37th Annual VFS Student Design Competition

Leonardo's Aerial Screw: 500 Years Later

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To Vertical Flight Society:

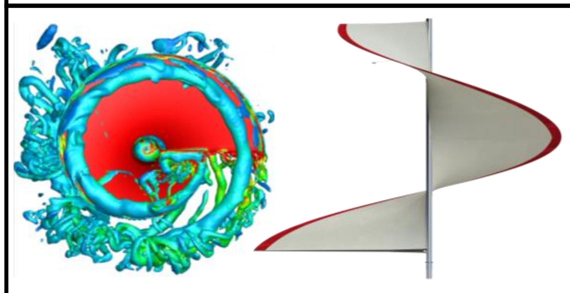
The members of the University of Maryland Graduate Student Design Team hereby grant VFS full permission to distribute the enclosed Executive Summary and Final Proposal for the 37th Annual Design Competition as they see fit.

The UMD Graduate Design Team

Elico: 500 Years of Technological Development

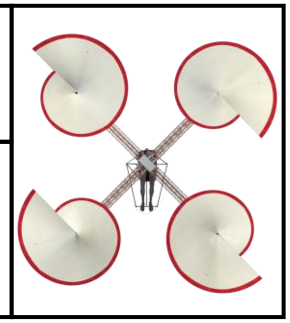
Modern Aerial Screw

The tapered surface keeps vortex attached to surface, generating lift.



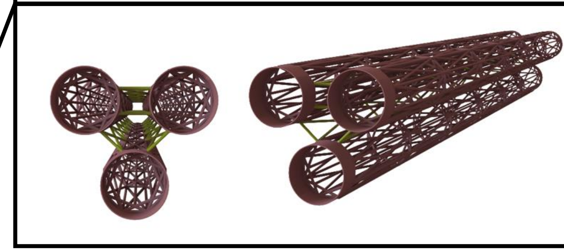
Quadrotor Configuration

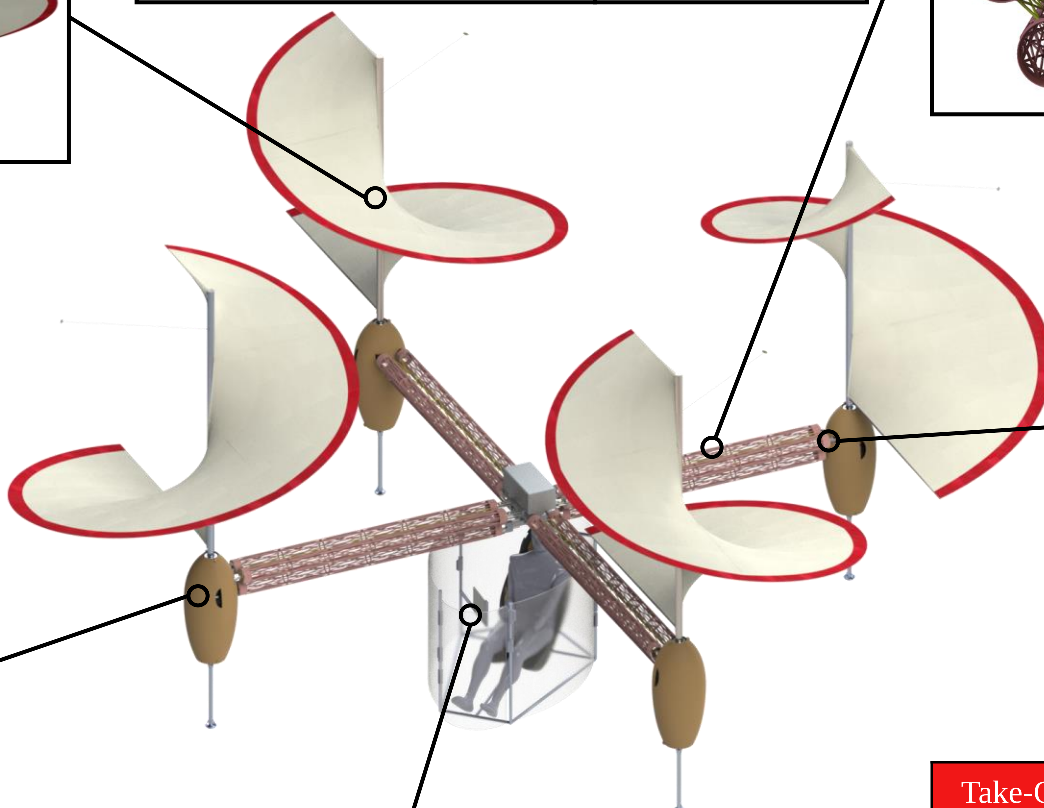
Balances rotor torque and provides superior control authority.

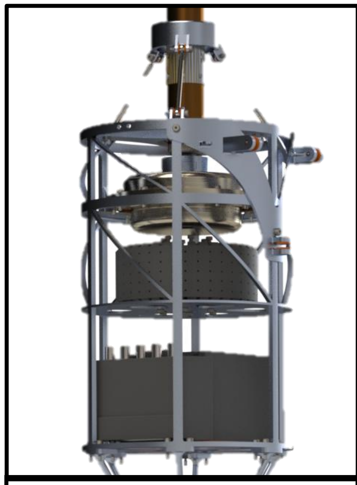


Ultralight Structure

Triangular arrangement of cellular truss minimizes structural weight.

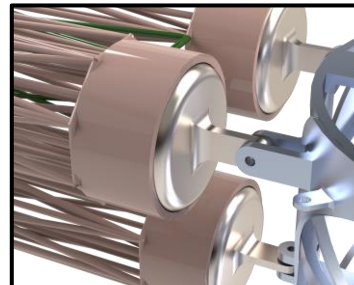






All-Electric Propulsion

Efficient power supplied to rotors and enables rapid RPM control.



Modular Components

Bolted connections of each system allow for interchangeable systems.

Autonomous Operation

State of the art avionics and controls enable waypoint navigation from takeoff to landing.

Take-Off Weight	276 kg	609 lb
Rotor Radius	Top: 0.74 m Bot: 1.46 m	Top: 2.4 ft Bot: 4.8 ft
Overall Height	3.27 m	10.8 ft
Footprint	39.5 m^2	425 ft^2

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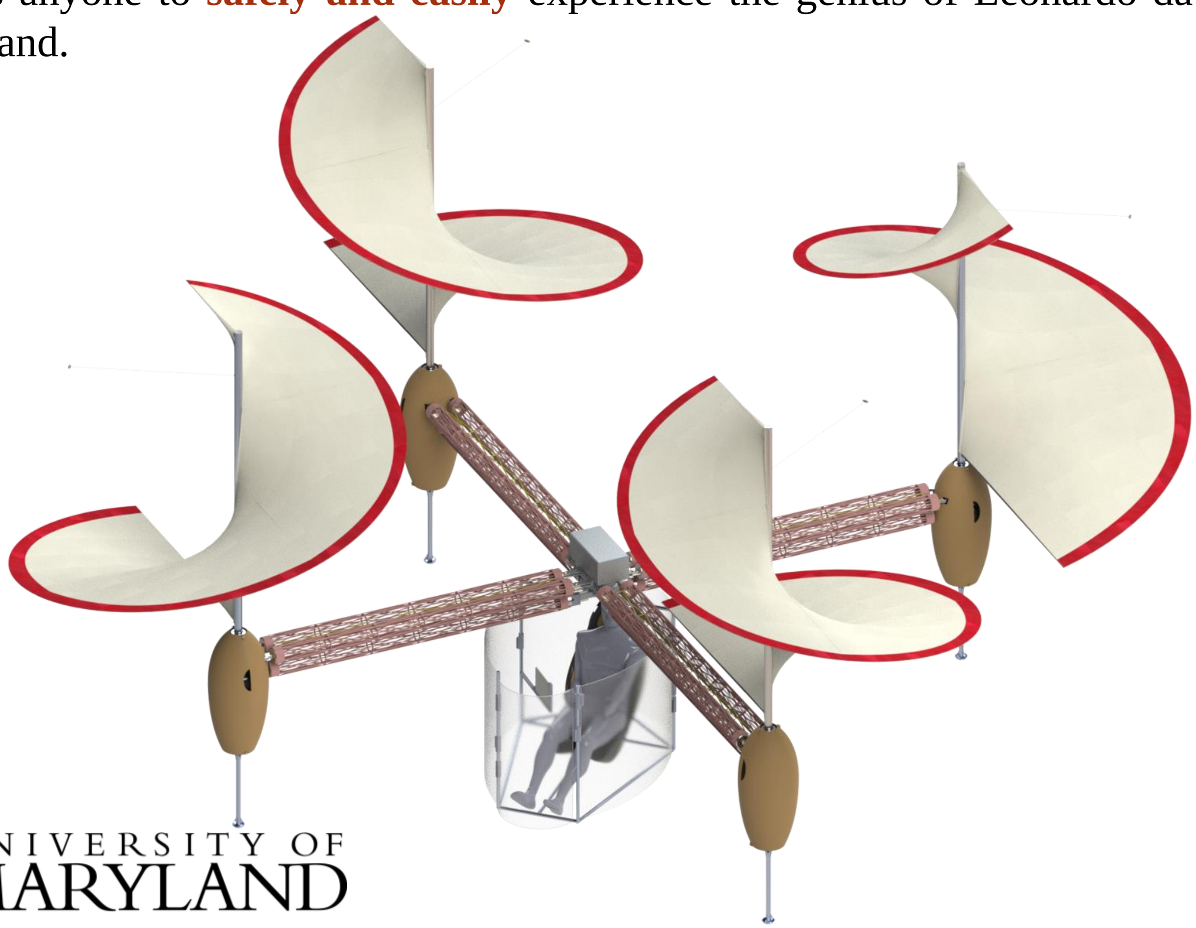
Elico: Cracking the Code

Over 500 years ago, Leonardo da Vinci envisioned a machine designed to carry a person into the air and hover just like the hummingbirds sketched in his notes. The primary feature of Leonardo's machine, the aerial screw, has since inspired centuries of people to build and fly their own helicopters. Leonardo was a dreamer, born in an era well before those dreams could be realized. Now, 500 years later, **advanced analysis tools**, **rapid prototyping**, and **revolutionary materials** have brought Leonardo da Vinci's vision to life. ***Elico*** is the first to crack the code and discover the secrets of the aerial screw's capabilities.

Elico, deriving its name from the Italian root used for the words helicopter, propeller, helix, and screw, is rooted in Leonardo's drawing of an aerial screw. ***Elico*** is a **fully autonomous, manned, quadrotor vehicle** designed by the University of Maryland in response to the 37th Annual VFS Student Design Competition Request for Proposal (RFP) sponsored by Leonardo Helicopters.

Developed as a technology demonstrator, ***Elico*** utilizes a tapered aerial screw rotor to provide all lift, thrust, and control of the vehicle. A modular framework allows ***Elico*** to adapt to changing mission requirements. With an all-electric powerplant, ultralight composite airframe, and push button operation, ***Elico*** allows anyone to **safely and easily** experience the genius of Leonardo da Vinci first-hand.



