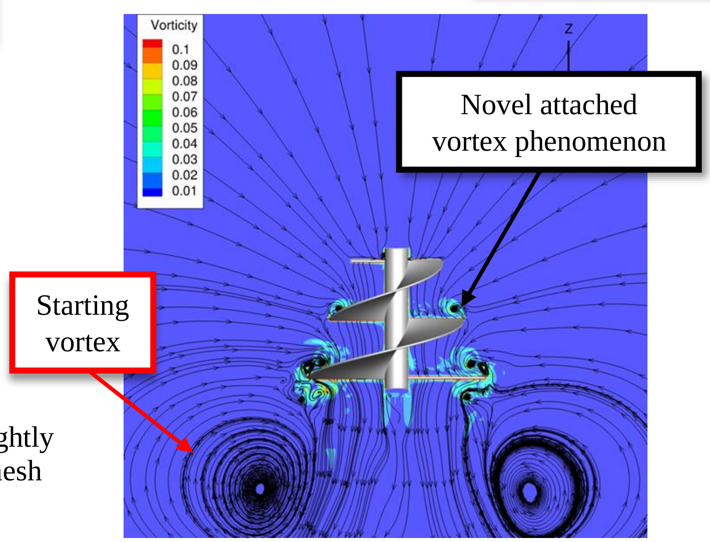
CFD Results	Small Scale	Full Size
Rotor Radius (m)	0.075	1.518
RPM	2,500	340
Tip Mach Number	0.057412	0.158
Tip Reynolds Number	9,832	$5.47*10^5$
C_T	0.0346	0.0365
C_P	0.013	0.0107
FM	0.35	0.46

Close agreement with testing results

Higher efficiency achieved by full scale rotor



Meshing system used was comprised of three sections, tightly knit strand layers (red), a nested off-body background mesh (green), and a background mesh (blue)



Streamlines show inflow coming in from the sides as well as the top of the rotor

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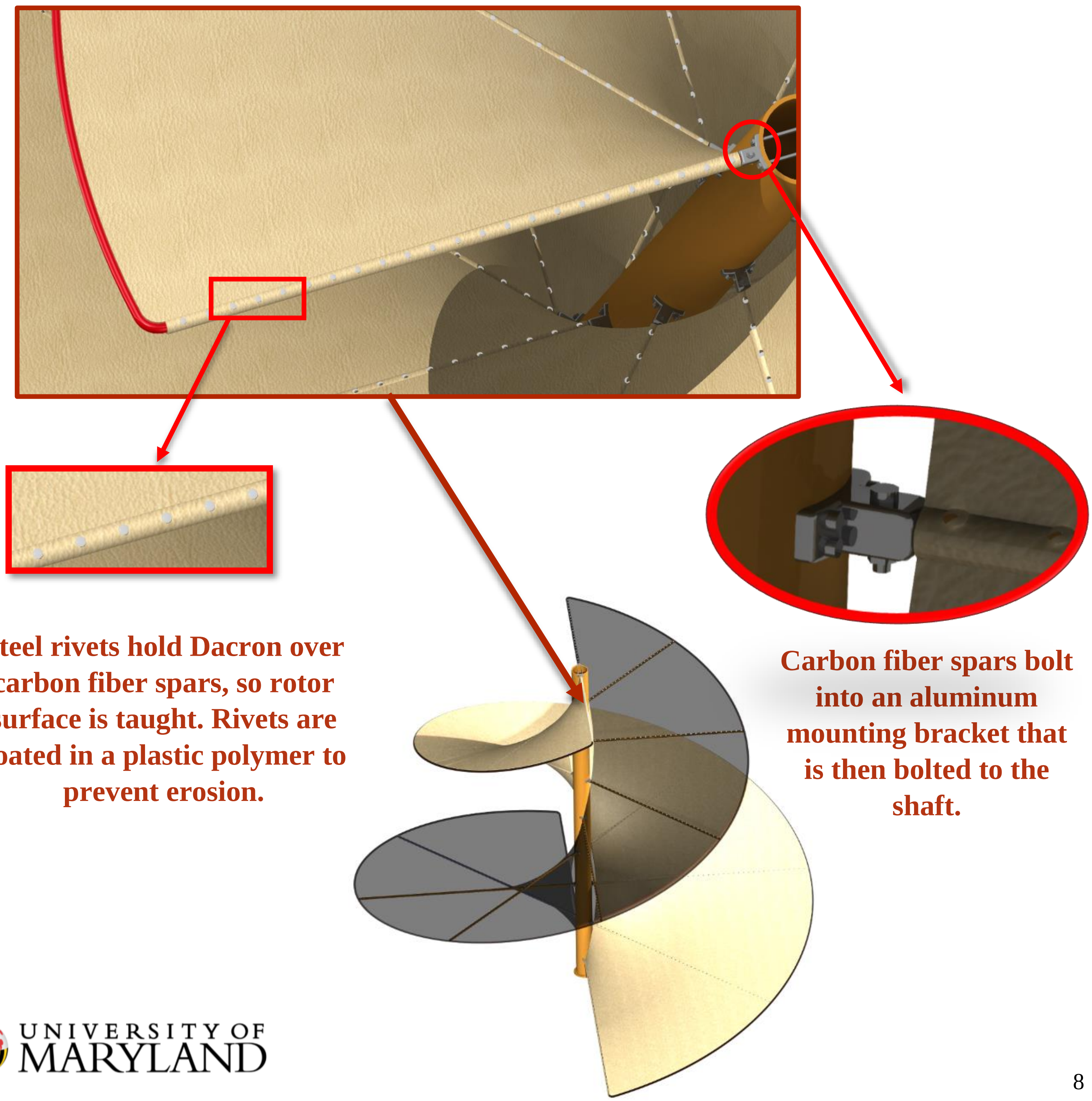
Rotor Structure and Materials

