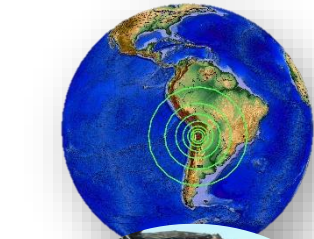


Halcyon

Calming the Storm



33rd Annual AHS Student Design Competition

Air Launched Unmanned Disaster Relief Delivery Vehicle

Sponsored by Bell Helicopter Textron, Inc.

Alfred Gessow Rotorcraft Center
Department of Aerospace Engineering
University of Maryland
College Park, MD 20742



UNIVERSITY OF
MARYLAND

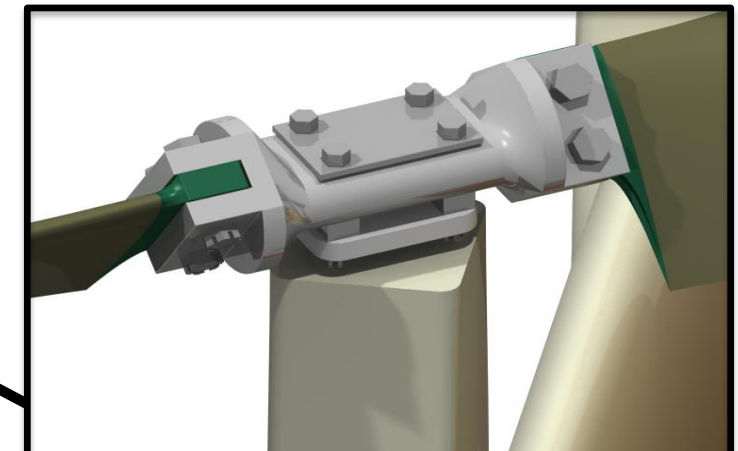
Halcyon System Overview

Deployment

- Passive stability achieved through CG placement
- Autonomous control achieved in axial flight by 13,900 ft ISA

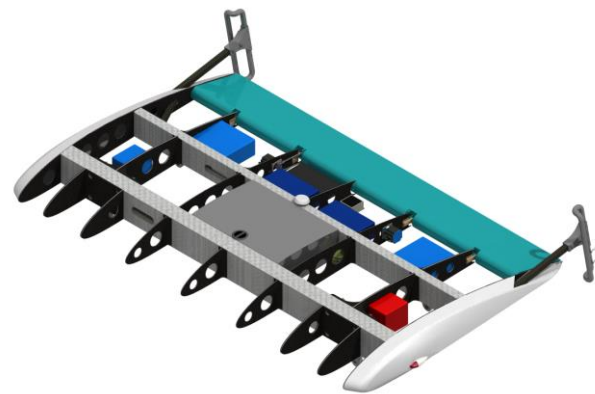
Turbo-generator

- 480 hp turbo-shaft connects to electric generator
- Electric motors allow for differential RPM



Proprotors

- Fixed root collective allows for mechanical simplicity
- Spar resists high flap moment in deployment



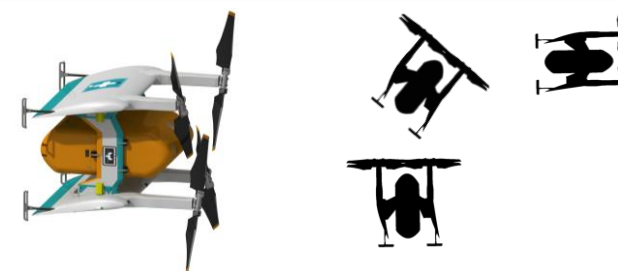
Wing

- Flaps maneuver vehicle into level cruise
- Constructed from lightweight composite



