



UNIVERSITY OF
MARYLAND

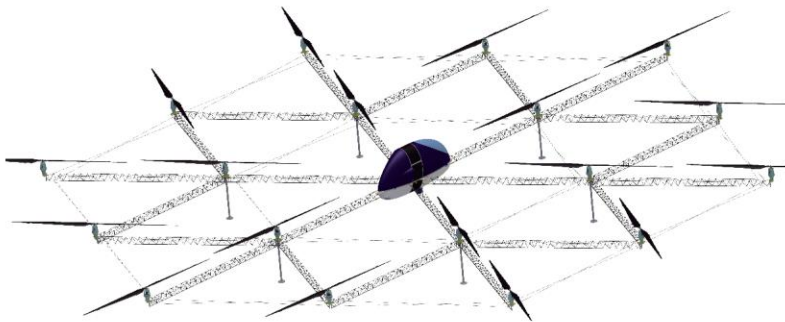
The *Chezoía* Multi Purpose Platform



Introduction

In response to the American Helicopter Society's 24 Hour Hover Request for Proposal, the University of Maryland presents *Chezoía*, a novel, unprecedented hover, multi purpose platform.

Chezoía's name is derived from the Greek words *chelóná* and *makrozoía*, meaning turtle and longevity respectively. This portmanteau has been created to reflect the University of Maryland's mascot, as well as the aircraft's main mission for extended hover.



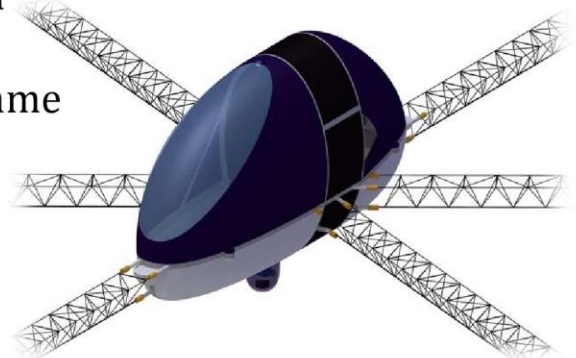
Aircraft Capabilities

Chezoía is a multi-rotor platform capable of 25 hours of continuous hover carrying a payload of 176.4 lbs, exceeding the requirements of the American Helicopter Society's RFP. Additionally, it is equipped

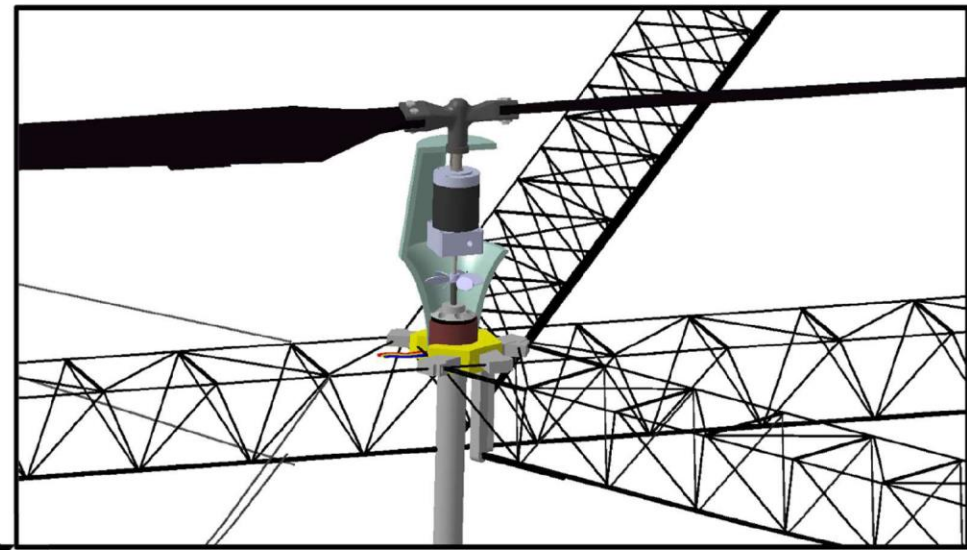
for fully autonomous operation from start to shutdown, further exceeding the stated challenging requirement. All of this is possible using developments based on currently available technologies, to synergize a system in stipulated time and exceeding all previous rotorcraft performance.

Design Highlights

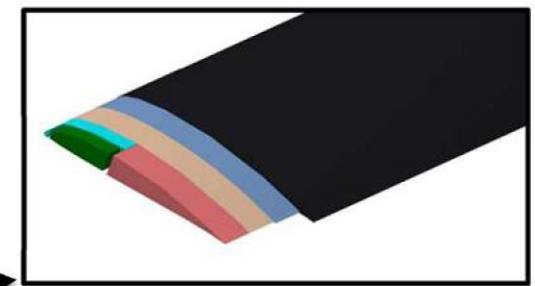
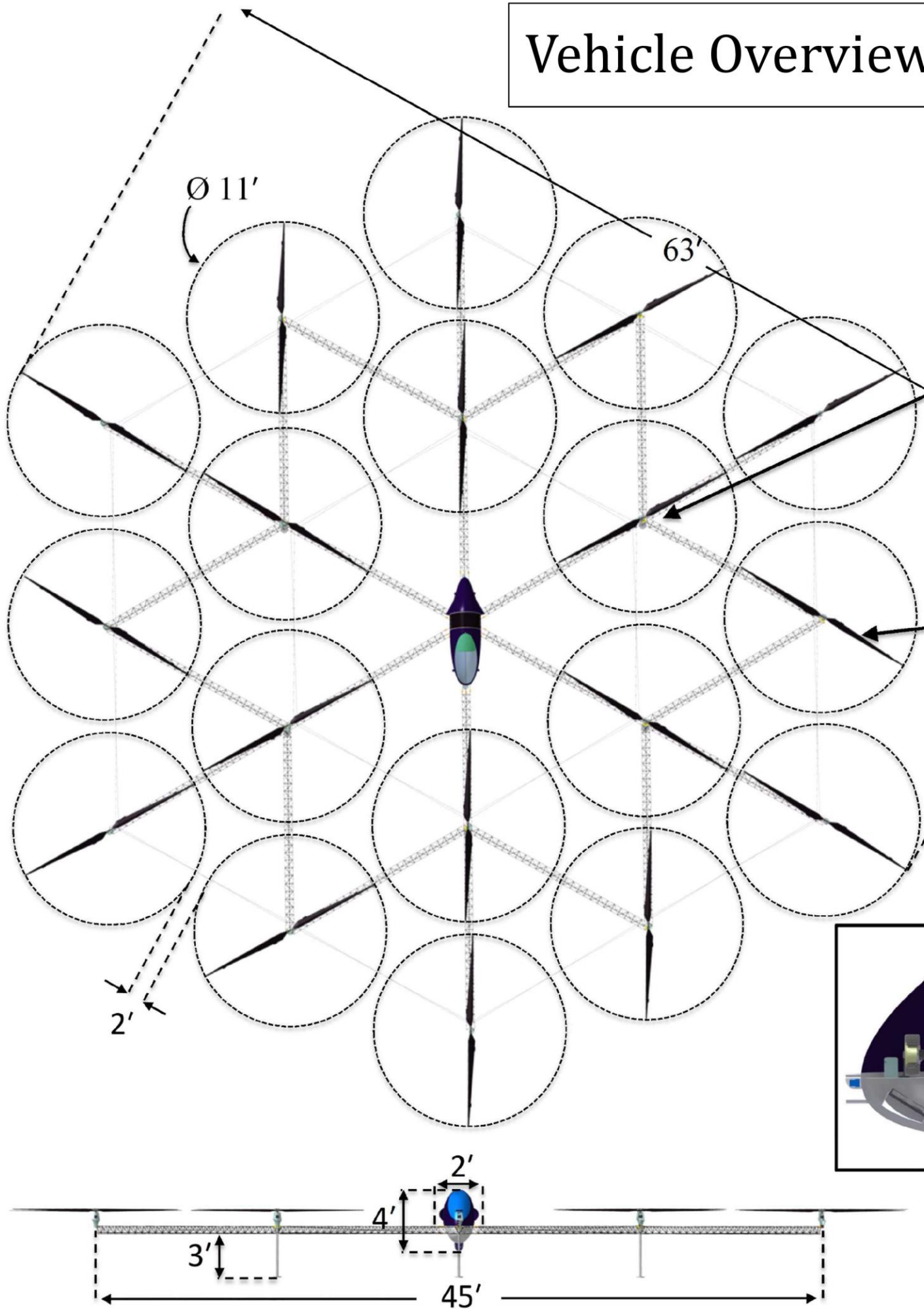
- Distributed propulsion - 18 rotor configuration
- Diesel-electric hybrid powerplant
- Innovative ultralight microtruss modular airframe
- Superior avionics and obstacle avoidance suite
- Multi purpose mission capabilities
- Design based on team-developed algorithms
- Multiple control redundancies with RPM variations



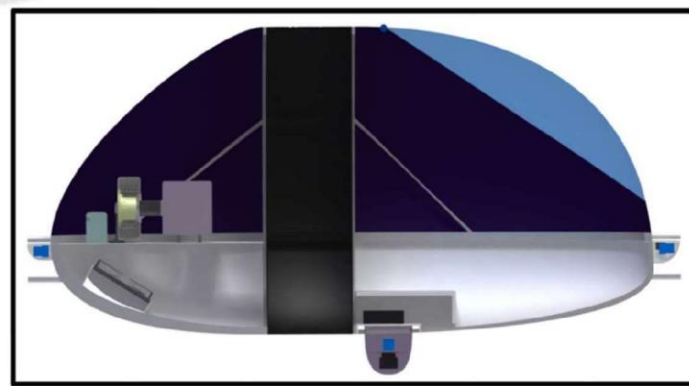
Vehicle Overview



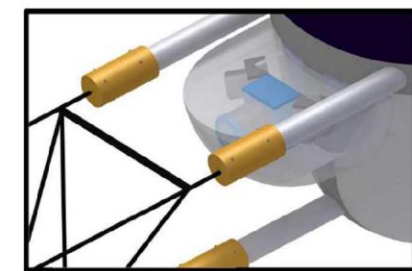
Hub design promotes airflow for cooling through integrated fan, as well as maintaining fixed pitch for rotors.