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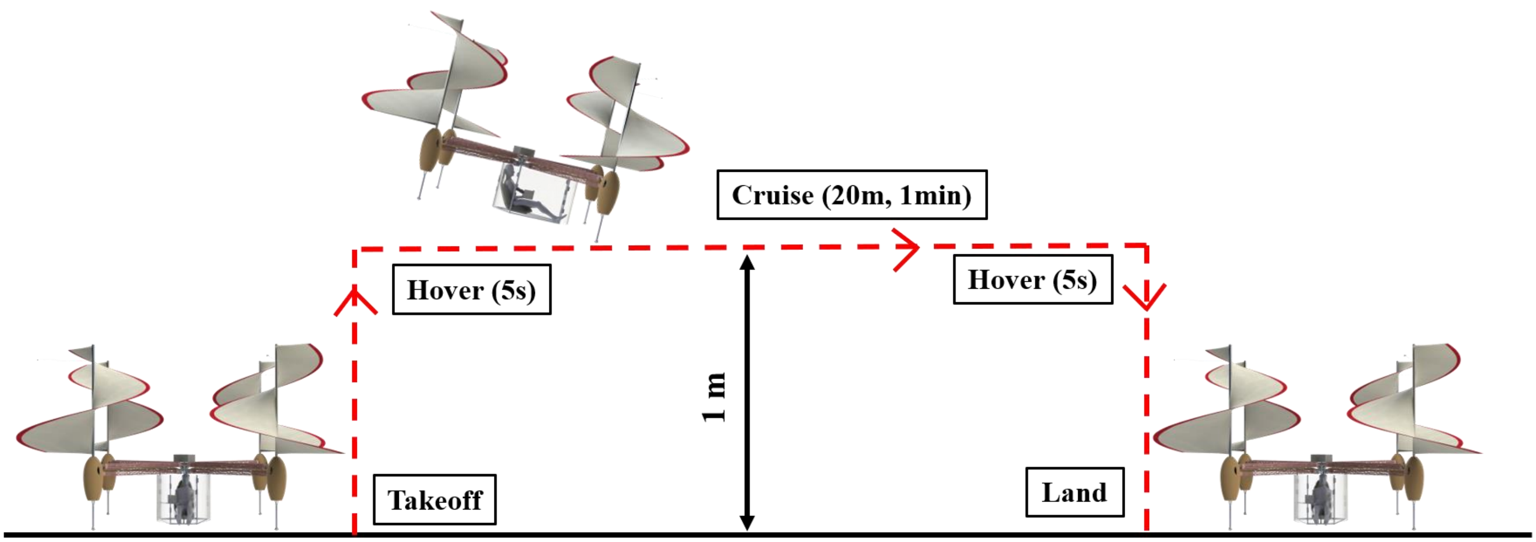
Mission Overview

As a technology demonstrator, ***Elico*** is designed to perform a unique mission exhibiting its hover and forward flight capabilities. ***Elico*** relies on one or more aerial screws to provide lift, thrust, and:

- Carry a 60 kg (132 lb) pilot or passenger
- Take off vertically, holding position for at least 5 seconds
- Fly for at least 1 minute and cover at least 20 m over ground
- Land vertically, after holding position for at least 5 seconds



Elico exceeds requirements and expectations:

	RFP Requirement	*Elico* Capability
Ferry Range	**20 m**	**74 m** **311 m (no payload)**
Hover Endurance	**70 sec**	**3 min**
Payload	**60 kg**	**134 kg**

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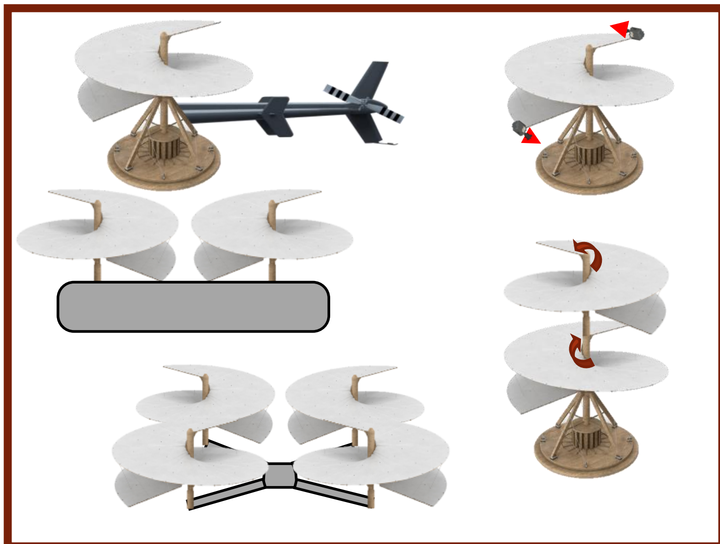
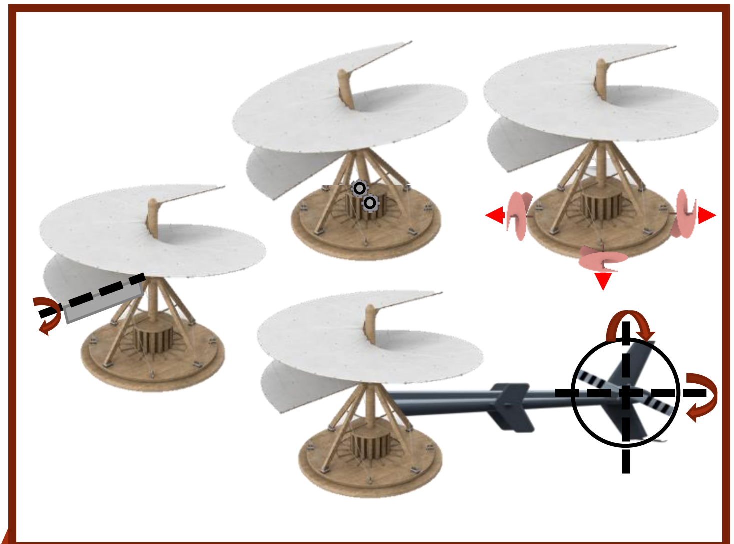
Configuration Selection

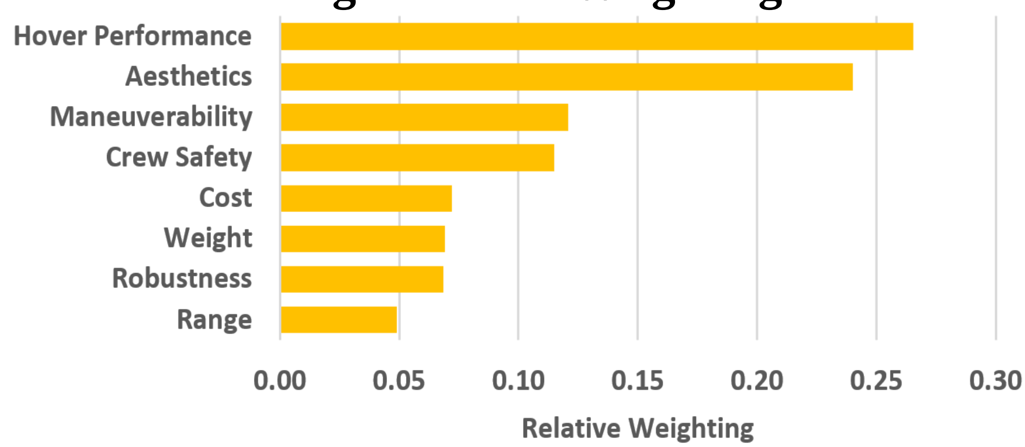


Rotor Configuration Concepts
SMR, Tip Jet, Twin Rotor,
Coaxial, Quadrotor



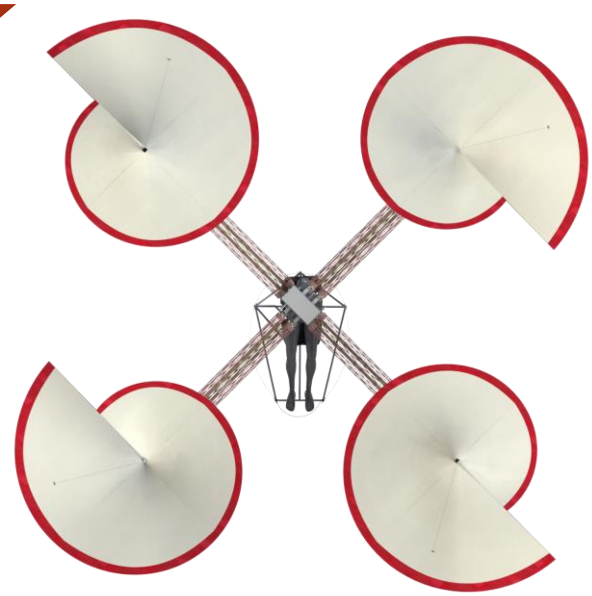
Vehicle Control Concepts
TE flap, Gimballed Rotor,
Propulsors, TR cyclic, Quadrotor

Design Criteria Weighting



Quadrotor

- Highest maneuverability platform
- Simple antitorque solution
- Durable and robust



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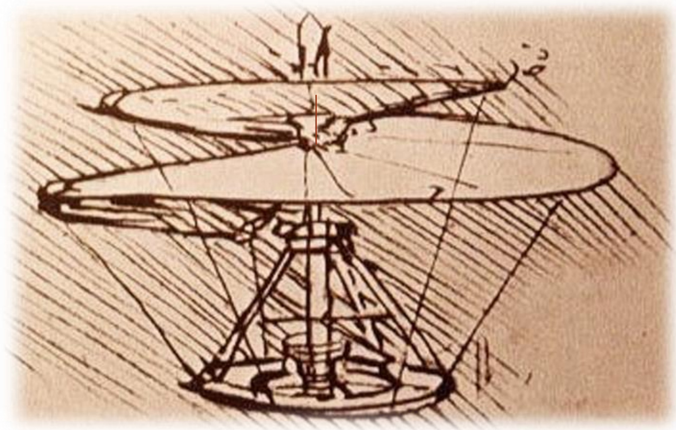
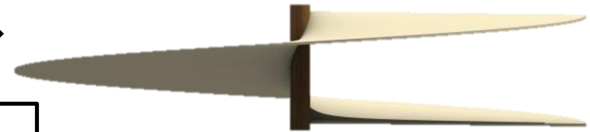
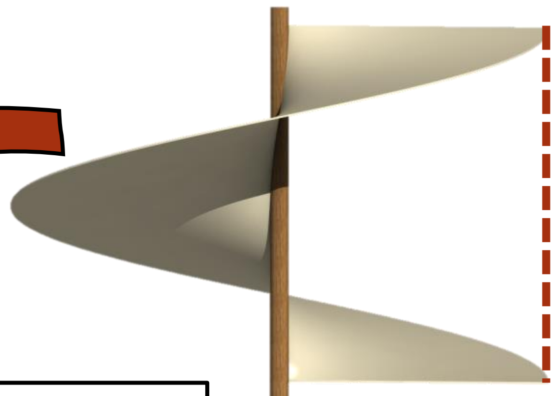
Evolution of *Elico's* Aerial Screw