Payload Delivery

- Hoist lowers payload through latching doors



Quadrotor Tailsitter Biplane

- Overlapping rotors for storage
- Transition to propeller-mode



Landing Gear

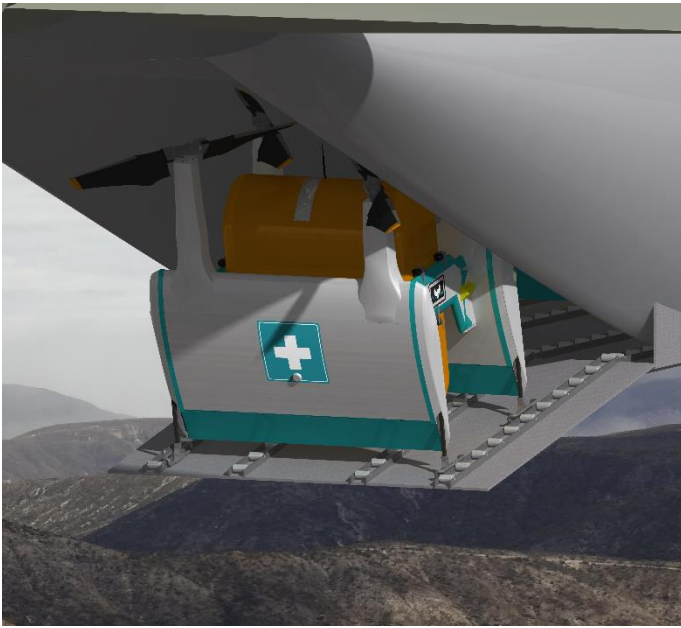
- Dual mode landing gear
- Interfaces with C-130J cargo rail system



The *HALCYON* AIRCRAFT



In Greek mythology, the goddess *Halcyon* was transformed into a sea bird that brought peace and calm weather during the storms of mid-winter. Her selfless love is still remembered in Greece, where the *Halcyon Days*, symbolizing tranquility and healing, are celebrated today.