Blade structures designed for weight reduction, as well as aeromechanic considerations

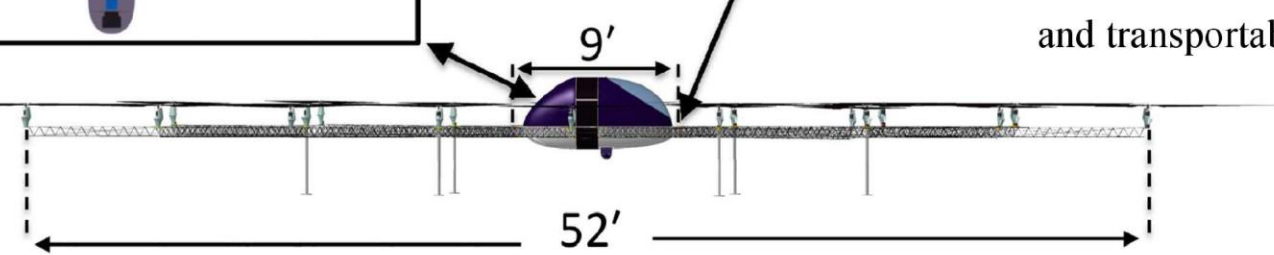


Fuselage contains payload, main engine and generator, fuel tank, cooling systems, as well as most of craft's avionics package.



Microtruss structure supports fuselage through three pinned connections at all six connection nodes. This allows for structural integrity as well as modularity and transportability.

GTOW	1003.4 lbs
Empty Weight	607.0 lbs
Payload	176.4 lbs
Fuel Weight	220.0 lbs
Number of Rotors	18
Blades per Rotor	2
Rotor Diameter	11.0 ft



Design Drivers



Mission Stages by Time:

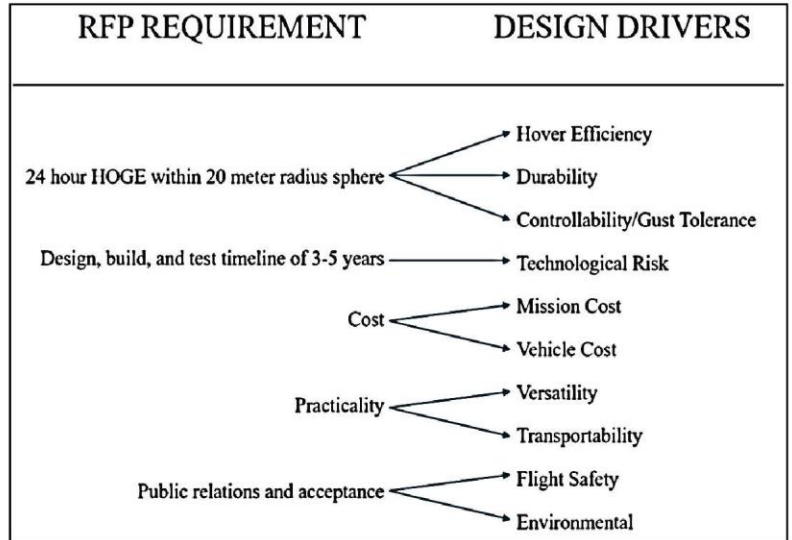
The mission profile is dominated by hovering flight. Vehicle is designed to hover for 25 hours. The extra hour accounts for disturbances and movement between hover stations.

For forward flight between hover stations at 30 knots (15.4 m/s), the total time will be less than 0.2% of a 25 hour mission

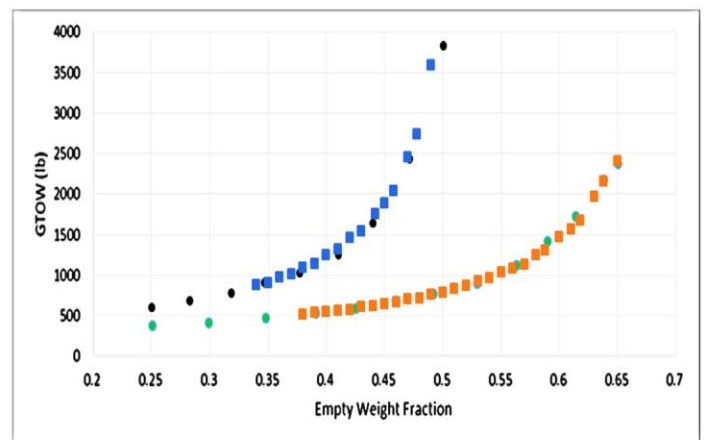
Time spent climbing to at least 2 vehicle dimensions amounts to about 0.2% of the total mission time.

Chezoia's design based on team-developed sizing algorithm utilizing:

- Tishchenko Methodology
- Army's Aero Flight Dynamics Directorate (AFDD) NDARC equations
- In-house structural models
- Estimates for the power and energy density based on current motors and power sources
- Validated against RFP supplied data



Design philosophy most heavily emphasized **hover efficiency** and **durability** because of the mission's length and **controllability** due to the stringent definition of hover given in the RFP

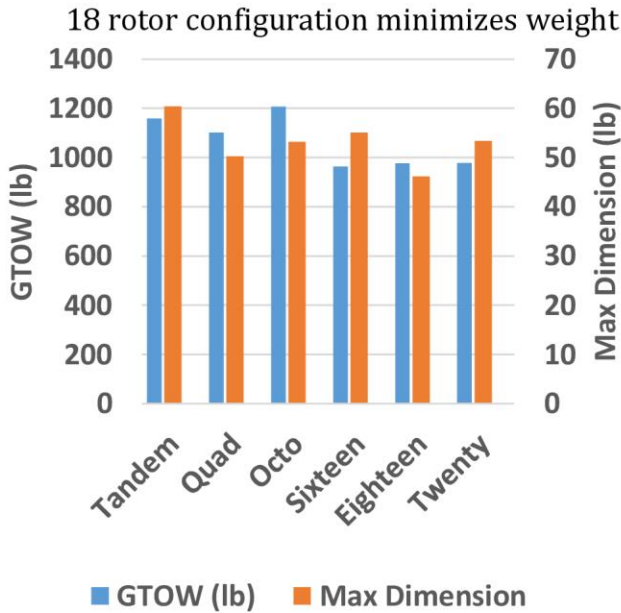


Data provided in the RFP (circles)
Data output by the sizing code (squares).

Multicopter Configuration



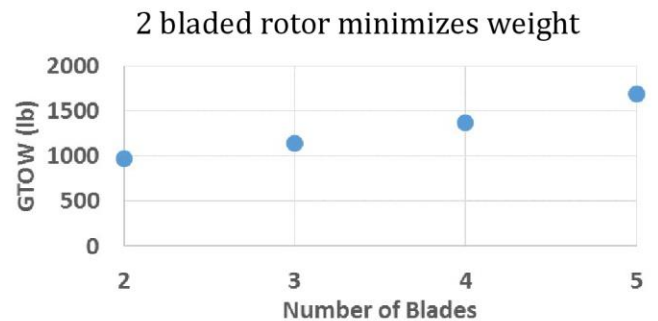
A multicopter configuration was chosen for *Chezoía* based on the sizing code and qualitative ranks using analytical hierarchy process and Pugh matrix. Further analysis using the sizing code showed that a design with 18 rotors, each with two blades is optimum for the mission, leading to the selection of the diesel-electric hybrid powerplant.