Samara's rotor is designed to be durable and lightweight. Its central shaft is a hollow, carbon fiber cylinder with carbon fiber spars extending outward to support a two-layer Dacron fabric. Each rotor contains 18 spars which support the aerodynamic loads during flight. The spars are wrapped and epoxied to an outer, carbon fiber helix by means of an unidirectional carbon fiber sheet.



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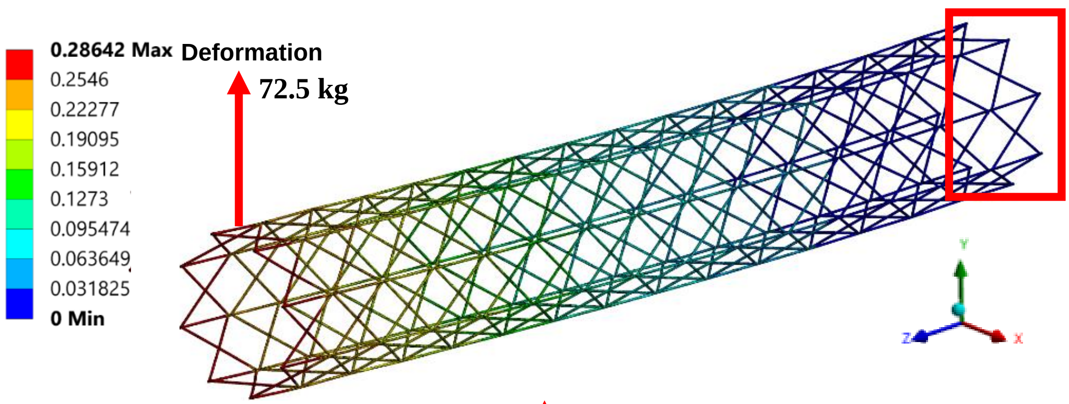
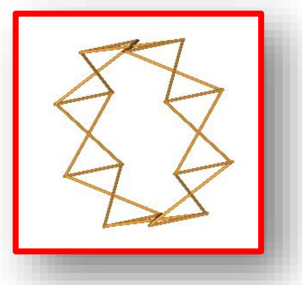
Airframe: The OctaTruss and Cockpit