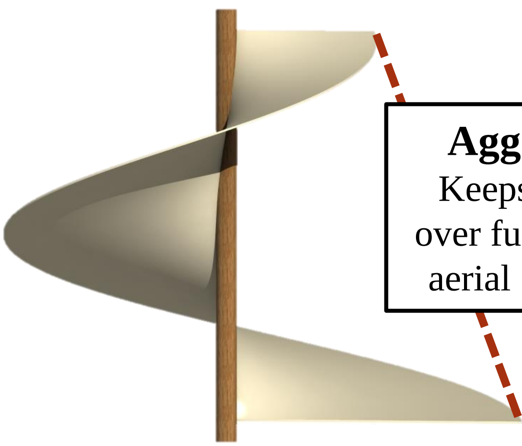
Leonardo da Vinci's Aerial Screw (1489)



Single Turn
Reduces load imbalance



Increased Pitch
Higher angle of attack, increasing lift and hover efficiency



Aggressive Taper
Keeps vortex attached over full length, allowing aerial screw to function

Modern Materials
Minimize rotor weight while maintaining strength

***Converged Design* (2020)**

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Experimental Testing

In order to generate the fundamental data to analyze the aerial screw, small scale testing was performed over a wide range of geometries. 3D printed rotors were designed with changes in **pitch, taper, number of turns, and lip profile.**

1

2

3

4

5

6

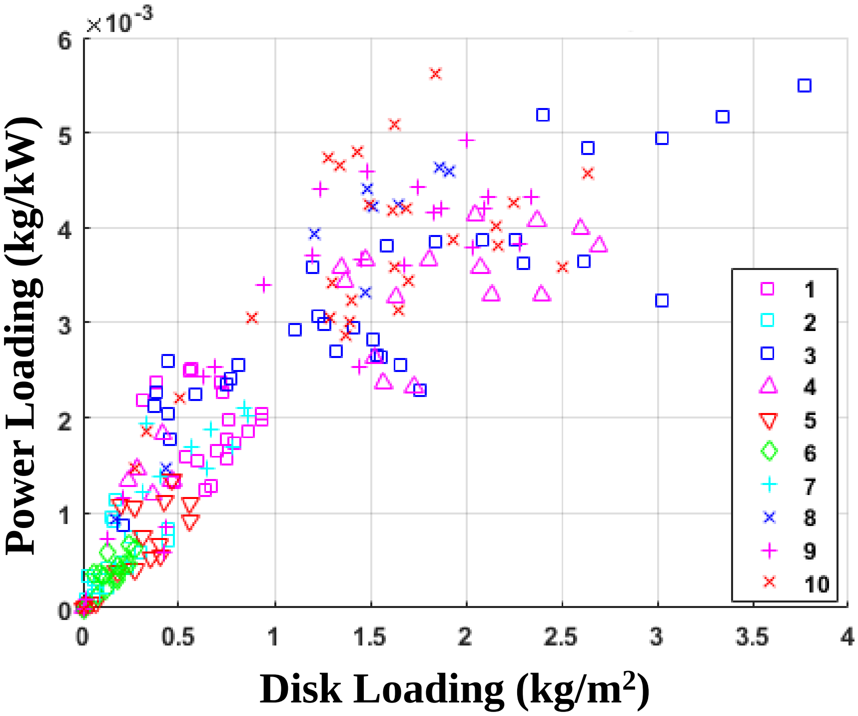
7

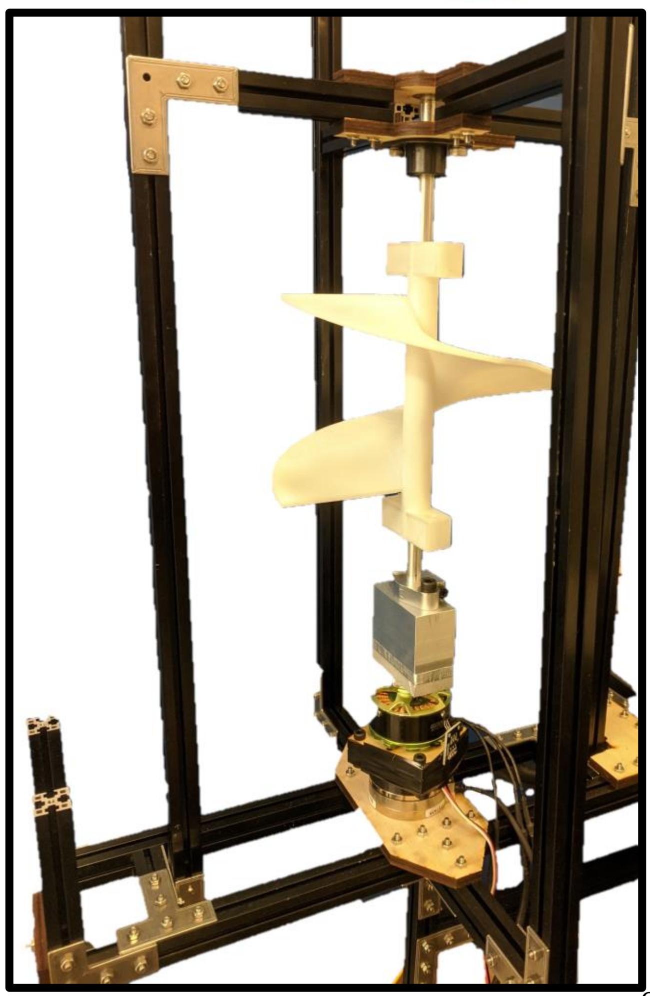
8

9

10

417 Rotor Test Points

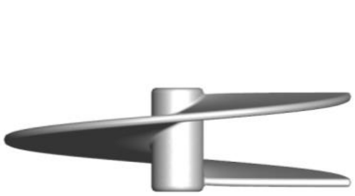




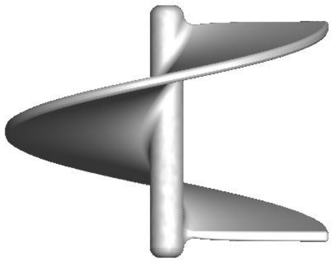
High-Fidelity Aerodynamics Models

Inspired by the top performing scale models, high-fidelity computational fluid dynamics (CFD) simulations were run to gain a better understanding of the lift generating phenomenon. Each CFD case required a wall clock time of over 30 hours and used University of Maryland High Performance Computing resource, Deepthought2. Without this analysis, the attached **'da Vinci vortex'** would still remain a mystery.

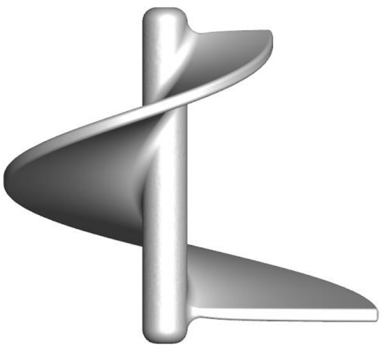
Low Pitch



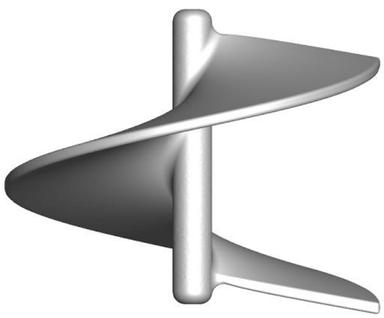
High Pitch



Tapered



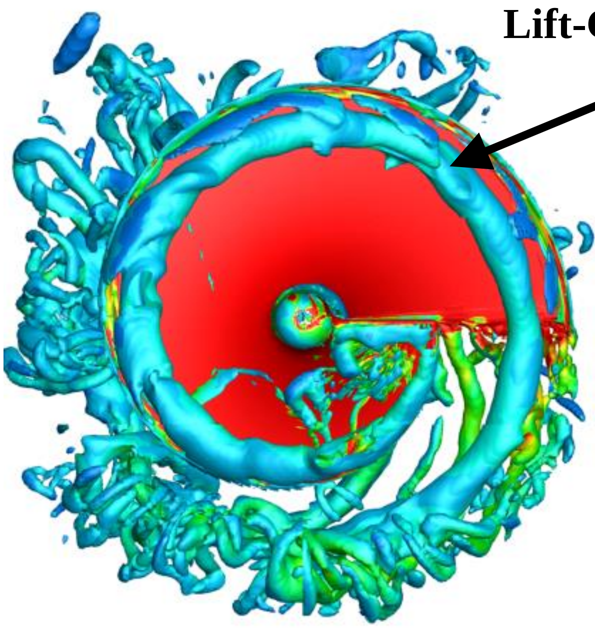
Anhedral



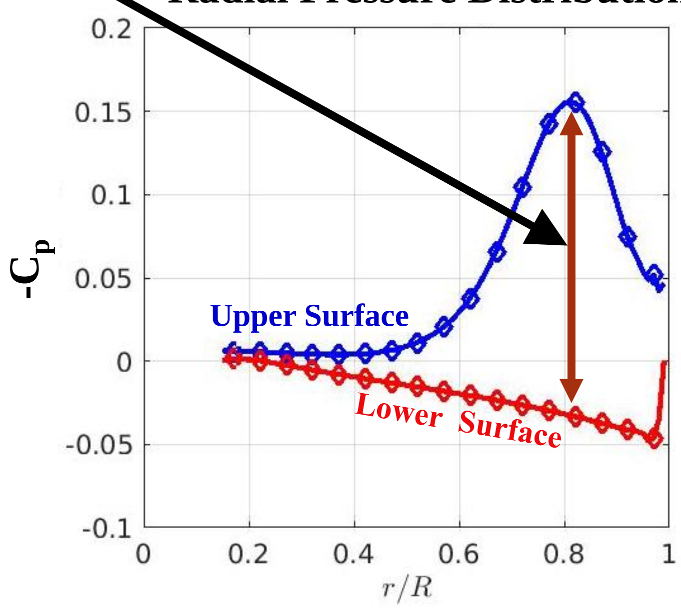
Isolated Rotor Performance

	FM	C_T	C_P
Low Pitch	**0.11**	**0.0051**	**0.0023**
High Pitch	**0.52**	**0.0439**	**0.0125**
Tapered	**0.41**	**0.0274**	**0.0080**
Anhedral	**0.52**	**0.0437**	**0.0123**