Multicopter Characteristics

- Low disk loading
- Low blade loading
- Variable RPM for flight control
- Torque balanced
- Hybrid propulsion system
- Proven control scheme
- Mechanically simple construction
- Multiple redundancies

Parameter	Value	Description
Rotors	18	2 bladed
Engine	1	Flat diesel
Generator	1	Brushless AC motor
Transmissions	18	BLDC motor, planetary gearbox
Arms	6	Tapered carbon fiber truss
Branches	12	Carbon fiber truss



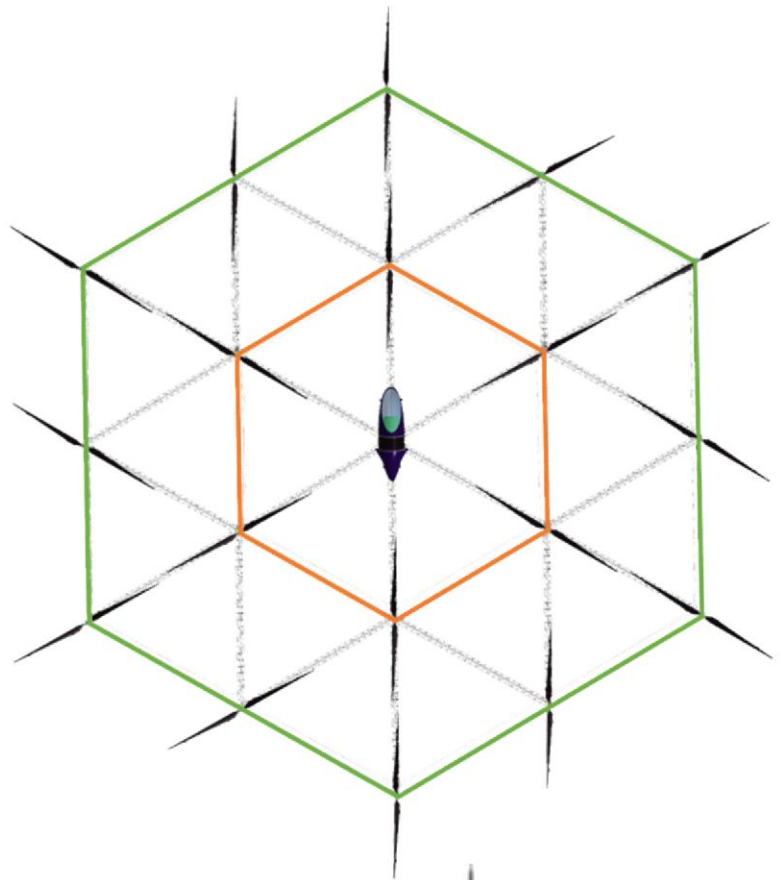
Helicopter	Disk Loading
Robinson R22	2.6 lb/ft ²
Chezoía	0.61 lb/ft ²
Gamera	0.03 lb/ft ²

Optimized Structures

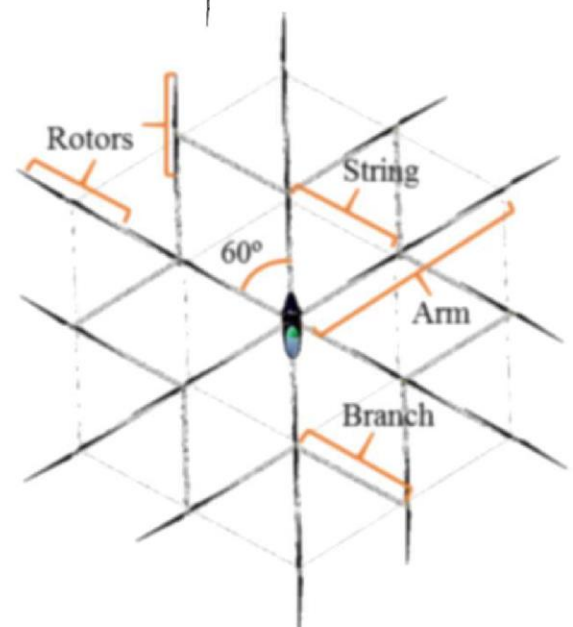


Chezoia's rotor layout was created with **symmetry, structural integrity, and controllability** in mind. These drivers resulted in the compact dual hexagon layout.

The layout, along with the directionality of the rotors, facilitates **control redundancy** for cases of single or multiple rotor failure. In these cases, the autopilot adjusts for the failures by increasing thrust from the remaining rotors.



Additionally, the structural robustness has been **optimized to minimize weight** for areas with lower loading. As such structural members are categorized as either **arms, branches, or strings** in descending order of weight.



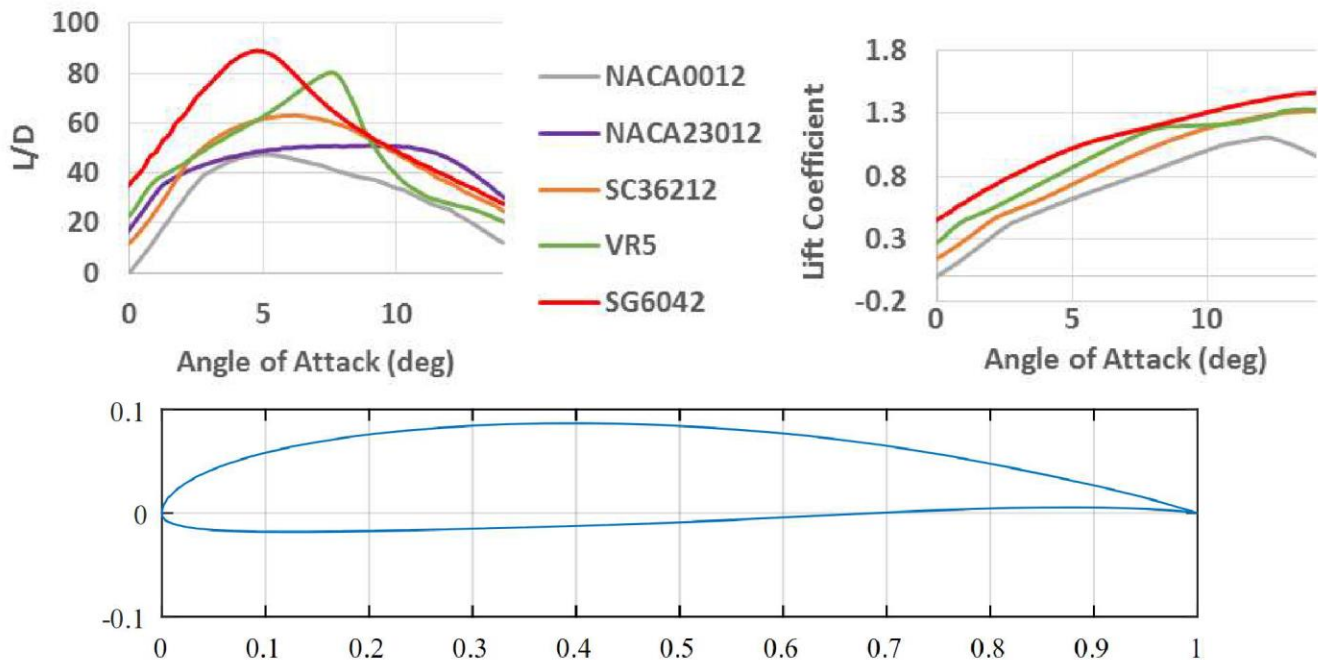
Sizing Results :

- Blades per rotor = 2
- Tip speed = 260 ft/s
- Aspect ratio = ~ 20
- Baseline tip Reynolds number = 400,000
- Radius = 5.5 ft
- Disk Loading = 0.6 lb/ft^2

SG6042 chosen:

The resulting blade has a power loading of 39.7 lb/hp. Most of the blade's angle of attack is within the range of 4 to 6 degrees, where the highest L/D occurs.

Airfoil characteristics from XFOIL

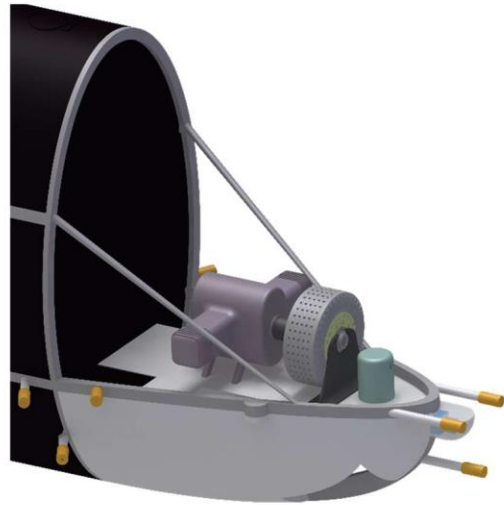


Chezoía's aerodynamics was optimized using BEMT code that included tip loss effects and an airfoil lookup table based on angle of attack and Reynolds number.

The code used a sweep of design variables while constrained by 56 lb thrust per rotor, the rotor was designed to minimize the power in hover

Blades with Dihedral, bi-linear twist and taper and the use of multiple airfoils have more manufacturing penalties than aerodynamic benefits.

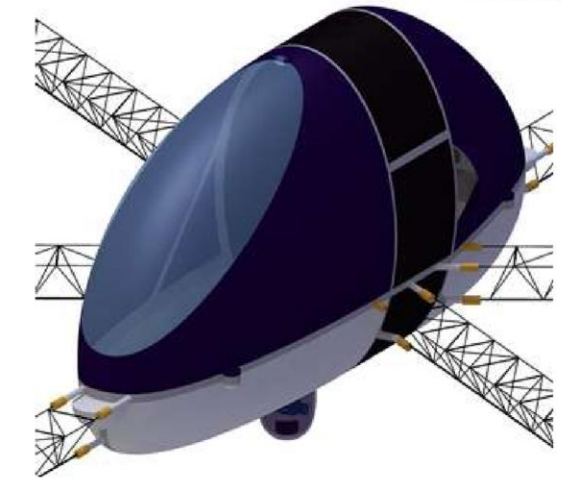
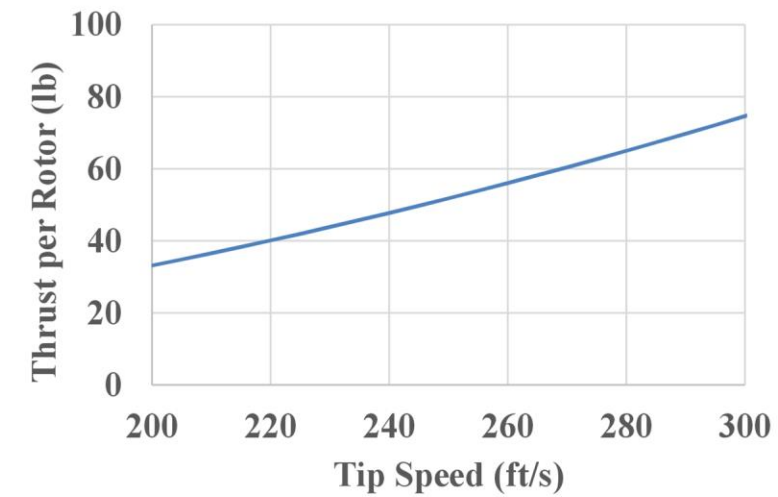
Rotor and Vehicle Performance