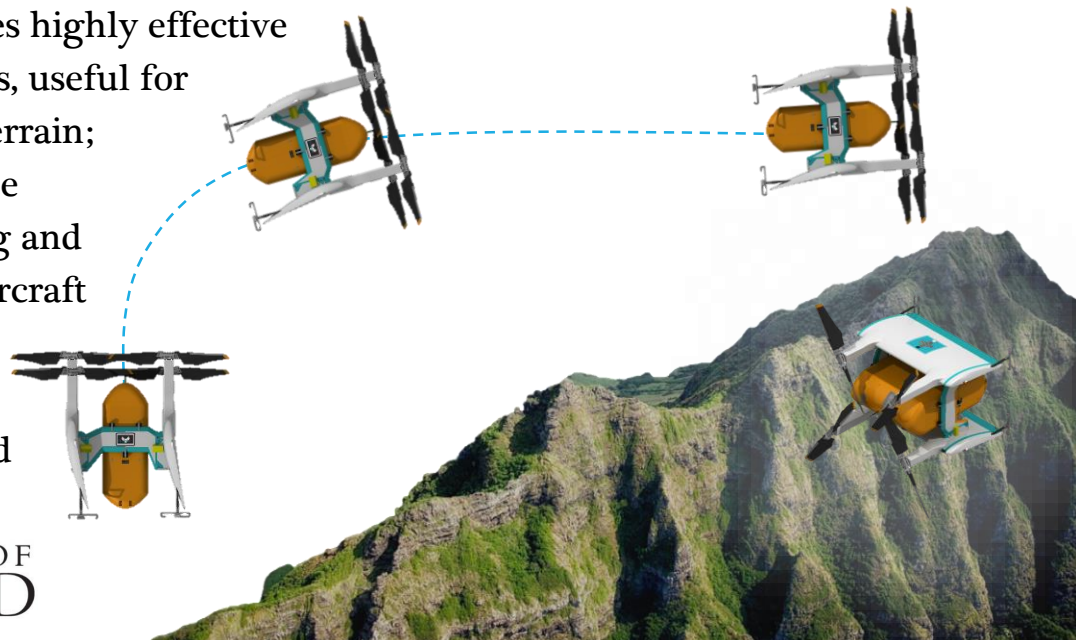


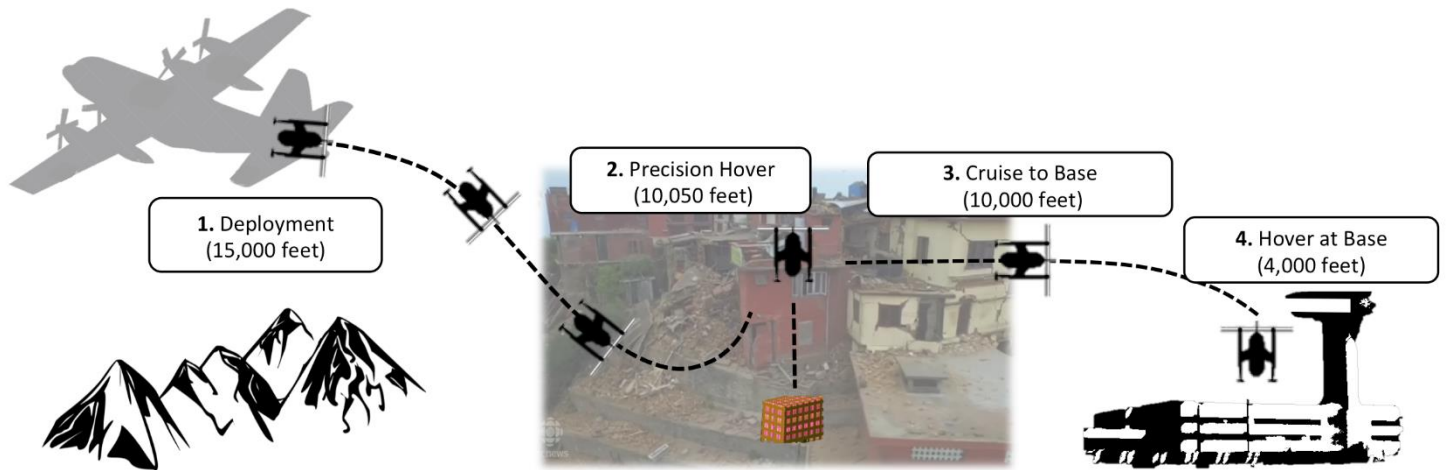
Inspired by the myth, *Halcyon* is a fully autonomous air-launched disaster relief UAV created by the University of Maryland in response to the Annual AHS International 2015 Request for Proposal sponsored by Bell Helicopter Textron, Inc.

Through a synergy of proven technologies and recent advancements in electric propulsion, advanced turbine engines, and innovative VTOL design, *Halcyon* represents a transformative approach to disaster relief.

Halcyon is a **quadrotor biplane tailsitter** that combines the best features of each configuration to meet and exceed the objectives of the mission. Capable of efficient hover, precise control, and low power cruising flight, *Halcyon* is designed for **high performance, low maintenance, safety, and mission flexibility**.

Halcyon is powered by a state-of-the-art **serial hybrid propulsion system** that combines an advanced turboshaft engine with high power density electric motors for extended range and highly responsive controls. Sporting an **advanced sensor suite** and avionics package, *Halcyon* possesses highly effective obstacle sensing awareness, useful for traversing mountainous terrain; a traffic collision avoidance system for communicating and coordinating with other aircraft in flight; and a precise, redundant navigational system for reliable payload delivery and recovery.





1. Deployment

At an altitude of 15,000 ft ISA, flying at an equivalent airspeed of 140 knots, *Halcyon* is launched from the cargo bay of a C-130J transport aircraft.

2. Transition to Autonomy

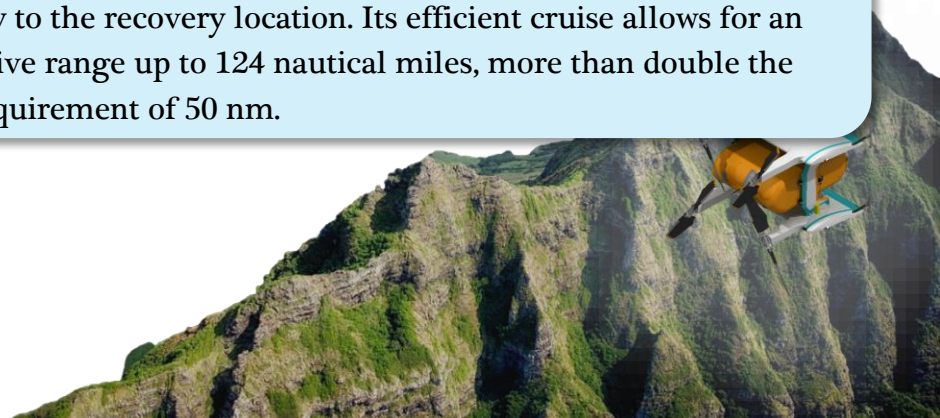
Halcyon passively stabilizes after launch, then powers up the rotors to enable variable RPM control. *Halcyon* transitions to controlled flight at 13,900 ft, well above the 11,000 ft RFP requirement.

3. Precision Hover

From a 50 ft hover at an elevation of 10,000 ft, *Halcyon* delivers its 508 lb payload using an FAA-certified rescue hoist and automated tether system, using a gust-mitigation anti-swing controller to complete delivery in 30 seconds.

4. Return to Base

Halcyon transitions from hover into airplane-like cruise for its journey to the recovery location. Its efficient cruise allows for an expansive range up to 124 nautical miles, more than double the RFP requirement of 50 nm.