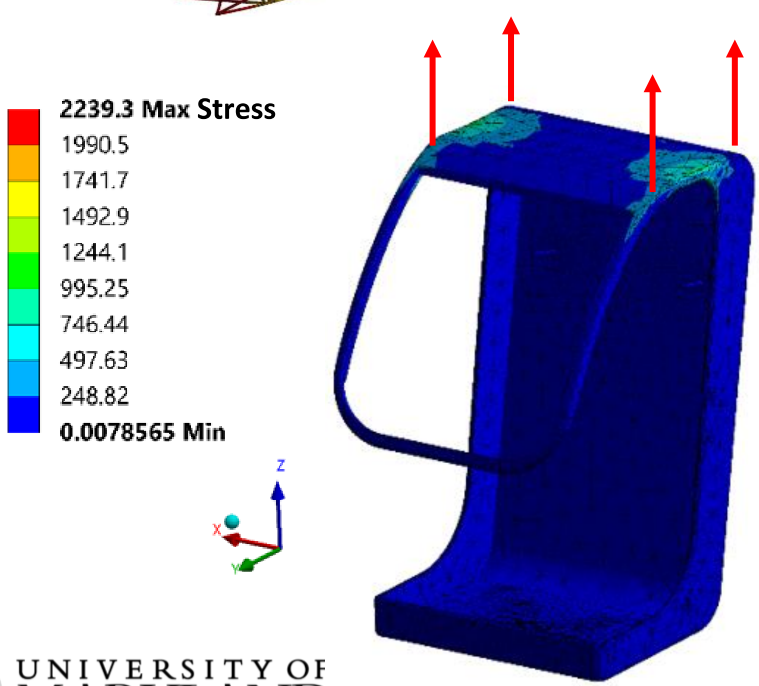
The 2 m (6.59 ft) composite OctaTruss consists of an octagonal cross-section formed with longitudinal rods and diagonal rods crossing at a 45-degree angle with respect to each other. The light-weight truss is sized to resist flight loads with a tip deflection less than 2% of its total length. The OctaTruss **absorbs combinations of bending, shear, and torsion loads.**

Max Bending Load Case

- Factory of Safety = 8.10
- One Arm = 2.81 kg







Cockpit

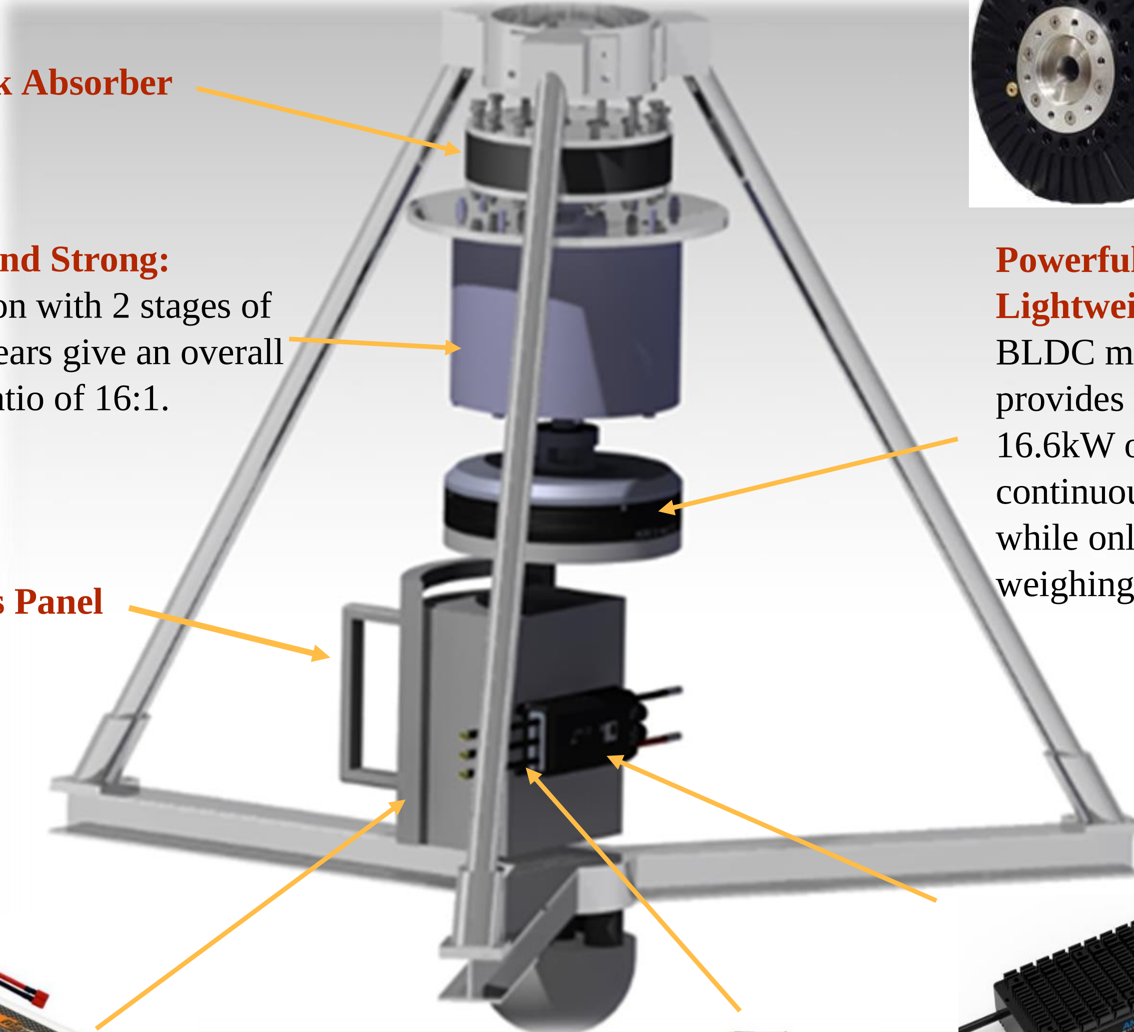
- 2389 N (536 lb) net force applied during take-off
- Carbon Fiber Frame
- Good Field of View
- Safe, Ultra-light, and Compact