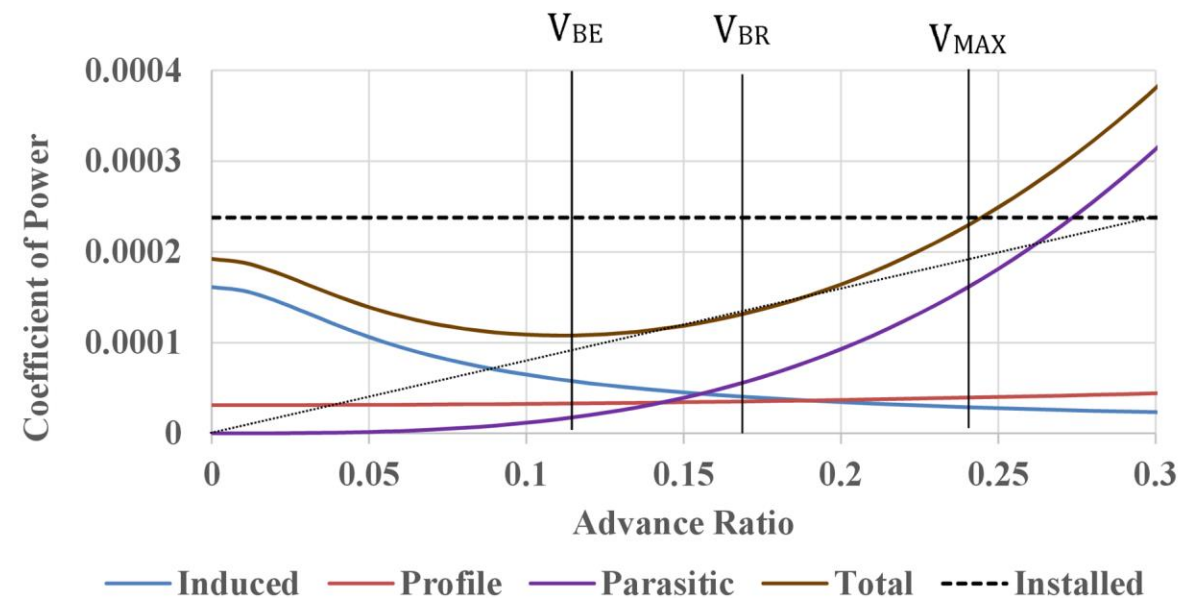
Rotor Parameters

Rotor Parameter	Value
C_T	0.0037
C_P	$1.96 \cdot 10^{-4}$
FM	0.803
K (induced power factor)	1.0475
Taper Ratio	0.144
Twist (Root to Tip)	6.39°
AR	20.5
C_T/σ	0.175

Tip Speed Control



Forward Flight



Vehicle Range and Endurance

Maximum Hover Time	25 hours
Maximum Range	717 nautical miles
Maximum Endurance Time (at V_{BE})	32.6 hours



Optimized Blades



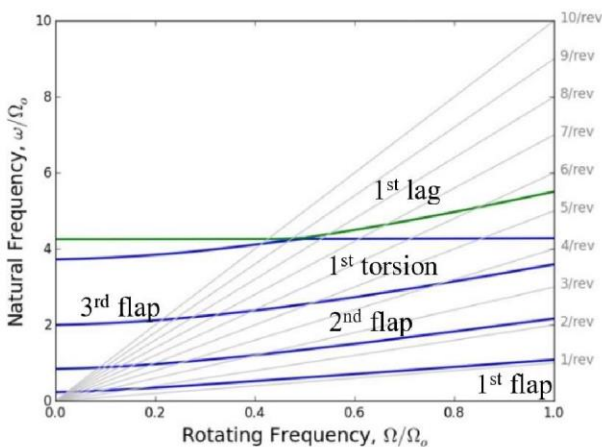
Chezoia's variable RPM rotors achieve efficient hover and minimize the weight and complexity of the rotor system. A fixed-pitch design enables an extremely simple hub, minimizing cost and maintenance time.

Using blade element momentum theory, fixed-pitch blade designs were assessed in hover to determine the optimum blade twist and taper.

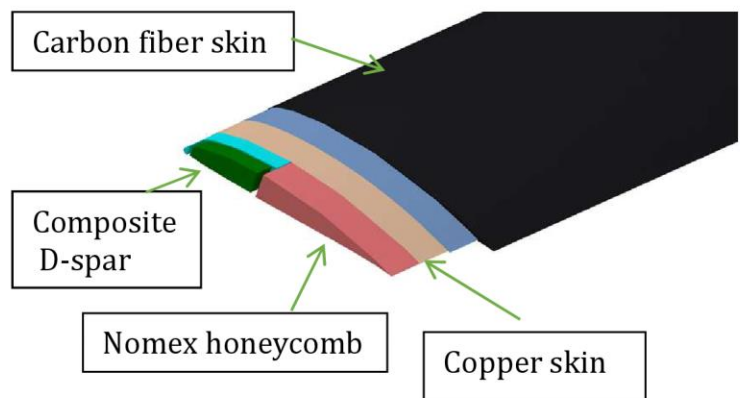
Hover efficiency was prioritized to reduce the vehicle empty weight while preserving sufficient stall margins and propulsive efficiency.

The hingeless, stiff in-plane blades are built using composite materials for the D-spar and outer skin to provide stiffness. The filler material is Nomex honeycomb to minimize weight.

Parameter	Value
Number of Rotors	18
Blades per Rotor	2
Rotor Radius	5.5 ft (1.68 m)
Rotor Tip Speed	260 ft/s (79.2 m/s)
Taper Ratio	6.94:1
Airfoil	SG6042
Root fixed-pitch	15°
Twist	1.36°/ft (4.16°/m)
Blade Weight	3.75 lb (1.7 kg)
Figure of Merit	.803



Chezoia rotor fan plot





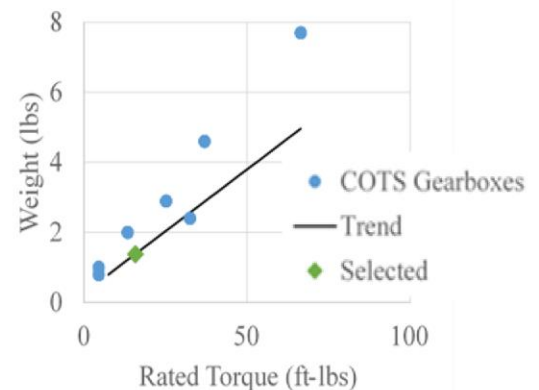
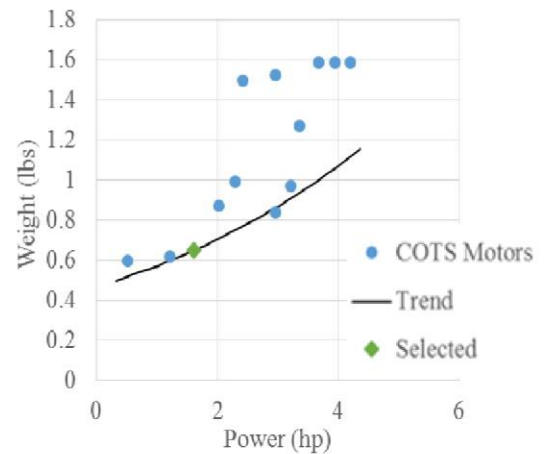
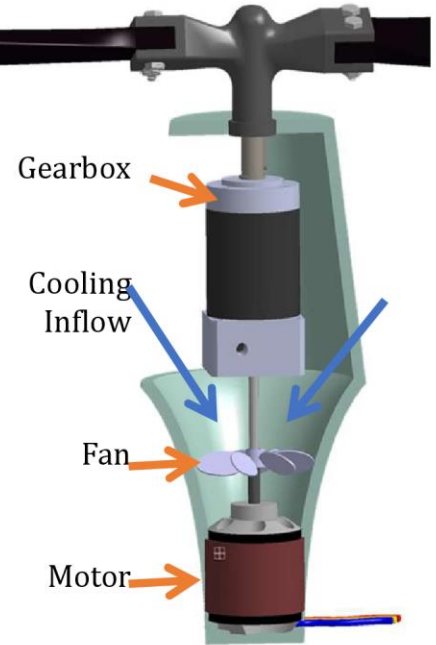
Currently available brushless DC motors and gearboxes were analyzed to generate *Chezoía's* assembly.

The selected motors are “rubber” motors, sized at 1.61 hp, 0.65 lbs, with efficiencies of 95% at the operating RPM. Planetary gearboxes are used for their reliability, ease of integration and efficiency.

The electric motors are air cooled by a small ducted fan connected to the shaft directly above the motor.

Turnigy Super Brain 100A Brushless Electronic Speed Controllers were selected to control the motors.