Lift-Generating Vortex



Radial Pressure Distribution



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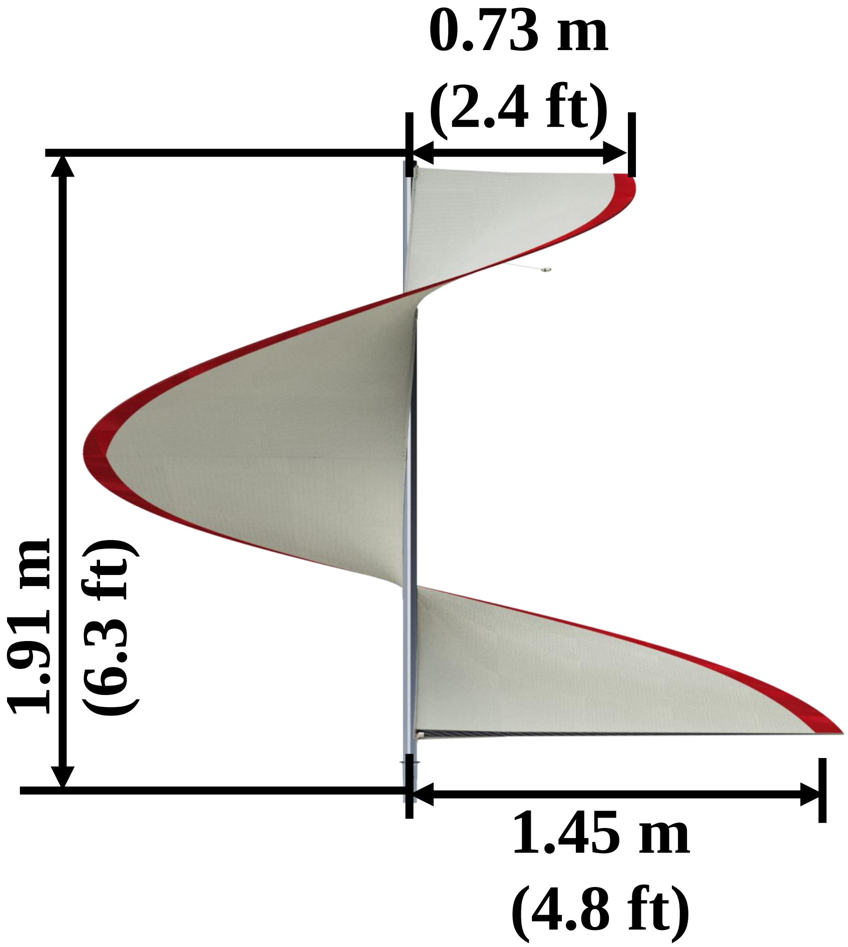
Innovating the Aerial Screw

Elico's aerial screw design is the result of extensive experimental and computational studies into the nature of an aerial screw.

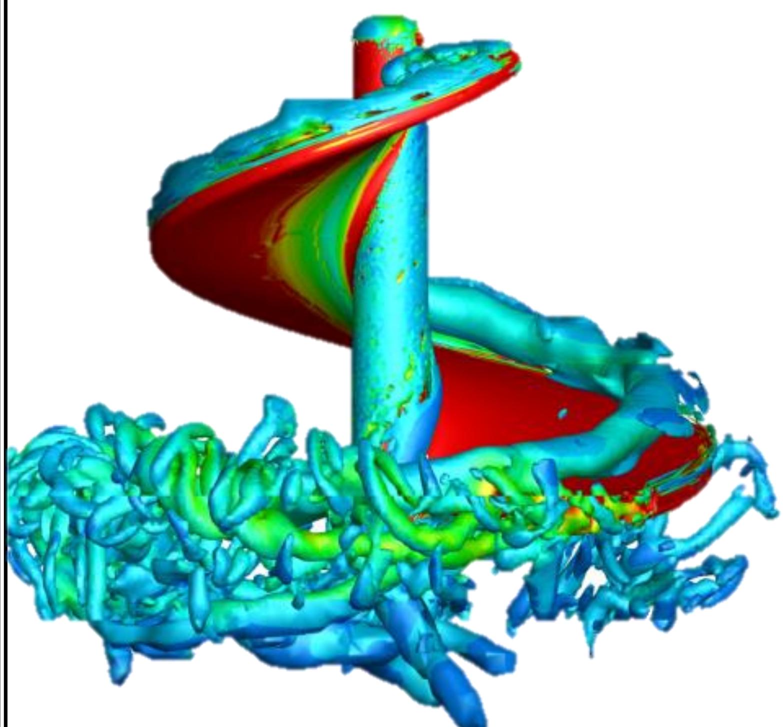


Geometry

- Number of Turns: 1
- Pitch: 1.91 m (6.3 ft)
- Radius: 1.45 m (4.8 ft)
- Screw Taper Ratio: 1:2

Performance

- Rotor Speed: 367 RPM
- Thrust: 677 N (152 lb)
- Power: 50 kW (67 hp)
- Figure of Merit: 0.416



The Secret Code

- The main lift generation is through a **vortex above the aerial screw surface**
- Vortex created at the leading edge of the rotor
- Remains at 80% span **along the entire surface** of the tapered rotor
- Bottom surface unable to push the air down effectively

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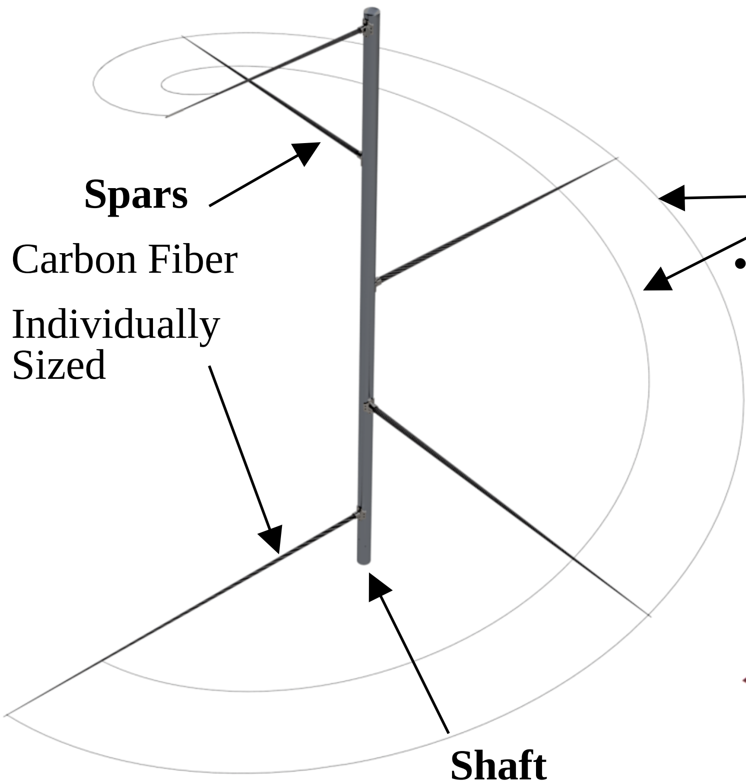
Modern Materials, Historic Design

Elico's aerial screw is comprised of four components: the shaft, spars, ribs, and skin:

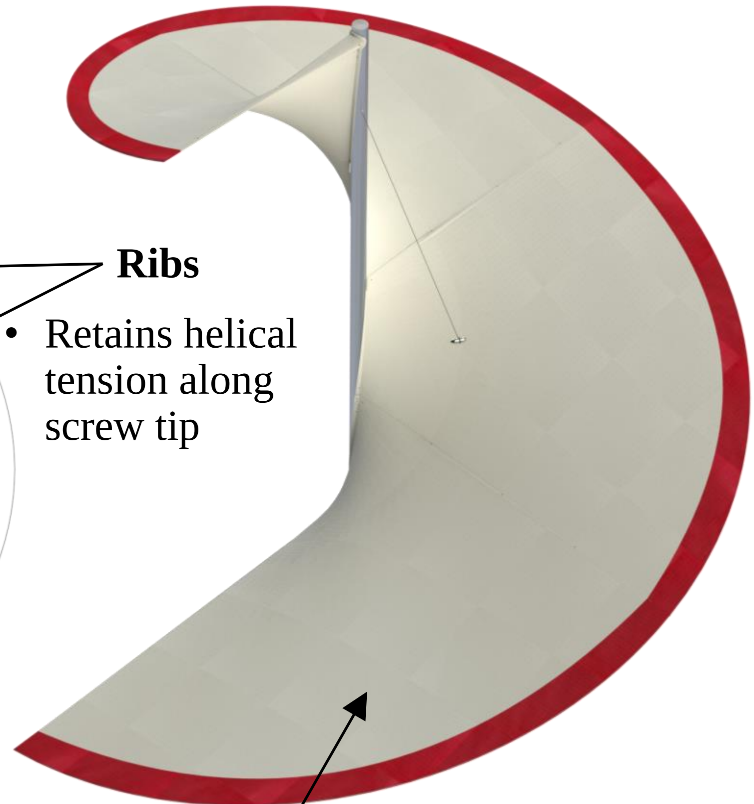


Spars

- Carbon Fiber
- Individually Sized

Ribs

- Retains helical tension along screw tip

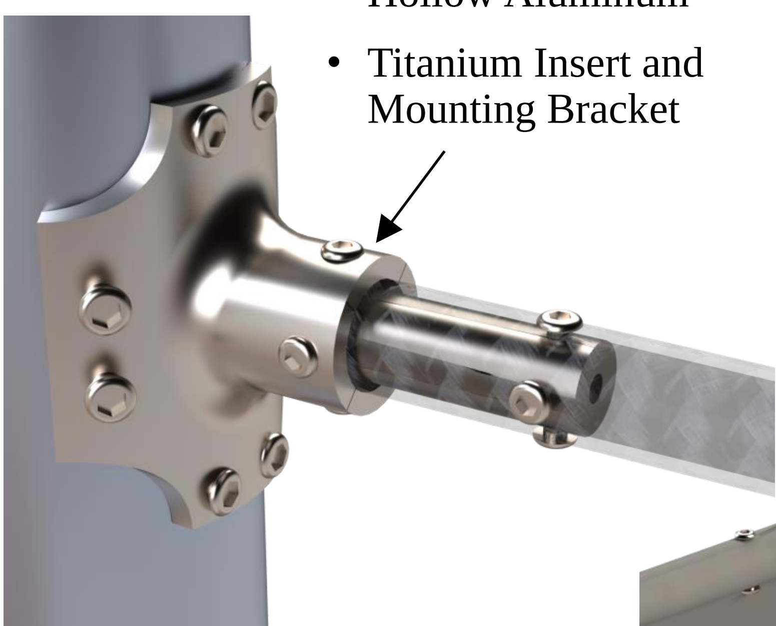


Shaft

- Hollow Aluminum
- Titanium Insert and Mounting Bracket

Skin

- Ripstop Nylon Sailcloth
- Tensioned onto spars
- Wrapped and sewn for continuous surface