Powertrain Configuration

*Scaled motor based on EMRAX line of products

Bearing Collar

Shock Absorber



Compact and Strong:
Transmission with 2 stages of planetary gears give an overall reduction ratio of 16:1.

Powerful and Lightweight:
BLDC motor* provides up to 16.6kW of continuous power while only weighing 4.15kg.

Access Panel

Confidence:
High performance electronic speed controller and battery modules ensure that ***Samara*** is responsive to pilot's inputs, while keeping the pilot informed about motor and battery status.

Long-Lasting Batteries:
Max Amps 9000XL batteries provide a total of 36000mAh, and up to 183 seconds of hover endurance per flight

Landing Gear and Shock Absorber

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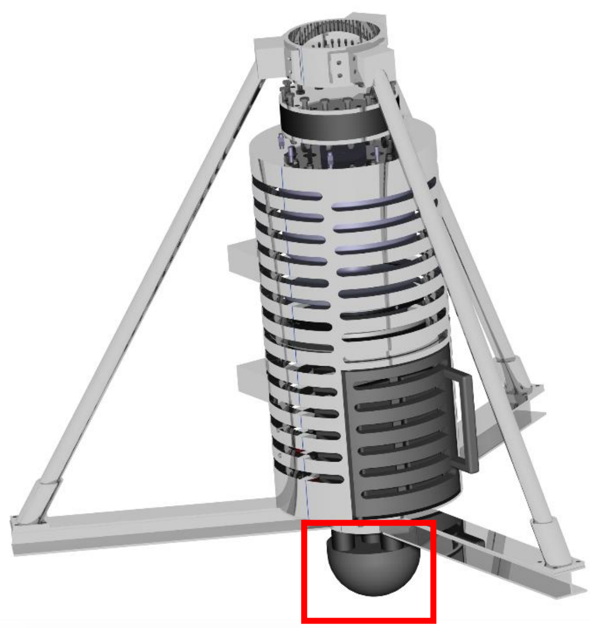
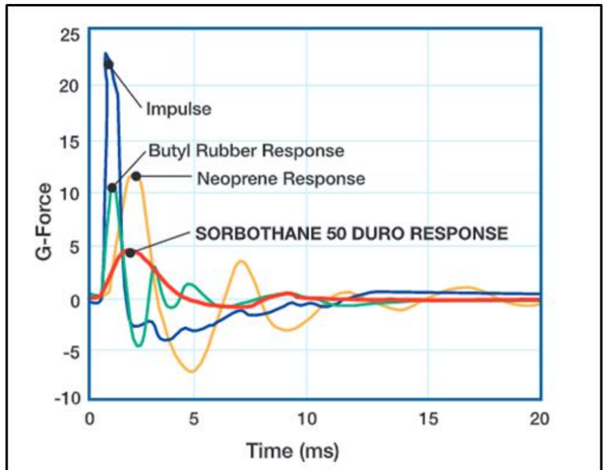
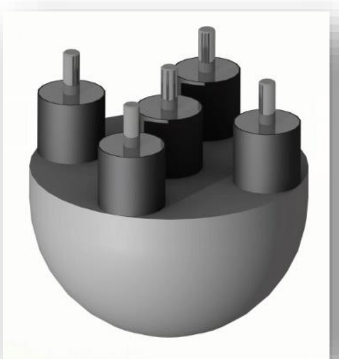
High Shock Absorbent Landing Gear