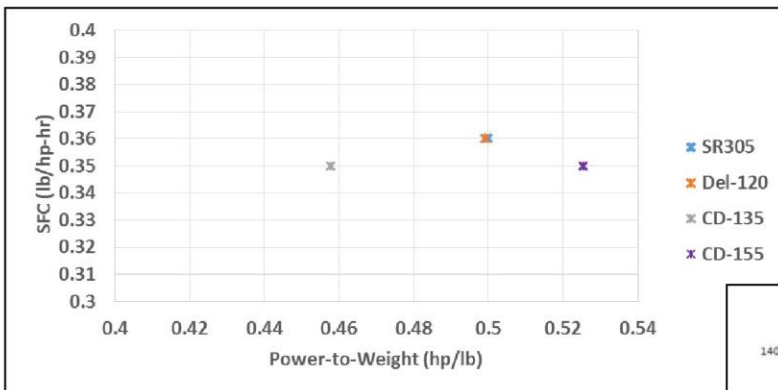
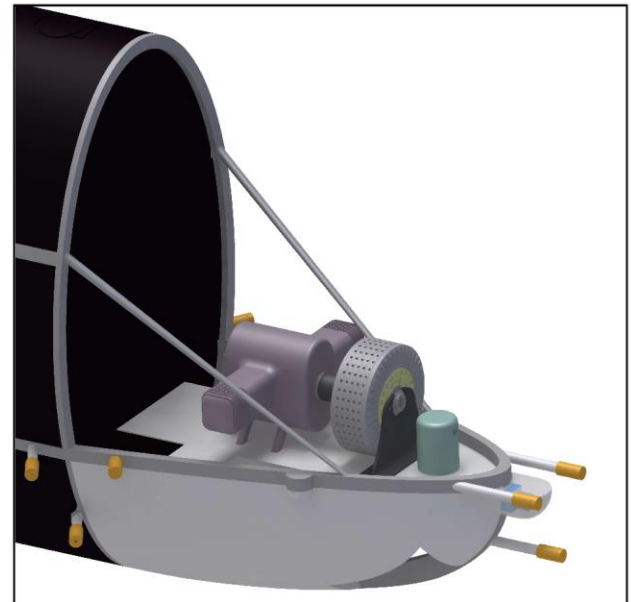
Due to the simple, fixed pitch design of the rotors, *Chezoía* reduces weight and increases reliability for each of its 18 rotors through the elimination of collective or cyclic controls.



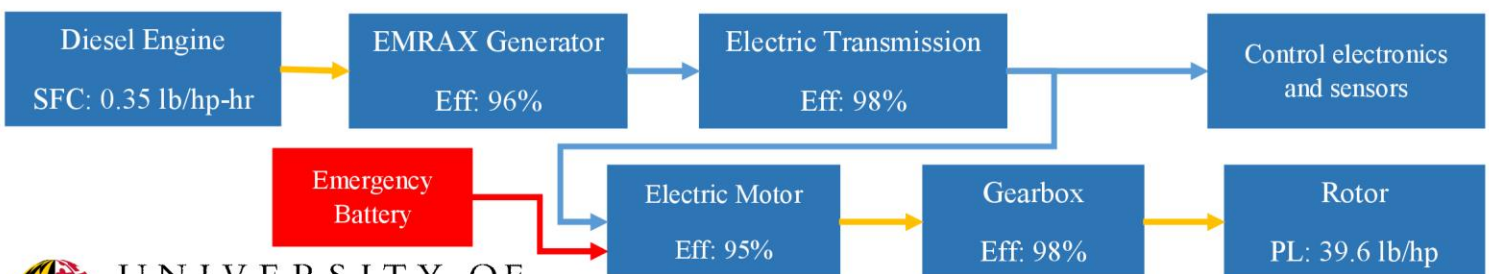
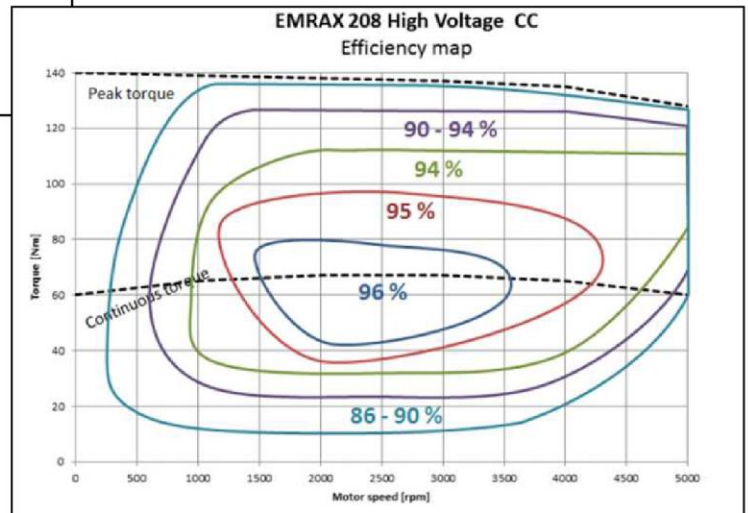
Powerplant



Chezoia utilizes a single “rubber”, flat diesel engine that incorporates current technology. The engine has a power-to-weight ratio of 0.5 lb/hp, and a specific fuel consumption (SFC) of 0.35 lb/hp-hr. The flat configuration reduces vibrations and each of the two cylinders has maximal surface area for cooling.

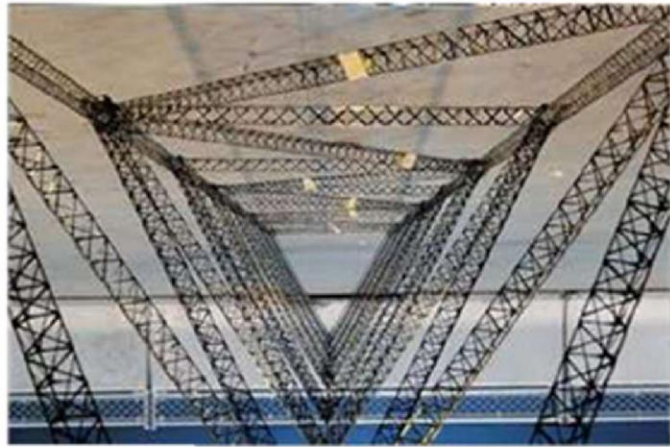


The selected generator for *Chezoia* is the Emrax 208, a brushless AC motor. The low voltage, liquid cooled variant is used, to reduce the potential for arcing and to improve the heat dissipation of the generator. The generator can provide up to 43 hp of continuous power and is 95-96% efficient throughout its operating regime.

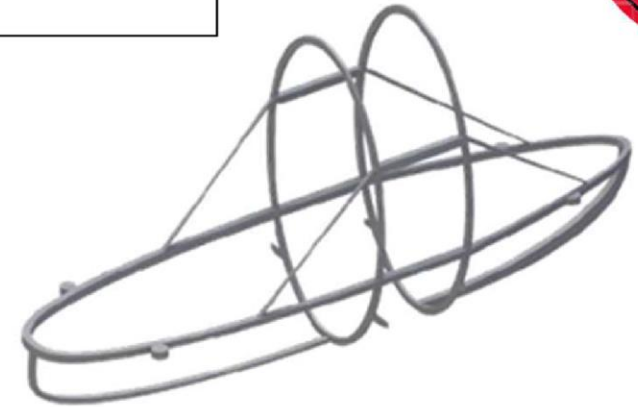
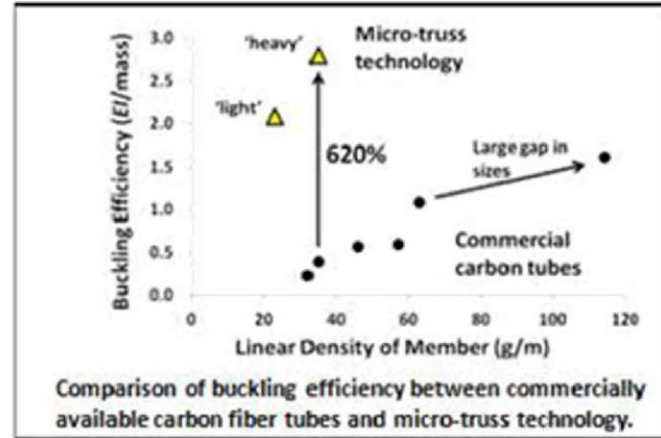