ENABLING RAPID RESPONSE



The first 72 hours after a natural disaster are critical for survivors left without water, shelter, and medical aid. *Halcyon* is there to help.



Stored in a fully self-contained kit, seven disassembled *Halcyon* aircraft can be carried by C-130J transport to strategic operating locations in the disaster-struck region. Assembled within minutes using the standard tooling included with the kit, six *Halcyon* aircraft can then be loaded with emergency supplies such as cases of water, temporary shelters, meals ready-to-eat, and first aid materials for delivery in a single flyover.

EASY MANEUVERING:

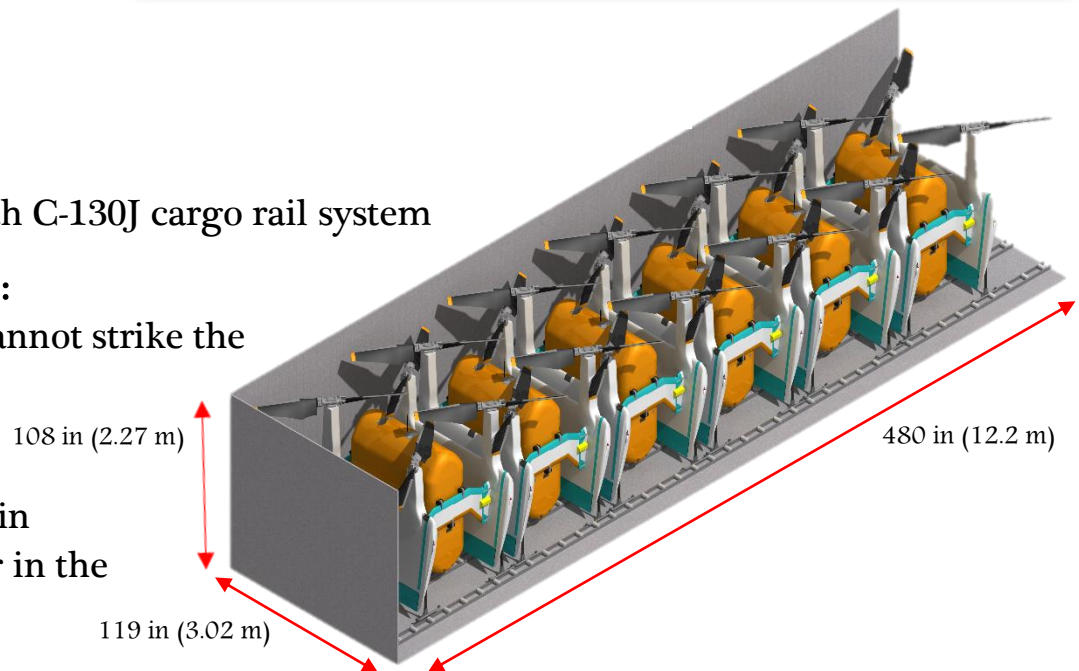
Seamless integration with C-130J cargo rail system

SIMPLE & PROTECTED:

Skids spaced so blades cannot strike the adjacent aircraft

SAFE:

Rotors held firmly in place by a torque limiter in the hub



3,048 lb PAYLOAD DELIVERED PER FLIGHT

Halcyon's unique overlapping rotor system allows six assembled aircraft, each carrying 508 lb of payload, to be packed within the 40 ft cargo bay while still complying with standard C-130J cargo regulations. Therefore 3,048 lb of emergency supplies – over six times the RFP requirement – can be delivered to disaster victims with each C-130J flight.



OPTIMAL CONFIGURATION FOR RESUPPLY



Halcyon's quadrotor biplane tailsitter design incorporates the best features of each configuration to meet and exceed the mission objectives.

Quadrotor

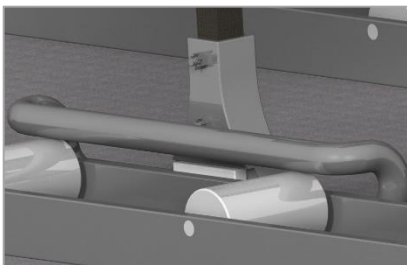
Halcyon employs a quadrotor's excellent control authority, utilizing four-point thrust and variable rotor RPM to maintain precise control. A simple fixed-pitch hub design supports a low maintenance, lower-cost aircraft while facilitating a successful mission and easy field repair or replacement.

Biplane

Two wings, each with an actuated flap, provide natural stability in deployment and lift in forward flight, enabling high speed, low power cruise, increased fuel efficiency, and extended range.