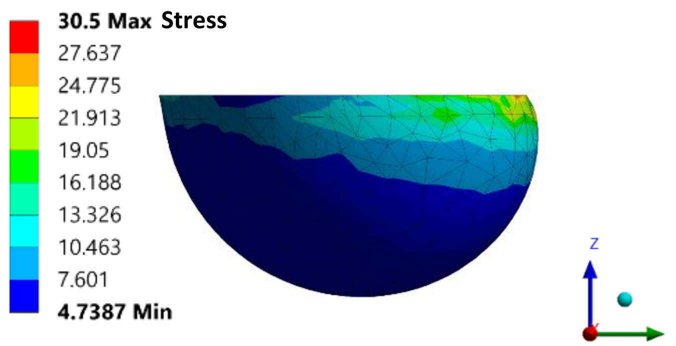
Samara's landing gear features five 0.03 m (1 in) radius sorbothane cylinders and a 0.1 m (4 in) radius sorbothane half sphere that act as shock absorbers due to their high damping coefficient. Three aluminum I-beams help to dampen vibrational moments created by the rotor.





Time Delay Effect of Impulse (Shock) Response of Selected Materials





Sorbothane half sphere absorbs shocks and allows for heavy landings on uneven surfaces.

- Max stress occurs at a 45-degree landing with respect to ground.
- Magnitude of force applied is 145 kg (320 lbs), ½ of GTOW.
- Safety Factor is 6.26

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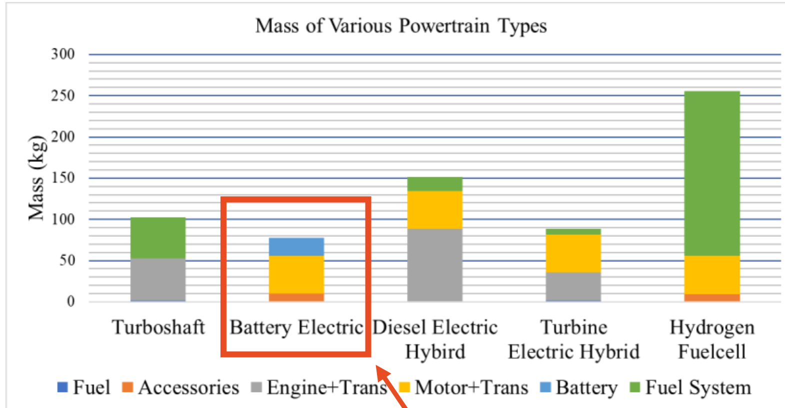
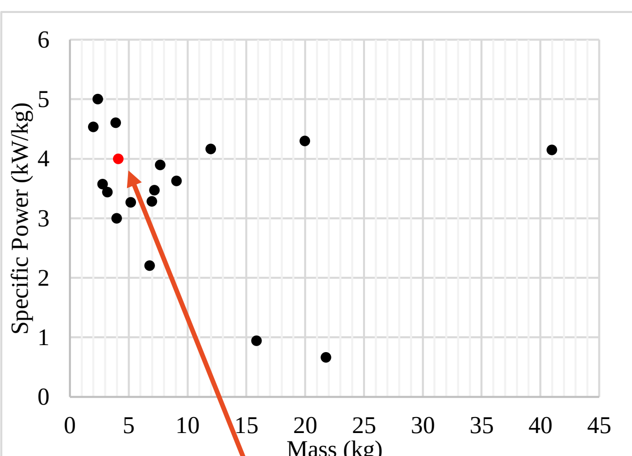
Brushless DC Motor

A brushless DC motor paired with a lithium-polymer battery provides the most efficient and lightweight powertrain for ***Samara***.

- Motor is extrapolated from EMRAX line of motors, envisioned as a ~15kW motor beneath their smallest motor, the 22kW 188
- Battery weights are kept low by using energy dense Li-po chemistry, and craft's limited endurance requirements
- Battery electric systems are mechanically simple, adding robustness

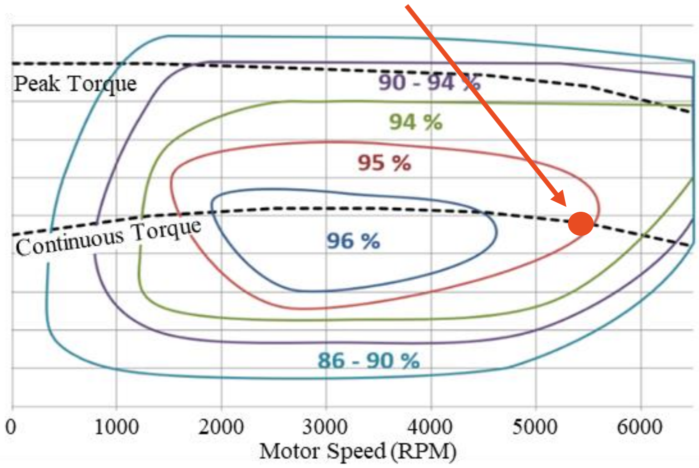


Samara uses the lightest powertrain configuration: battery-electric



Motor's specific power of 4kW/kg is a conservative figure for assumed specific power; still meets requirements for craft.