Structural Overview

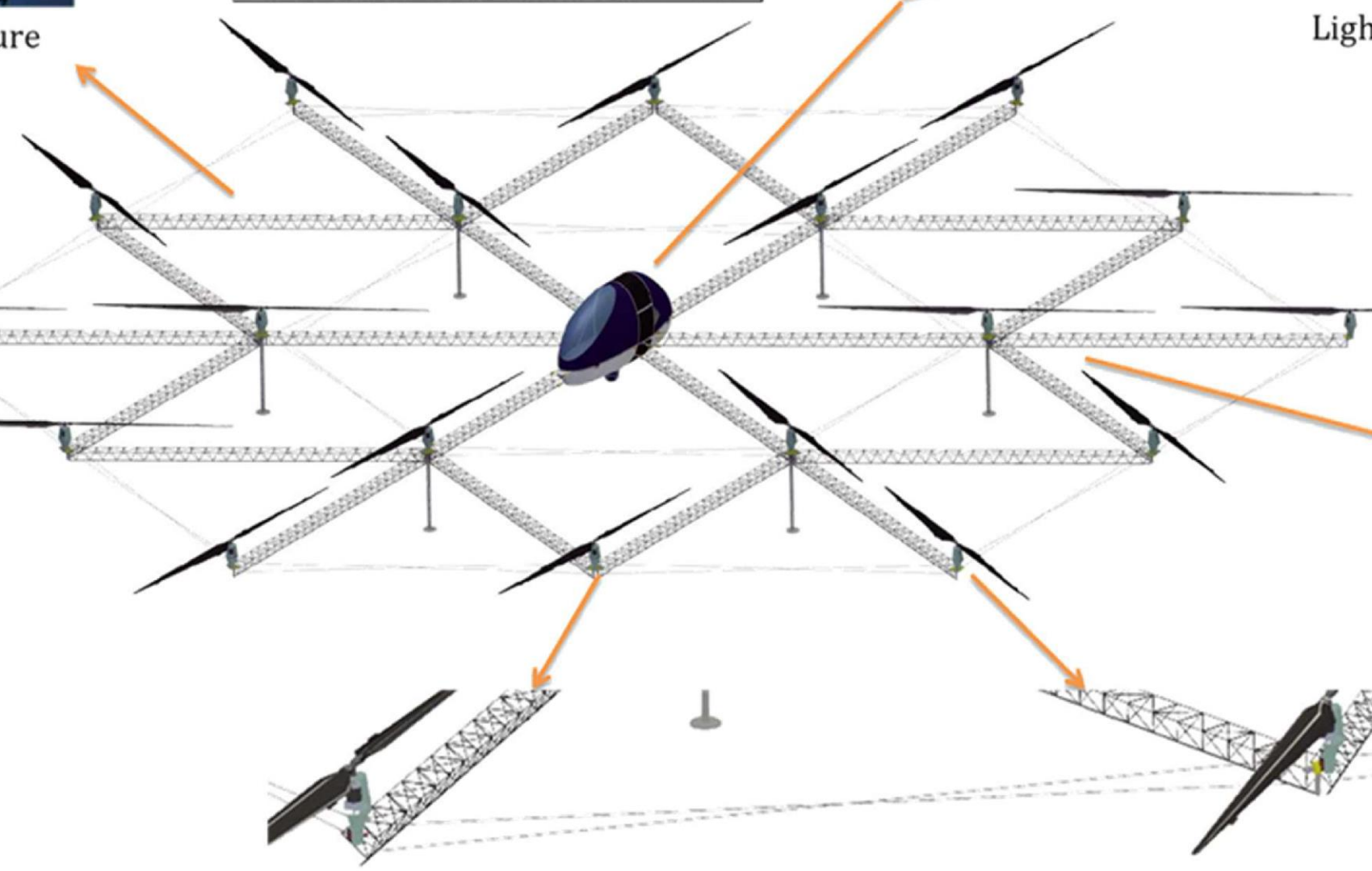
Microtrusses are 620% more efficient than carbon fiber tubes



Innovative microtruss structure



Lightweight fuselage frame

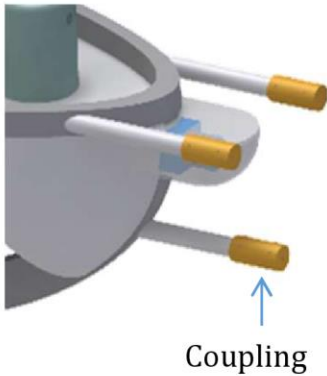


Lightweight landing gear

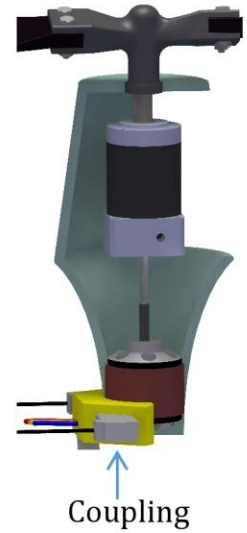
High tensile strength string resists torsional loads

Parameter	Value
Arms	6
Total Arm Weight	86.8 lb
Branches	12
Total Branch Weight	85.7 lb
Stringers	468 ft
Stringer Weight	.516 lb
Total Weight	173 lb

Modularity



Chezoía's fuselage and each of the hubs are equipped with shaft couplings that allow easy attachment and detachment of the arms.



The entire aircraft can be disassembled and the subassemblies packed into two crates:

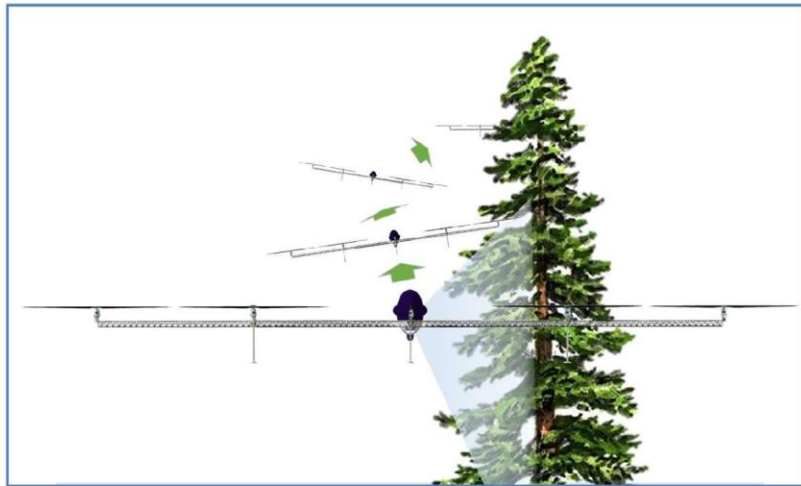
- The first crate is 9 ft x 2 ft x 4 ft, weighs 228.16 lbs and contains the entire fuselage section.
- The second is 13 ft x 2.5 ft x 2.5 ft, weighs 373.76 lbs, and contains the disassembled structure, hubs, rotors, and landing gear.

This assembly kit allows two full *Chezoía* aircraft to fit easily inside of a 17 foot U-Haul truck, four kits can be loaded in a Chinook, and four kits inside a standard 20 foot shipping container.

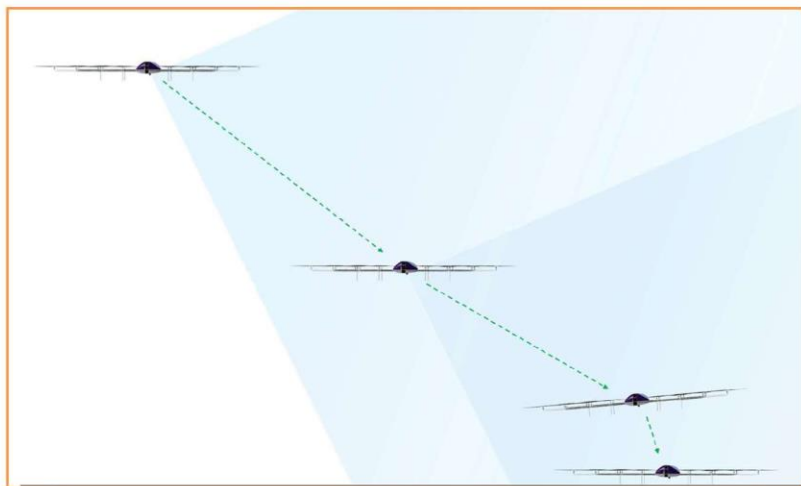
In addition, the modularity of each rotor assembly allows for ease of repairs and replacement of faulty components.



Dynamics and Controls



- (1) Detection of obstacle
- (2) Plot path around obstruction and execute rolling maneuver
- (3) Returns to original flight path



Decline landing allows for dynamic adjustment based on obstacle detection during landing

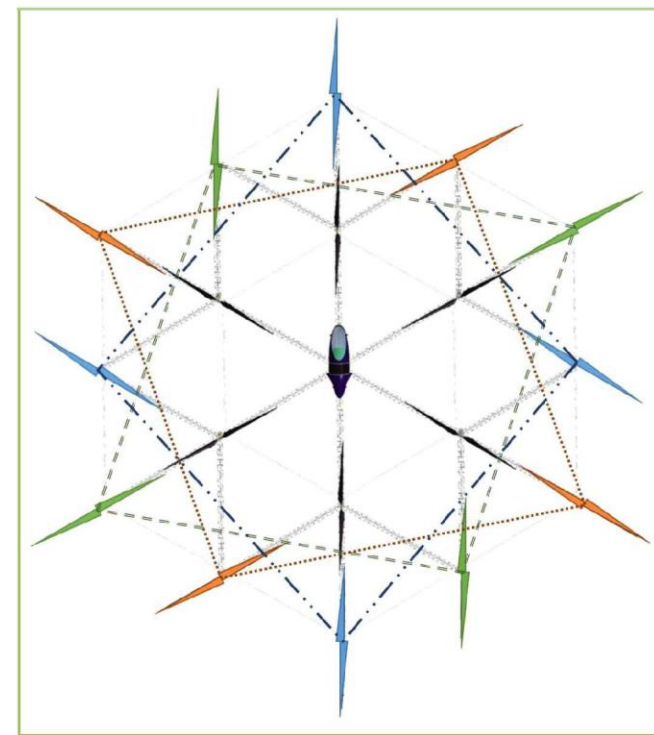
Chezoia's control scheme has been designed to take full advantage of the multirotor configuration for precision control, safety and mission assuredness through redundancy, as well as integrating a full obstacle avoidance suite for autonomous response to dynamic conditions.