Tailsitter

Compact tailsitter design results in a lightweight, compact aircraft that takes full advantage of the inner dimensions of the C-130J cargo bay, maximizing both the number of vehicles deployed and the amount of payload delivered in a single mission.

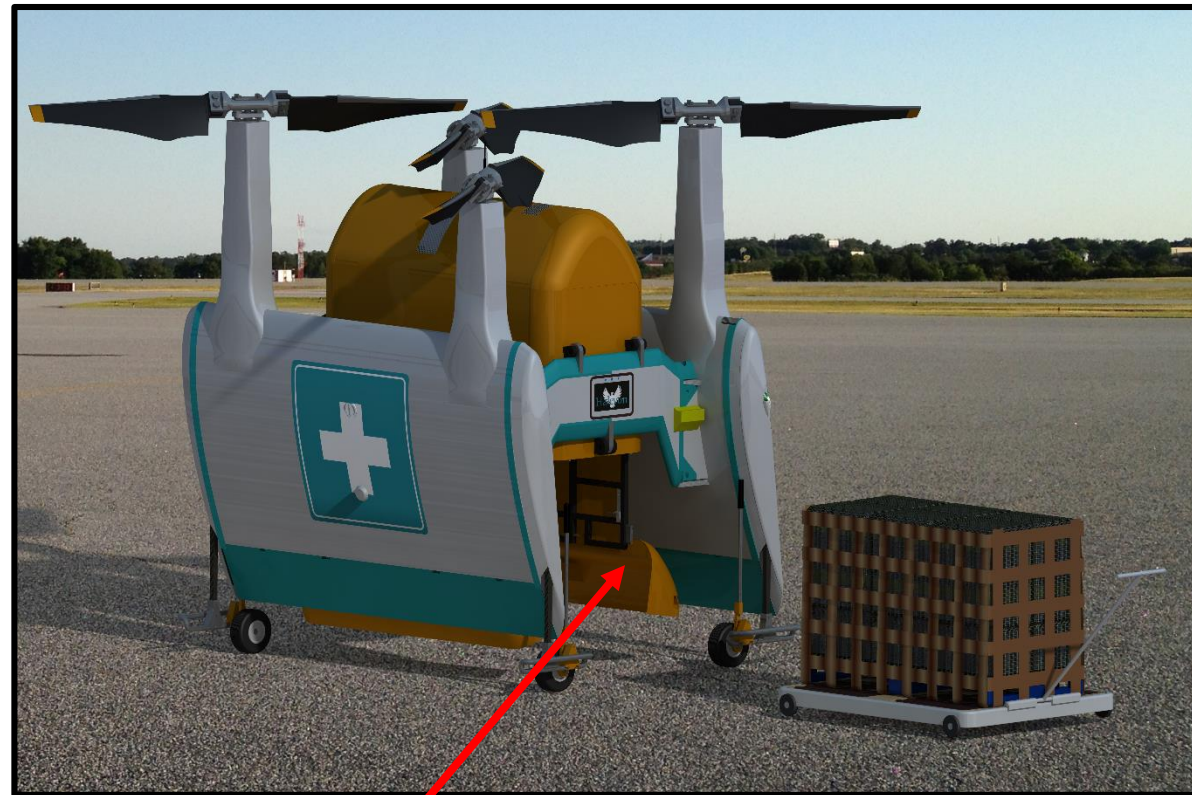


FEATURES

- Parachute-free deployment: *Halcyon's* CG placement naturally stabilizes the aircraft after launch, enabling the rotors to safely spin up
- Batteries recharge in-flight for minimal turnaround time
- Dual-mode skids seamlessly interface with the universal 436L cargo system used in the C-130J and lock onto ground handling wheels for maneuverability