Motor is 95% efficient in hover; it decreases size of battery to keep powertrain weight low.



Efficiency Plot overlaid on Torque vs. RPM for EMRAX 188

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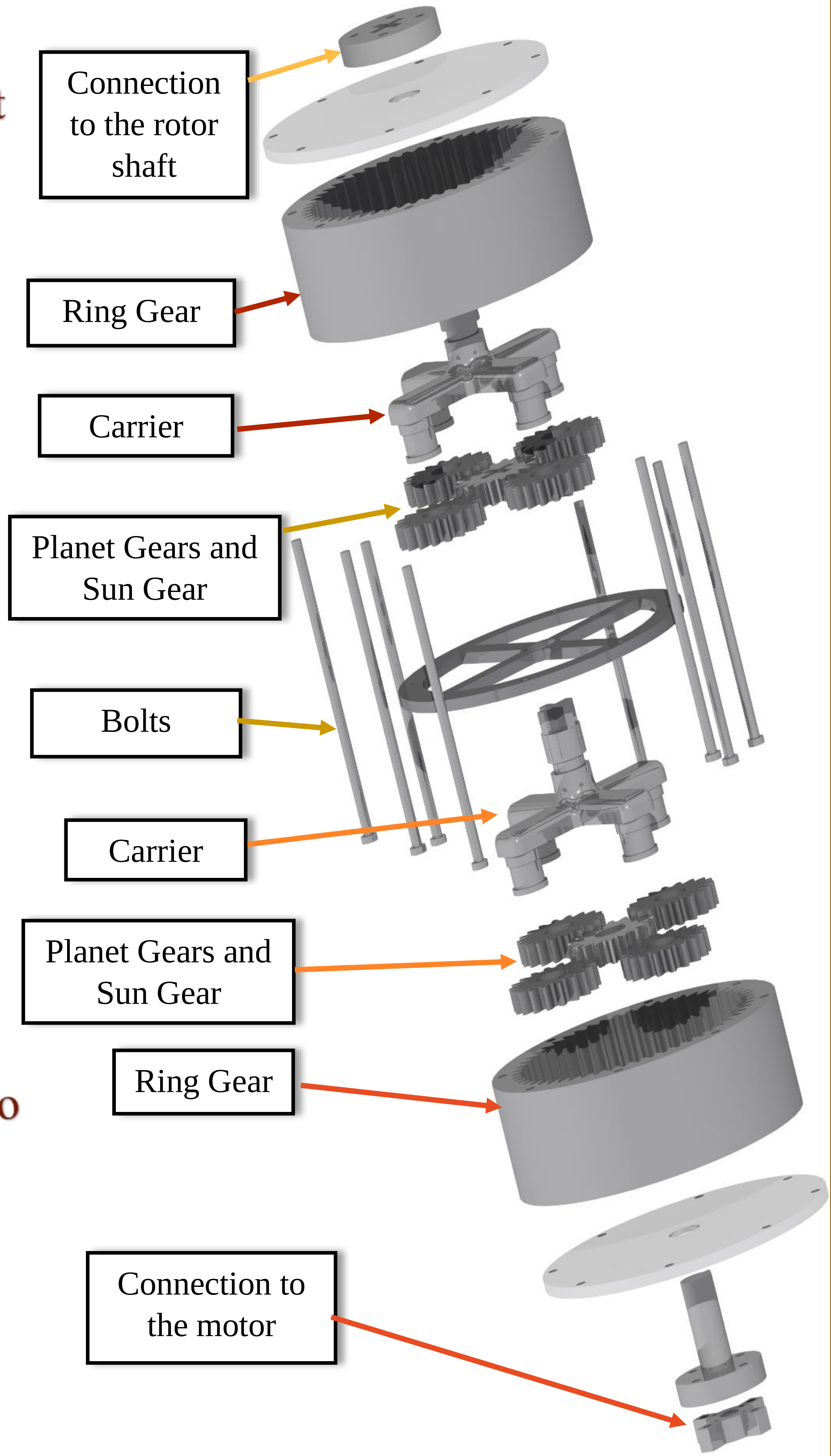
A Compact Gearbox Design