Innovative quadcopter control sets offer:

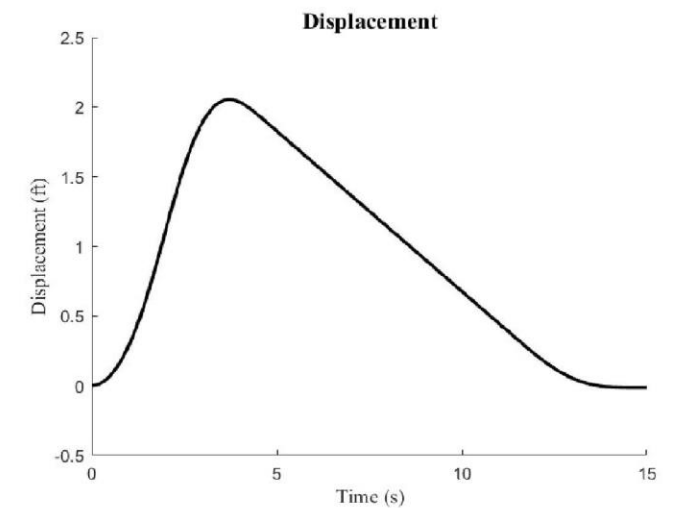
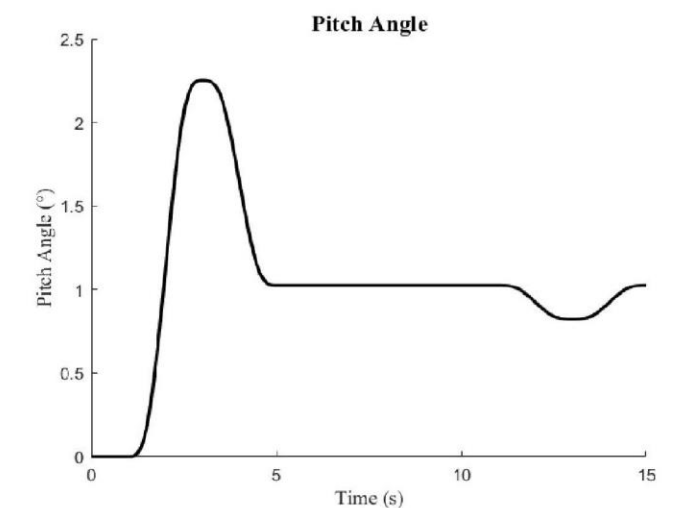
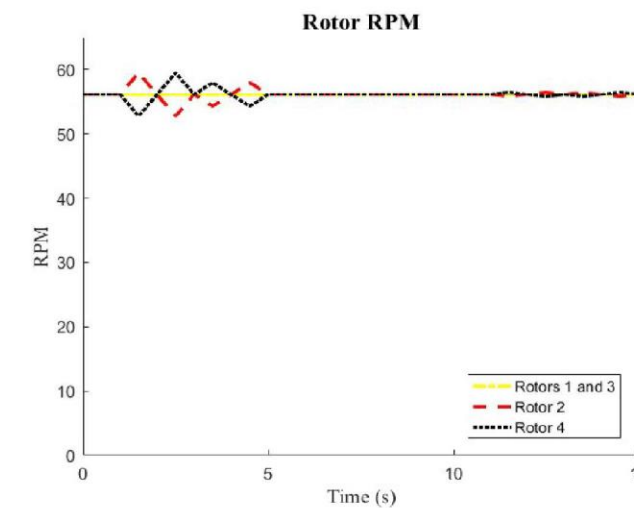
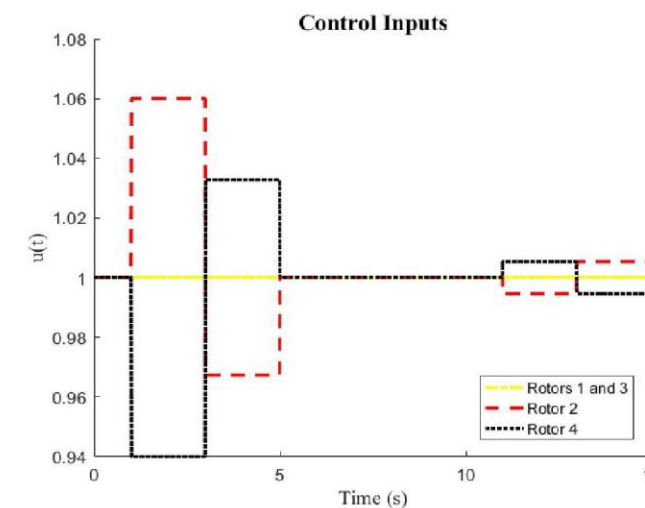
- 3 fully redundant control systems
- Excellent controllability
- Minimal coupling between rotation controls

In addition, the 2° rotor cant further increases stability, with minimal losses for efficiency.

Through integration with *Chezoia's* sensor and avionics suite, all phases and maneuvers of the flight mission have full autonomous capability, allowing for a seamless endurance mission.



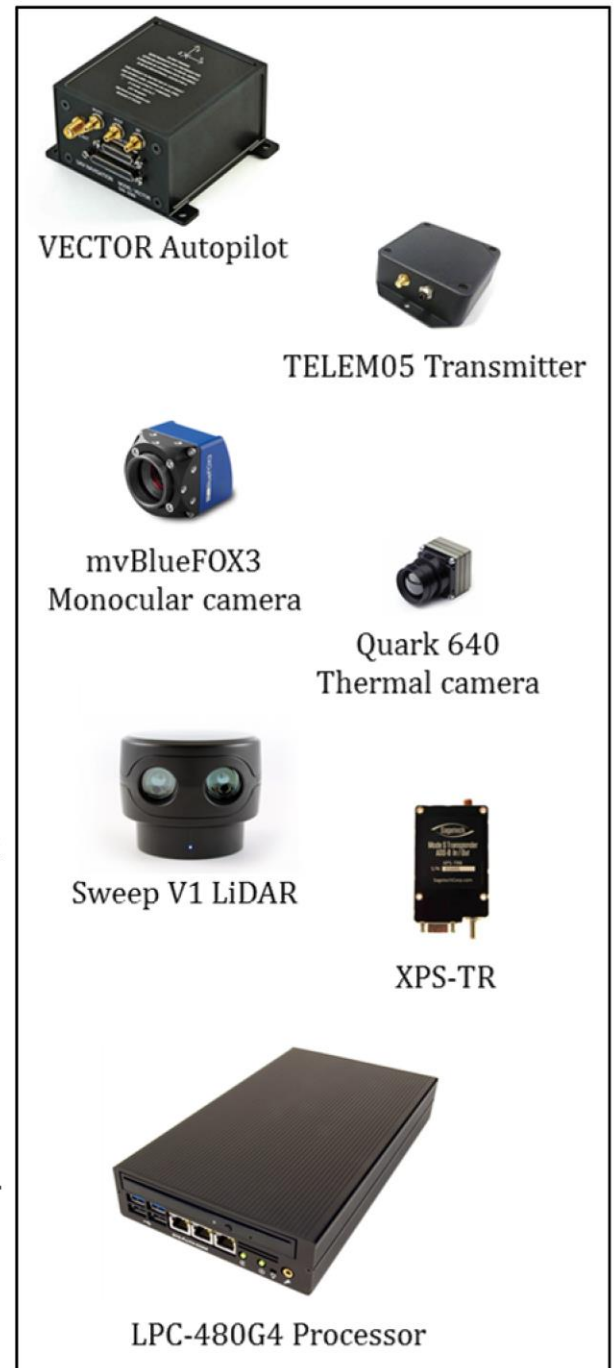
Innovative quadcopter control sets provide three level redundancy of control rotors. Retains full control capabilities with two or more rotors out. Each set is designed to minimize coupling across roll, pitch, and yaw controls.



Basic control response to attenuate sudden constant wind of 9.71 knots. Craft returns to equilibrium at original position within 15 seconds with only 2 feet of maximum displacement

Chezoia's advanced avionics suite provides complete 360° obstacle detection for minimal weight and power cost, using state-of-the-art techniques and technologies. This allows for a dynamically changing, autonomous mission.

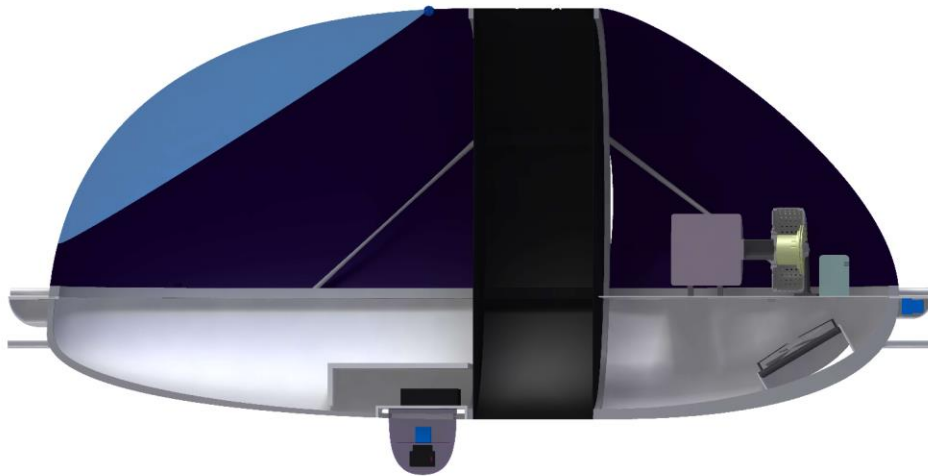
- Autopilot allows fully autonomous flight with built in internal power and algorithmic redundancies
- Temperature and current sensors monitor each motor to provide diagnostics feed
- Monocular cameras send images through an i7 processor to run LSD-SLAM algorithms detecting and communicating obstacles to the autopilot
- Thermal cameras improve awareness of live or moving obstacles such as birds or other aircraft, this data can then be integrated with the LSD-SLAM results to improve object detection
- Rotating LiDAR distance sensor adds redundancy and improved object detection in low-light conditions
- ADS-B transponder allows better tracking of other aircraft and satisfies FAA requirements
- LEDs allow visual detection