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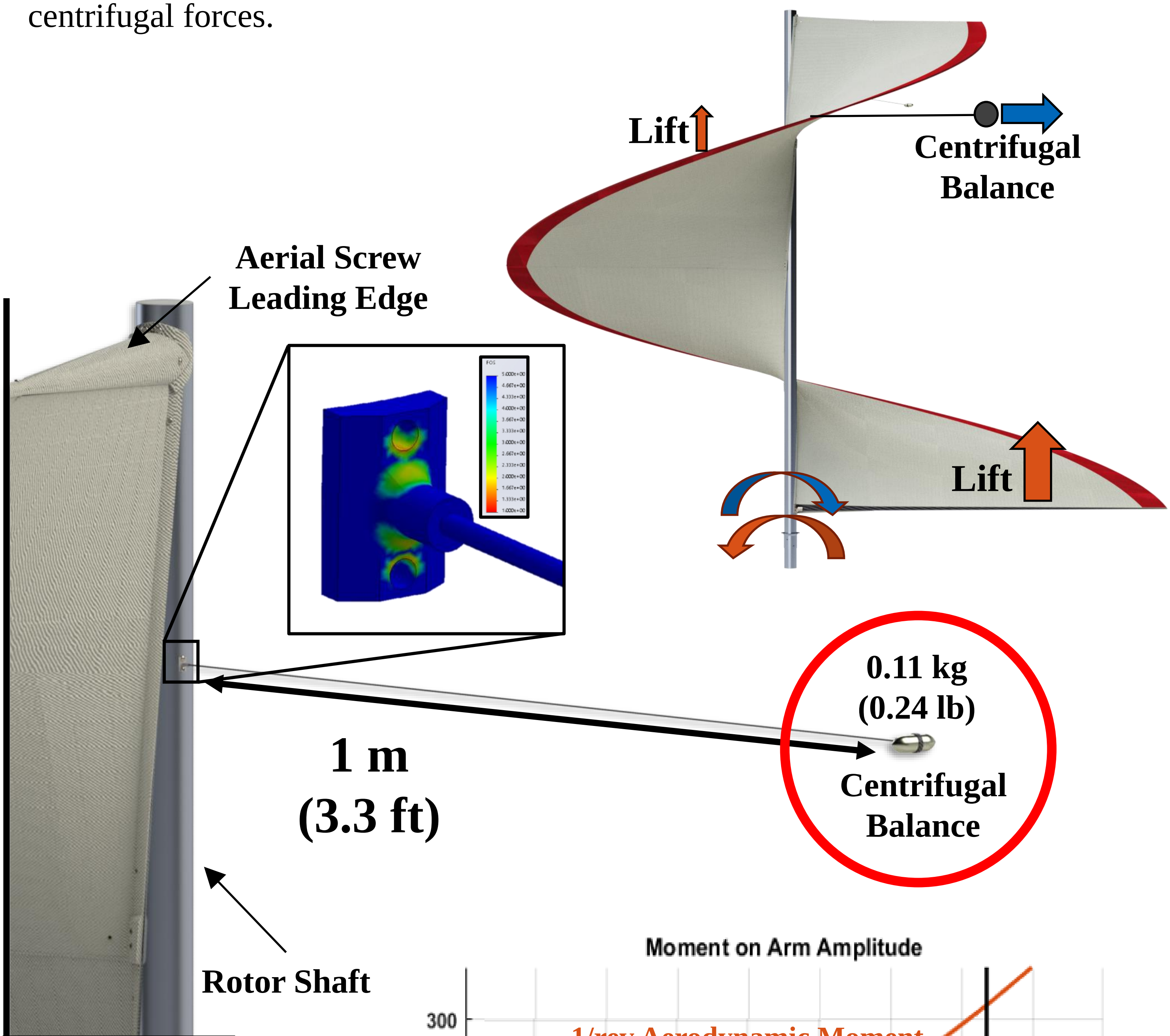
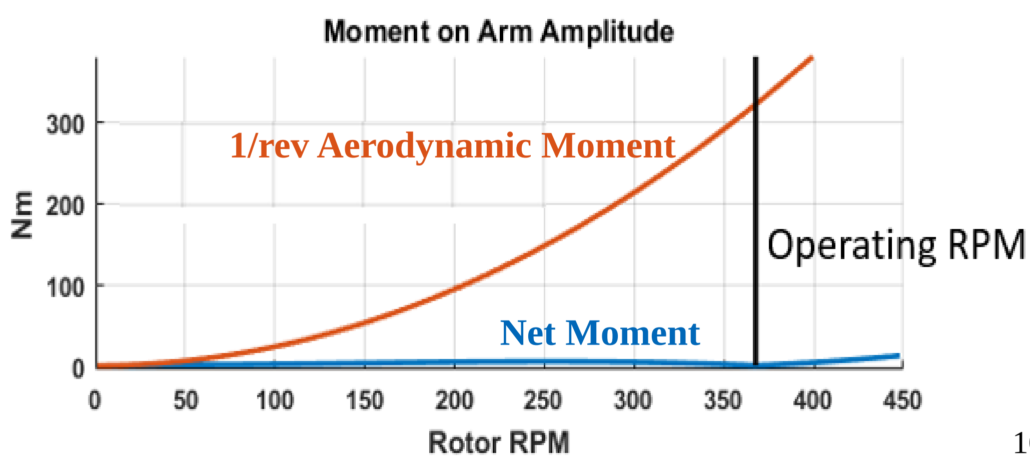
Balancing the Aerial Screw

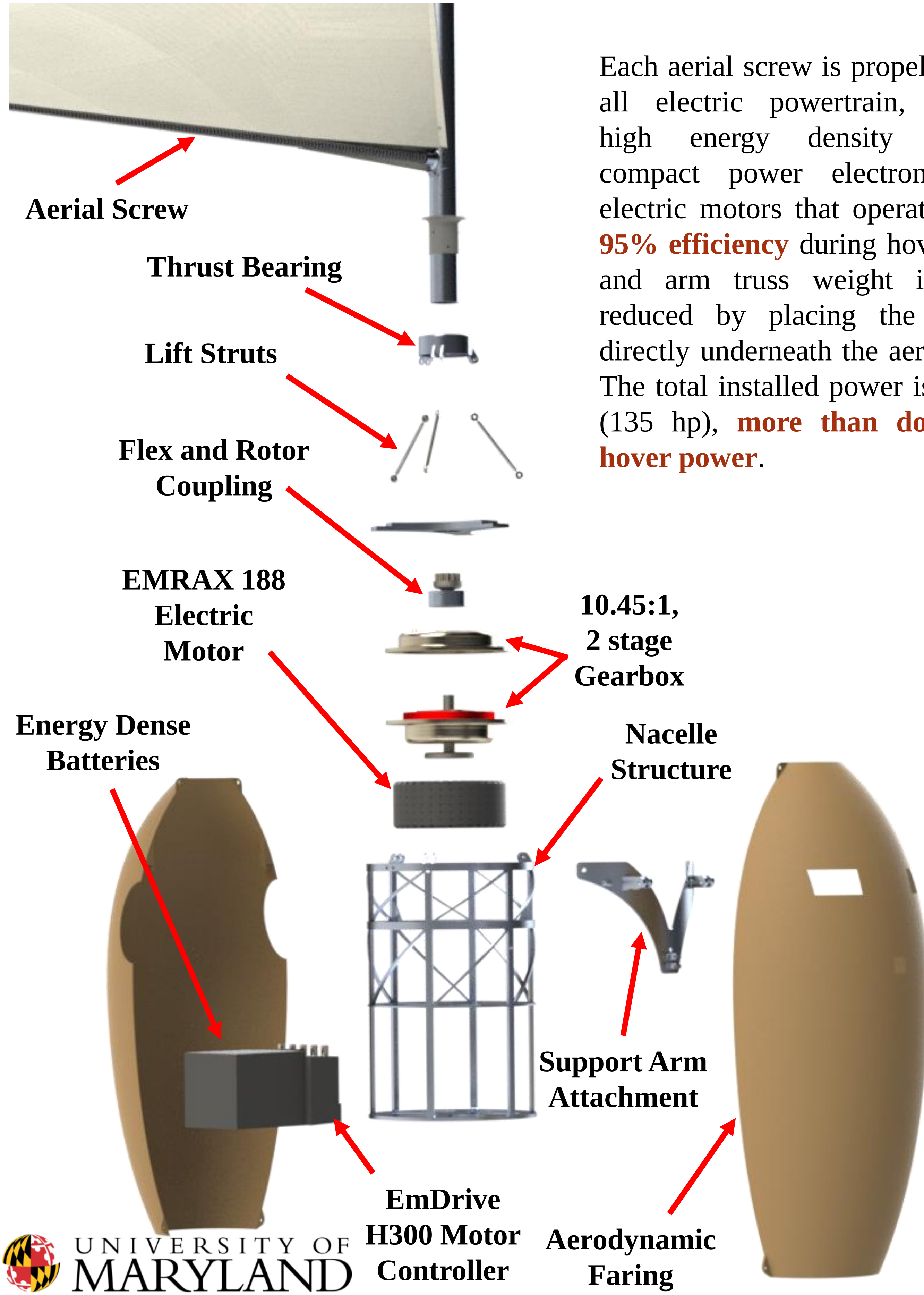
Due to the height of the aerial screw, even a structure with uniformly distributed airloads and a center of gravity on the rotation axis will generate large moments about the base of the shaft.

The 1/rev aerodynamic moments are **completely balanced** by adding only a 0.11 kg mass near the top of the shaft to generate an opposing moment due to the centrifugal forces.





Powering Da Vinci's Dream



Each aerial screw is propelled by an all electric powertrain, featuring high energy density batteries, compact power electronics, and electric motors that operate at over **95% efficiency** during hover. Cable and arm truss weight is further reduced by placing the batteries directly underneath the aerial screw. The total installed power is 101 kW (135 hp), **more than double the hover power**.

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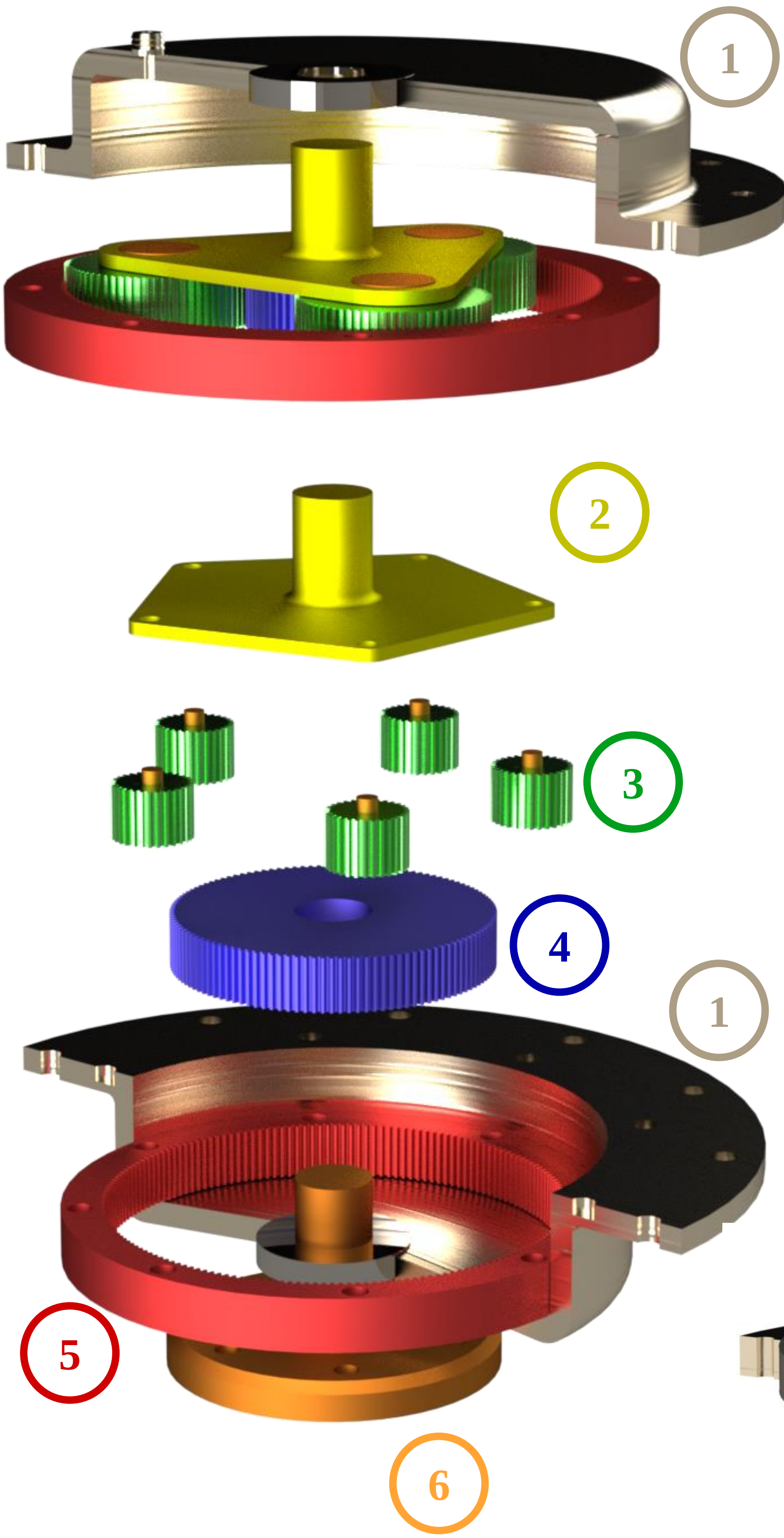
Compact Efficiency: Gearbox Design