- Two stage planetary gear box for a compact efficient design
- Each stage has a 4:1 gear ratio
- Total gear ratio is 16:1
- Each stage has 4 planetary gears
- Easily fits above the motor and inside the landing gear structure
- Reduces Motor RPM to a shaft output of 350 RPM for maximum drivetrain efficiency



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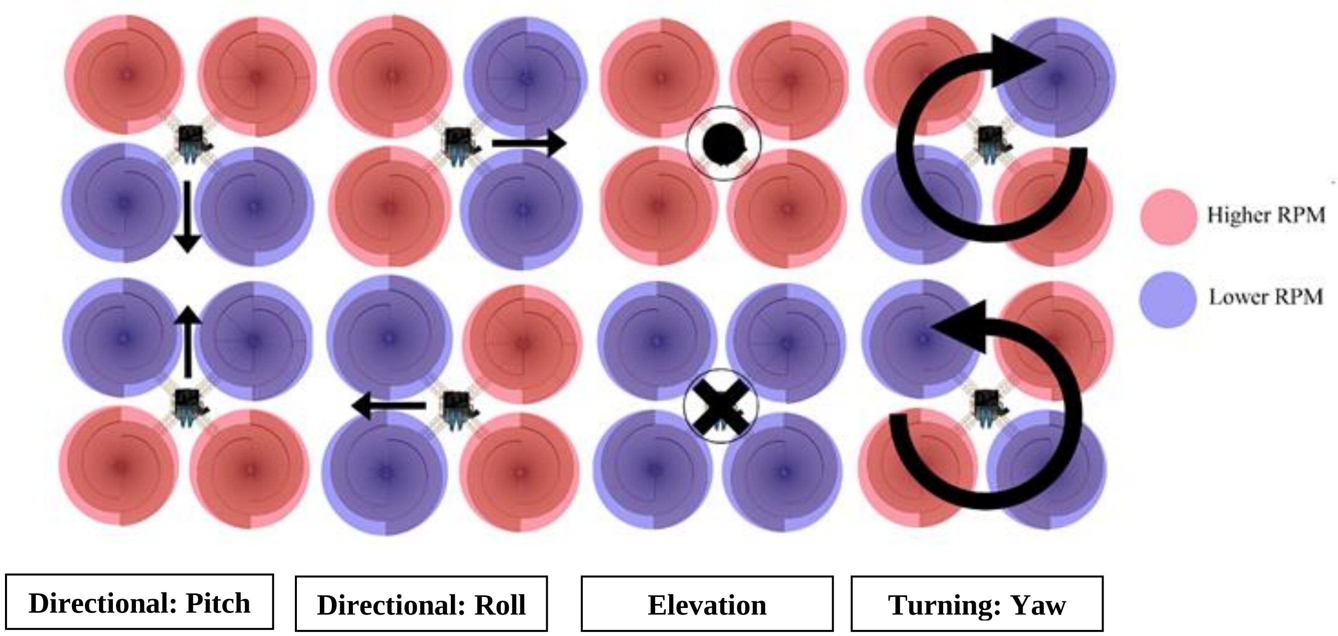
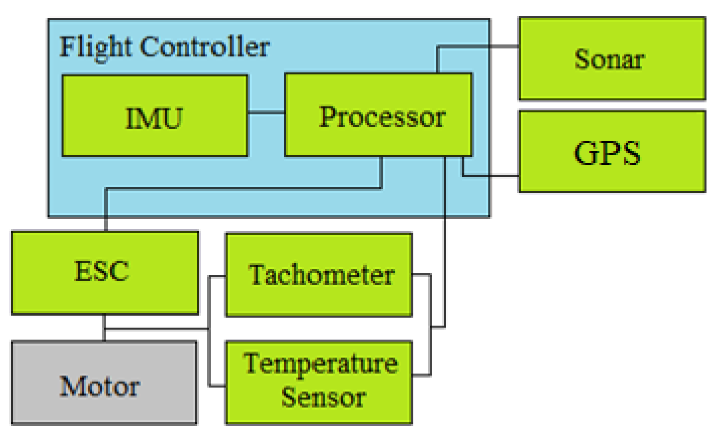
Flight Control System Design

The quadrotor configuration of ***Samara*** allows for maneuverability with simple RPM changes of the individual rotors. The mission profile's flight path is planned within the software system and each phase of the mission, as well as the transition in between, can be performed autonomously. Control can also be swapped to pilot control when necessary.