Fuselage Layout

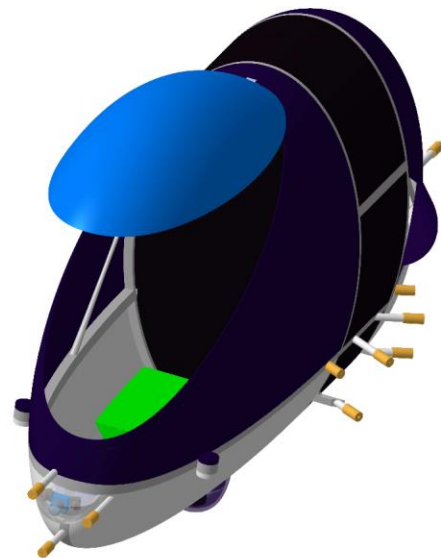


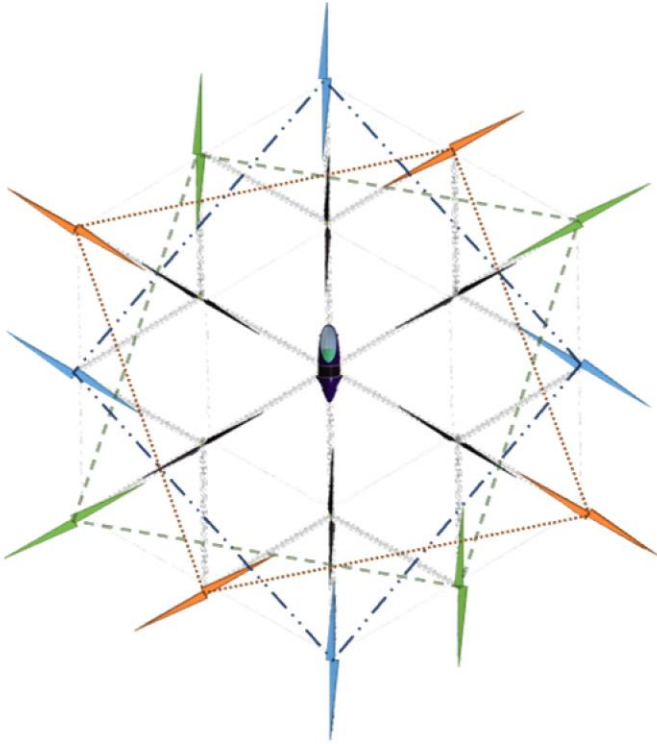
The fuselage has been designed to accommodate a payload of human size, as well as facilitate continued stability throughout the course of the 24 hour mission.



For these reasons, the fuel tank is placed at the center of gravity so that burning fuel does not change the craft's dynamics. Additionally the engine, generator, and payload are offset from each other to facilitate this center of gravity.

Fueling of *Chezoia* is done through the top of the fuselage, directly into the fuel tank. The front of the fuselage lifts to allow for ease of loading payloads as well.





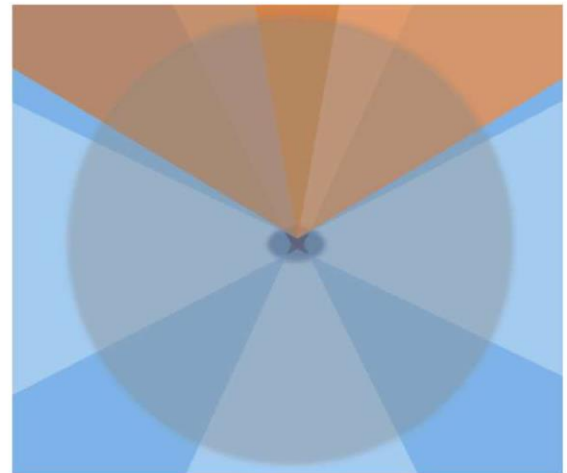
Each set of four highlighted rotors is a set capable of controlling the vehicle

Safety

- Temperature and current of each rotor is monitored
- Parachute in fuselage in case of total power loss
- Safety factor of 1.5 on all structural components
- Low induced velocity reduces risk of flying debris
- *Chezoía* is programmed to return to base in event of malfunction or attempt landing in event of major malfunction

Redundancy

- Rotors can compensate for thrust and control in the event of a rotor failure
- Overlapping monocular camera vision
- LiDAR provides backup low-light sensing
- Guidance systems contain internal redundancies
- Emergency battery provides over 3 minutes of flight time for landing procedure



Blue: Monocular fields of view
Orange: Thermal fields of view
Grey: LiDAR fields of view

Weight Analysis



Chezoia was designed as a lightweight vehicle to reduce the fuel and resulting mission costs. As a result, the payload and fuel make up a moderate fraction of the vehicle weight.

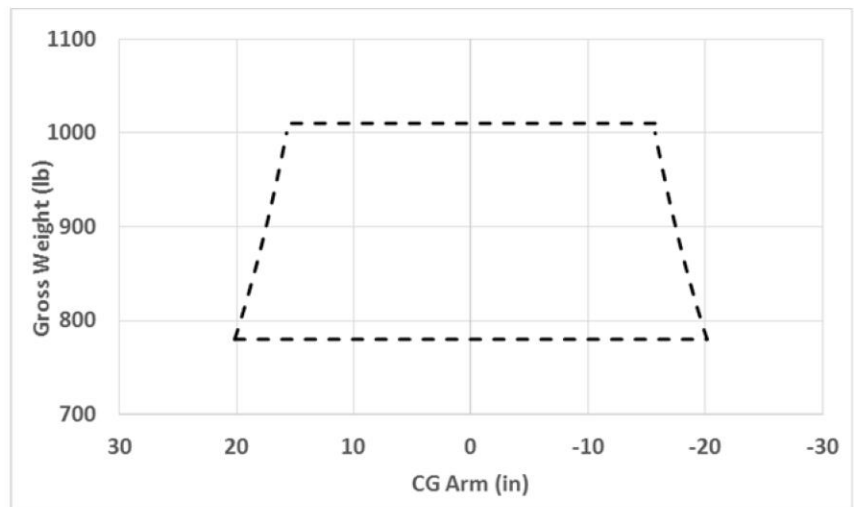
The empty weight fraction of the vehicle is 0.604.

COMPONENT	WEIGHT (LBS)	% EMPTY WEIGHT	X _{CG} (IN)
ROTORS	140	23.61	0.0
STRUCTURE	281	47.39	0.0
LANDING GEAR	7	1.18	0.0
PROPULSION	179.14	26.67	-17.42
AVIONICS	6.84	1.15	7.011
PAYLOAD	176.4	-	15.5
FUEL	220	-	0
Total	1008.38	100.00	0.03

The weight distribution ensures that the center of gravity remains as close as possible to the geometric center of the vehicle.

Chezoia's unique configuration allows for large stabilizing moment arms, so the center of gravity envelope for the vehicle is relatively large

The center of gravity remains unchanged as the vehicle burns fuel.



Longitudinal center of gravity envelope for Chezoia

Cost Analysis

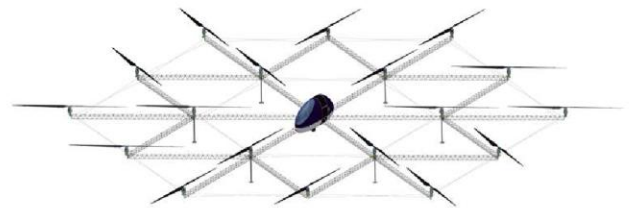


Cost consideration includes the initial purchase price of each component and the cost of fabrication and labor (priced at \$90 per manhour) using The Official Helicopter Blue Book

Production

Majority of production cost comes from the complex assembly of expensive composite materials for structural components

Component	Cost
Blades and Hubs	\$118,800
Microtruss Structure	\$135,245
Center Section	\$100,000
Landing Gear	\$20,160
Engine	\$30,000
Generator	\$6,800
Radiator	\$500
Motors	\$21,800
Gearboxes	\$26,840
ESCs	\$1,854
Avionics	\$20,075
Fuel	\$186
Total	\$482,260



Chezoia: \$482,260

Testing costs for *Chezoia* are greatly reduced by the use of available technologies. Order of testing includes single, quad, and full-rotor configuration tests, prior to full-system flight.

Operation

- Durability of systems allows for many flight hours
- Mechanical simplicity makes replacement simple
- Modularity of the vehicle allows for quick and easy repairs

Summary



Through careful analysis and leveraging available technologies to develop its innovative configuration, *Chezoia* offers an efficient, safe, and effective solution to a wide variety of possible missions. As a highly deployable and versatile aircraft, the design has the following features:

Low disk loading leading to **capability for 25 hours of hover**

Precision control through proven quadcopter control scheme and advanced obstacle avoidance

Safety and assuredness through redundancy in rotors, controls, and avionics

Modular design provides **excellent deployability and ease of maintenance**

Design through conservative studies lends **high technological readiness**

Variety of design considerations lead to **versatility and adaptability to new missions**