- **Double in-line planetary gear arrangement**
- **Gear reduction: 10.75:1**
  - **Stage 1: 2.5:1**
  - **Stage 2: 4.3:1**
- **Lubricated with aluminum based synthetic grease**

1. Gearbox Housing

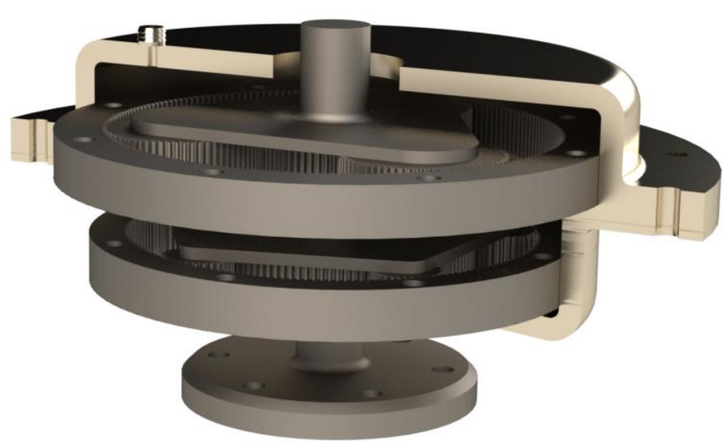
2. Carrier

3. Planet Gear

4. Sun gear

5. Ring gear

6. Motor connection



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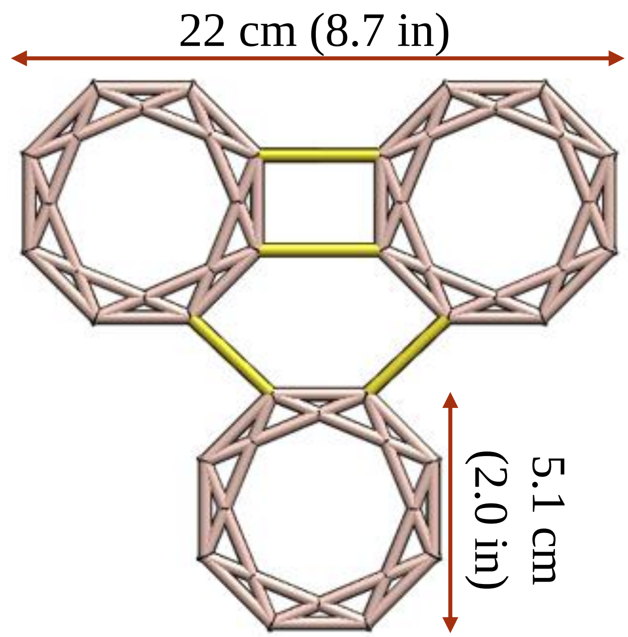
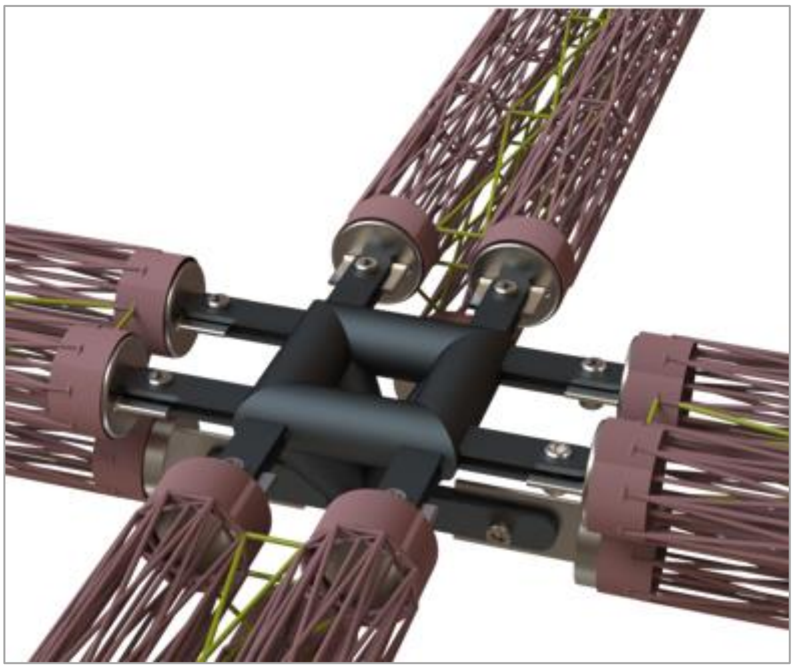
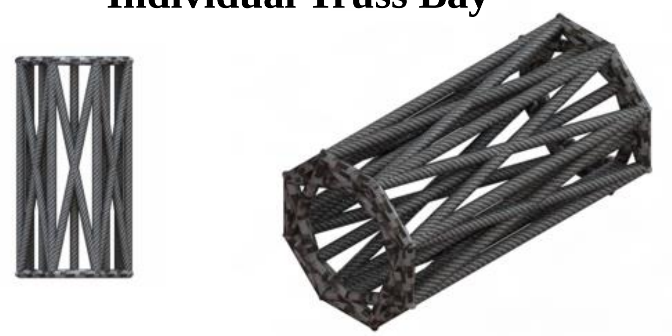
Ultralight Airframe

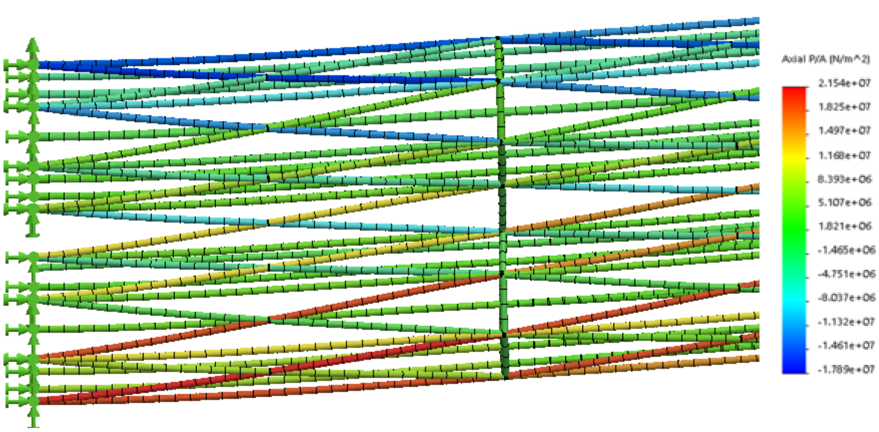
- Intricate truss pattern of carbon fiber tows weighs **3.5 kg/m (2.4 lb/ft)**
- Triangular configuration increases stiffness and compressive strength
- Pinned connections to central aluminum frame and nacelle



Individual Truss Bay







- Factor of Safety, buckling: **1.5**
- Factor of Safety, bending: **52**
- 1st Natural Frequency: **2.5 /rev**

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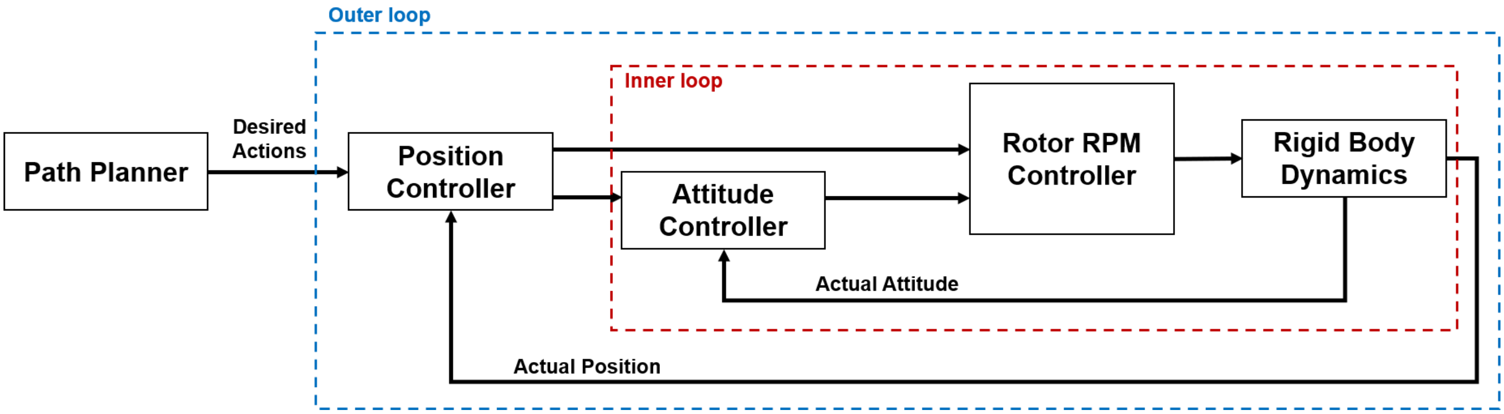
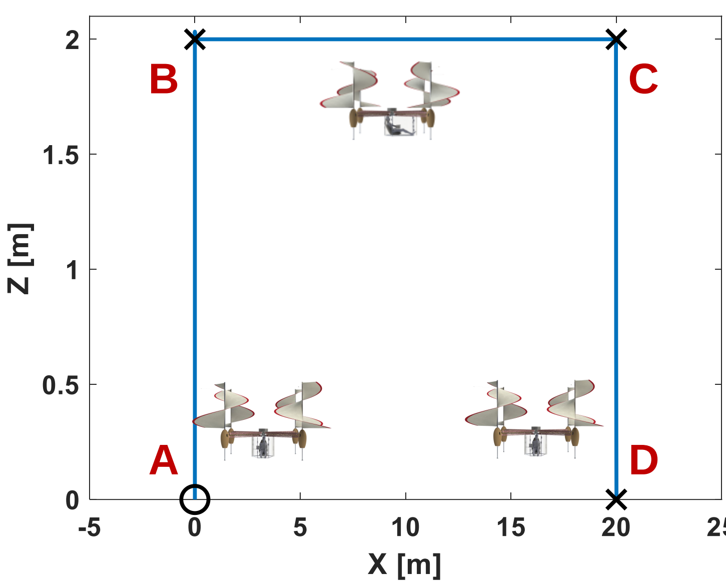
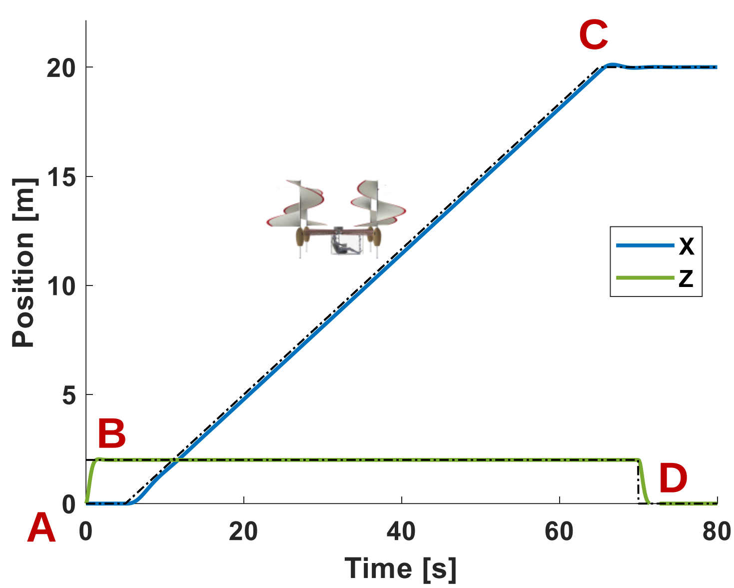
Autonomous Control Strategy