Each aerial screw can be tuned to a specific RPM based on the phase of the mission and the dynamics required so that the vectors of the vehicle result in the desired motion.



Navigation and drift can be monitored through the IMU, GPS, and the processor can communicate through the avionics system to autonomously correct any deviations during the flight.



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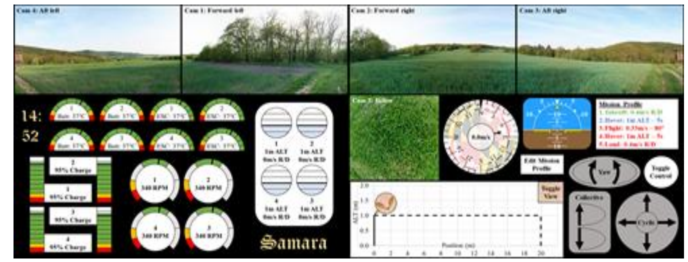
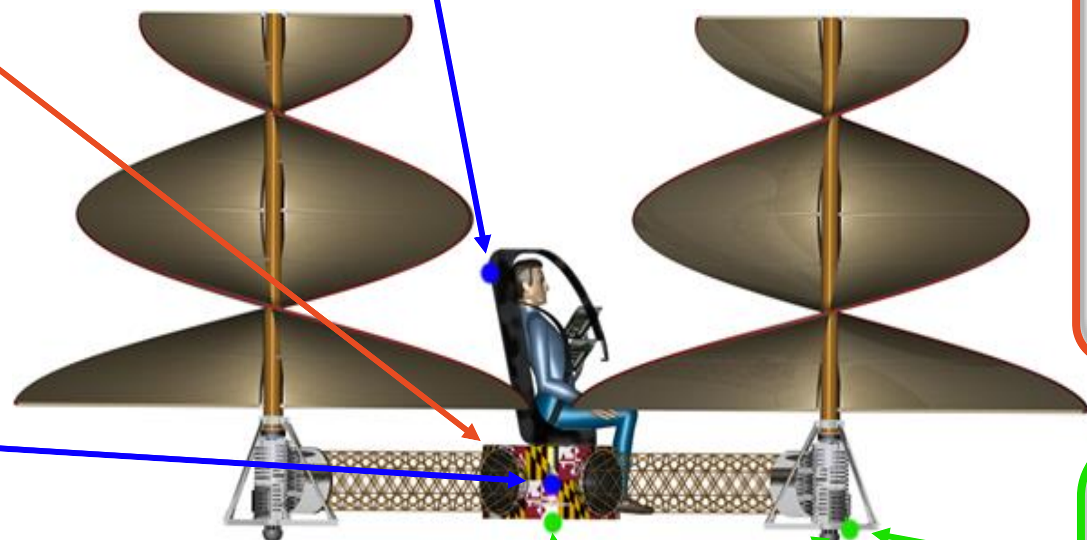
Avionics: Made for Reliability, Safety, and Low Pilot Workload

Avionics Bay

GPS System:
GPS module that is compatible with the Pixhawk.



Cockpit Display for Low Pilot Workload



Pixhawk:
Flight controller with a 32-bit processor and triple redundant internal IMU system.

Camera System:
- One per arm, one below cockpit
- High resolution camera to provide a live feed of the pilot's blind spots for obstacle avoidance.

Sonar Sensors:
- One per arm
- Ultrasonic distance sensor functioning as a distance sensor.

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Conclusion

After 500 years, one of da Vinci's most forward-thinking inventions - the Aerial Screw - is reborn as ***Samara***. This vehicle features creative design solutions that resulted from extensive testing, simulation, and analysis. With its distinct looks and uncompromised capabilities, ***Samara*** is a fitting tribute to one of history's greatest inventors.

Main Achievements:

- Successfully designed high-performance, single-bladed, concentric Aerial Screws
- Generated newfound research on physics of the Aerial Screw using CFD simulation and scale testing
- Designed a safe Aerial Screw with low vibratory loads
- Address all specifications required in the RFP

Bringing da Vinci into the Modern Era:

- Light weight, OctaTruss structure with the highest specific strength to weight ratio
- Efficient all-electric powertrain
- Compact powertrain and gearbox
- Modern avionics and autonomous control system
- Excellent pilot vision
- Shock absorbing landing gear