Electric motors rapidly vary rotor RPM for quick response to flight commands. No other control surfaces are required – this is a **proven and lightweight** design.



Using state-of-the-art avionics, ***Elico*** autonomously navigates to set waypoints with high accuracy and fast response time. Autonomous flight is designed for a **low pilot workload** – pilot sets waypoints and enjoys the flight.





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Pilot Interface

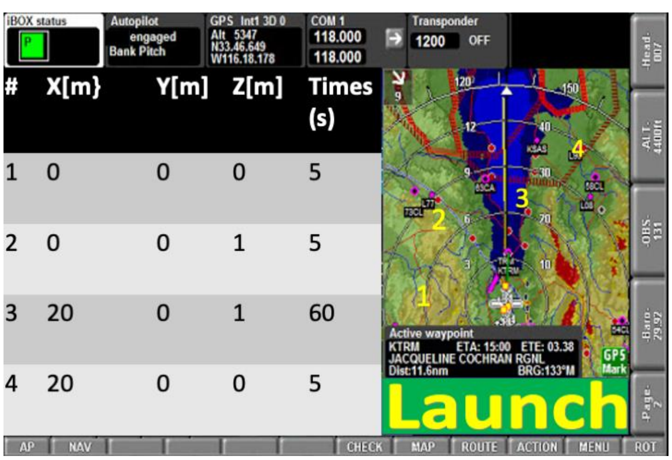
The pilot controls ***Elico*** with the touch of a button. The **multi-function display** reports critical information for monitoring the status of the vehicle. Pilot's view is only obstructed by the 0.36 m wide nacelles below each rotor.

Fully Transparent Cockpit

- Protection from rotor downwash
- Touchscreen controls and display

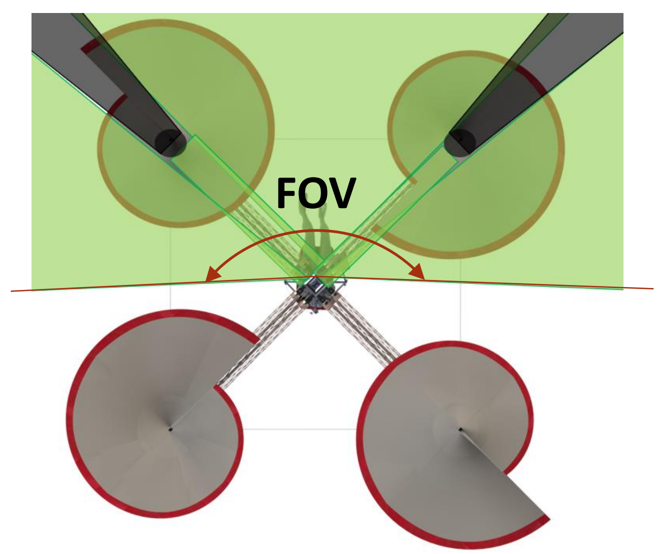
Multi-Function Display

- Side mounted tablet
- Head-Up display
- Mission waypoint entry
- HUMS for motors, batteries, and vibrations



Superior Field of Vision

- View only limited by rotor nacelles
- Augmented by external cameras



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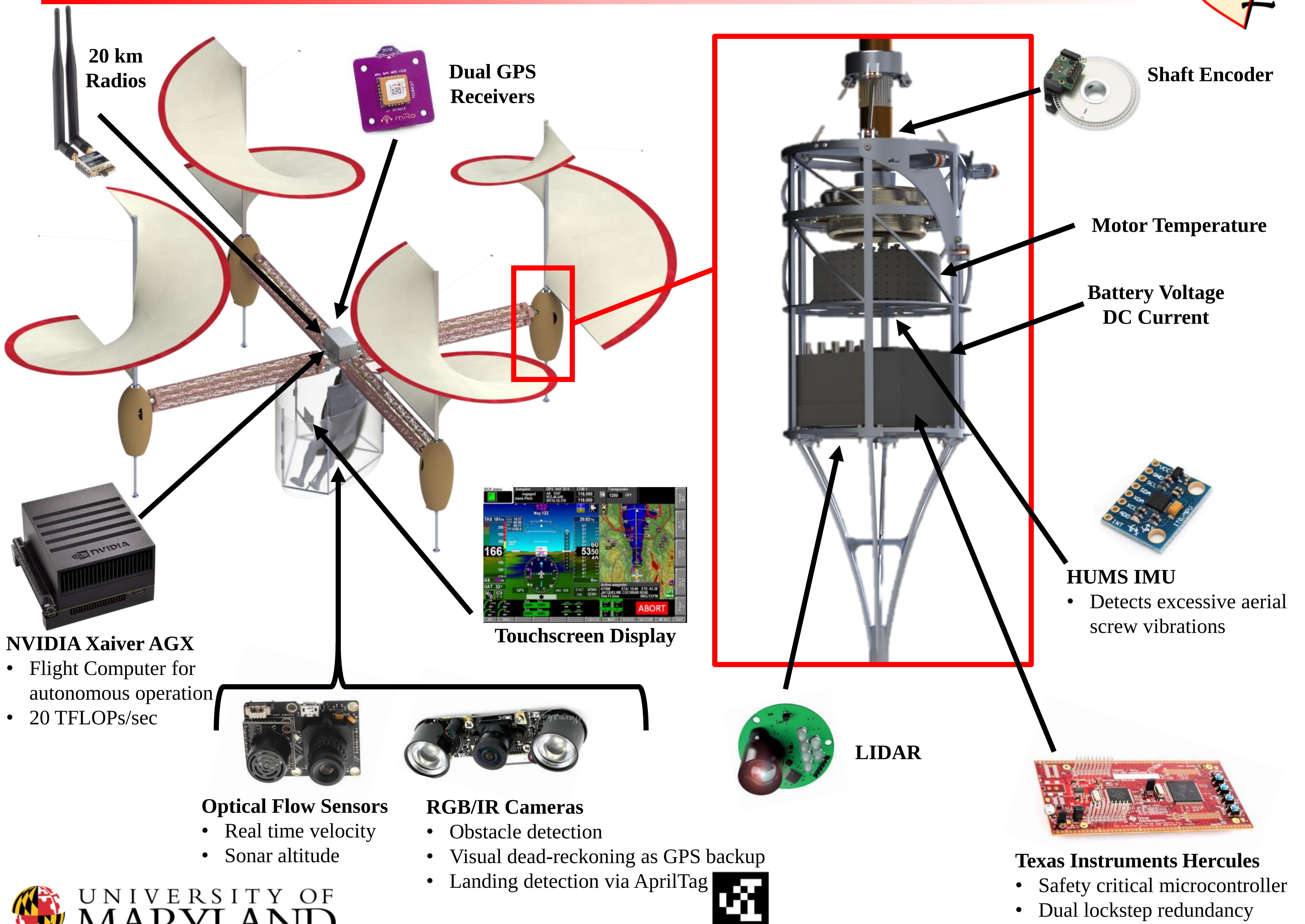
Avionics: Ensuring Safety and Autonomy



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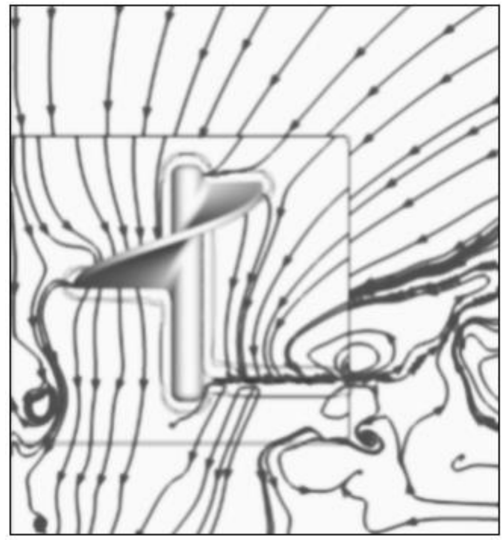
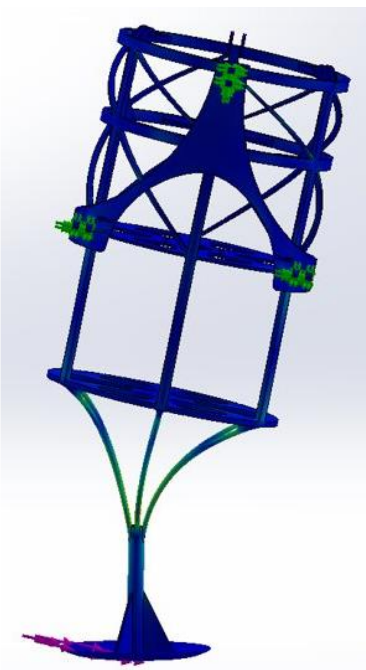
Designed for Safety

Elico's 10.4 kg/m^2 (2.13 lb/ft^2) low disk loading rotors have a downwash velocity of 12.9 m/s (25 kts) **equivalent to a strong breeze** on the Beaufort Scale.





Monopod legs are designed to **absorb landing loads** through flexing. Factor of Safety of 2 is achieved for 4*g* hard landing and 1*g* side loads.

Since there is no combustion and reduced vibrations, ***Elico's*** all-electric powerplant design is **inherently safer** compared to other alternatives. For autorotation, the motors can be driven to a zero torque state and ***Elico's*** autorotative index (AI) of 27 allows it to safely return to the ground.

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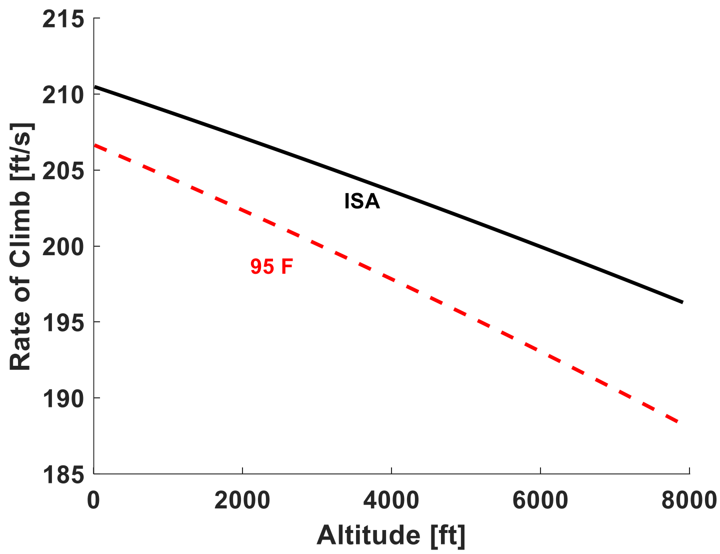
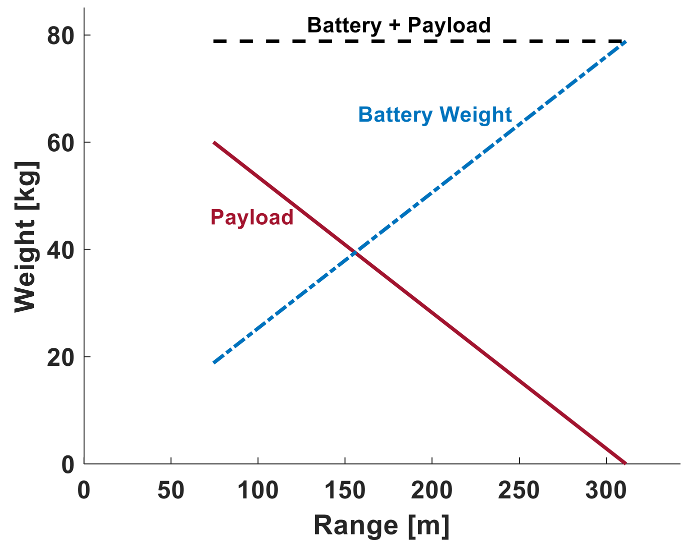
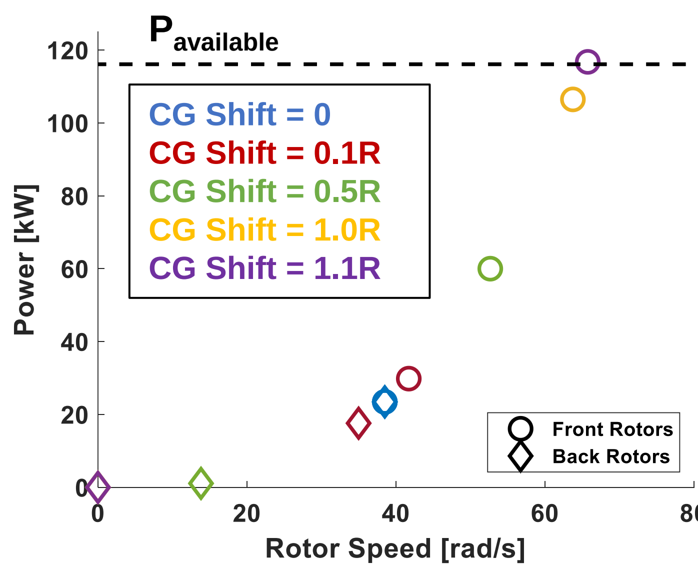
Flexible Performance





- Excess power enables rapid climb rates and hover at altitude much greater than mission requirements
- With 60 kg payload, ***Elico*** has a **range of 74 m**. But ***Elico*** can carry any passenger up 134 kg and still complete the mission outlined in the RFP. Trading payload for battery weight, ***Elico*** has a maximum range of **311 m**.
- Quadrotor configuration enables CG offset of up to 1.6 m from center



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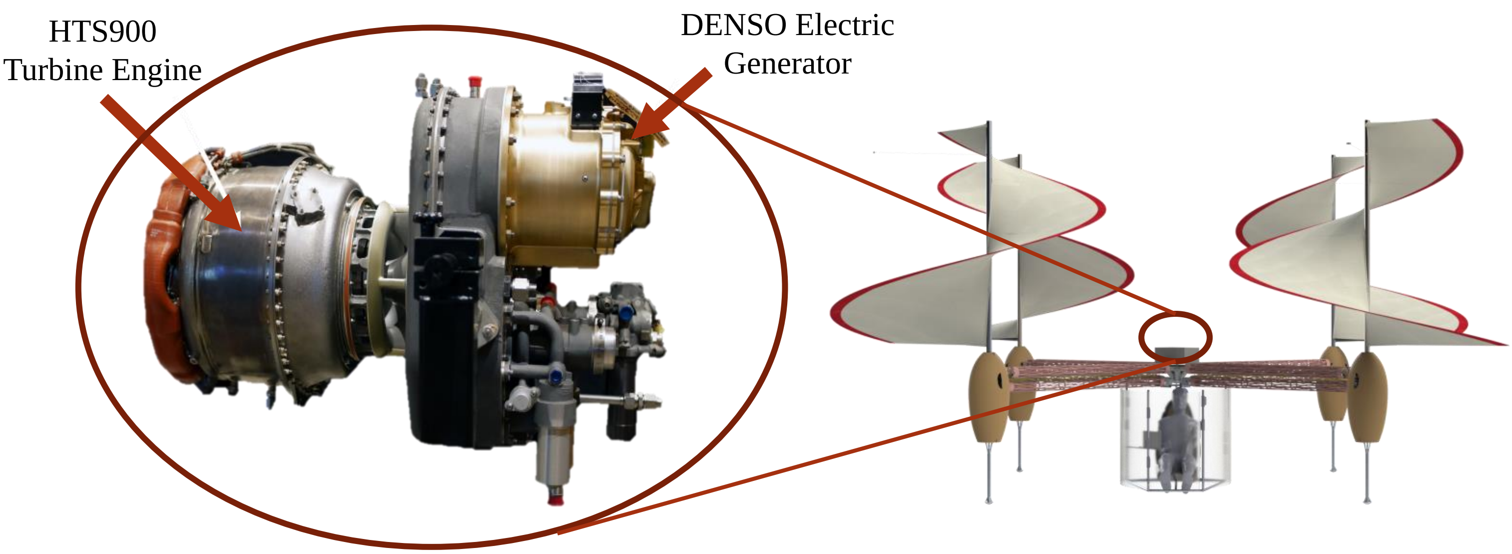
Special Applications

Replacing the batteries with a **turboshaft generator** can enable **flight for hours**, instead of minutes.



Due to the low tip speed, the rotor produces **very little noise and downwash,** making it ideal for stealth missions or operation in urban environments. In its current configuration, ***Elico*** is best equipped to operate at the greatest technological museums in the world, giving anyone the opportunity to experience **flight as Leonardo da Vinci envisioned** 500 years ago.

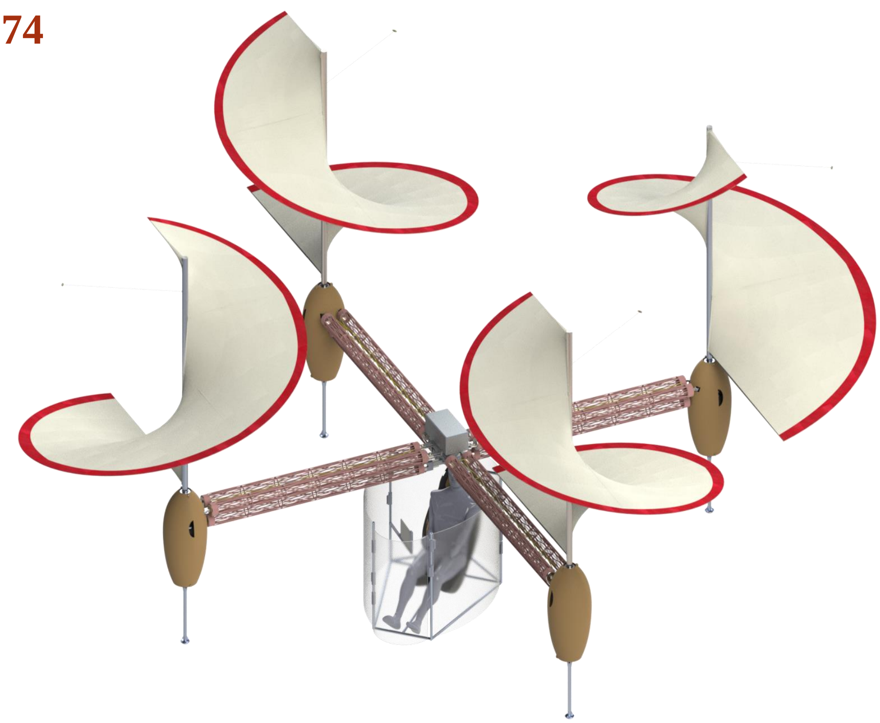
Elico hovering over the gardens at the Museo Nazionale Scienza e Tecnologia Leonardo da Vinci

Summary

Developed in response to the Request for Proposal for the 2020 VFS Student Design Competition, ***Elico*** is a technology demonstrator designed to enable safe, efficient, autonomous flight using an Leonardo da Vinci's aerial screw concept. Guided by an in-depth study on the physics of the aerial screw, structural dynamics, and flight mechanics, ***Elico*** meets and exceeds the requirements specified in the RFP.

- Tapered aerial screw **rotor generates lift via a bound vortex** over the entire rotor surface
- Aerial screw 1/rev moments **completely balanced** by 0.11 kg counterweight
- Quadrotor configuration enables **precise control and anti-torque**
- Ultralight cellular truss structure **maximize strength to weight ratio** of rotor support
- All-electric powerplant provides **safe and efficient power** to the rotors and allow for **rapid RPM control**
- Integrated avionics and controls system assure **autonomous flight** based on preset waypoints, minimizing pilot workload
- The pilot, seated below the structure, has an intuitive tablet interface and **unparalleled visibility**
- Estimated fabrication cost: **$200,374**

	RFP Requirement	Elico Capability
Range	**20 m**	**74 m**
Endurance	**70 sec**	**3 min**
Payload	**60 kg**	**134 kg**



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