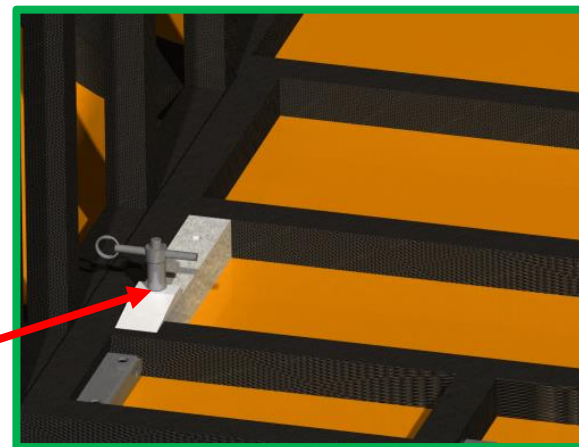


Payload Loading and Delivery



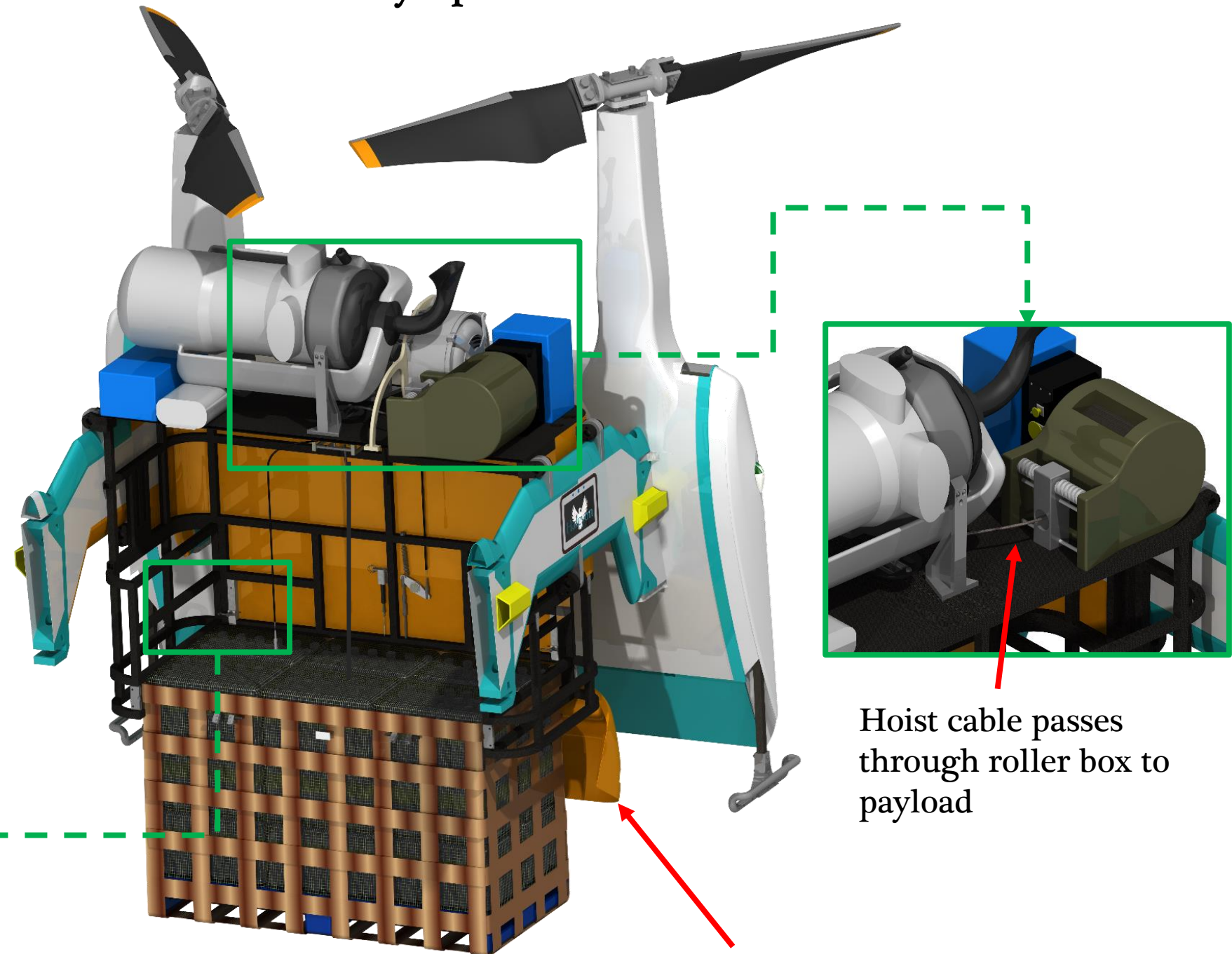
Loading Operations

Payload doors operable by hand and latch open



Adjustable stops and fuselage frame position payload

Delivery Operations



Hoist cable passes through roller box to payload

Pallet forces doors open for delivery

Payload System Features

- Payload easily loaded by one person using a single tool
- Touchpad interface enables easy use of vehicle hoist
- Door latches operated by hoist cable extension and retraction

AUTOMATED PAYLOAD DELIVERY

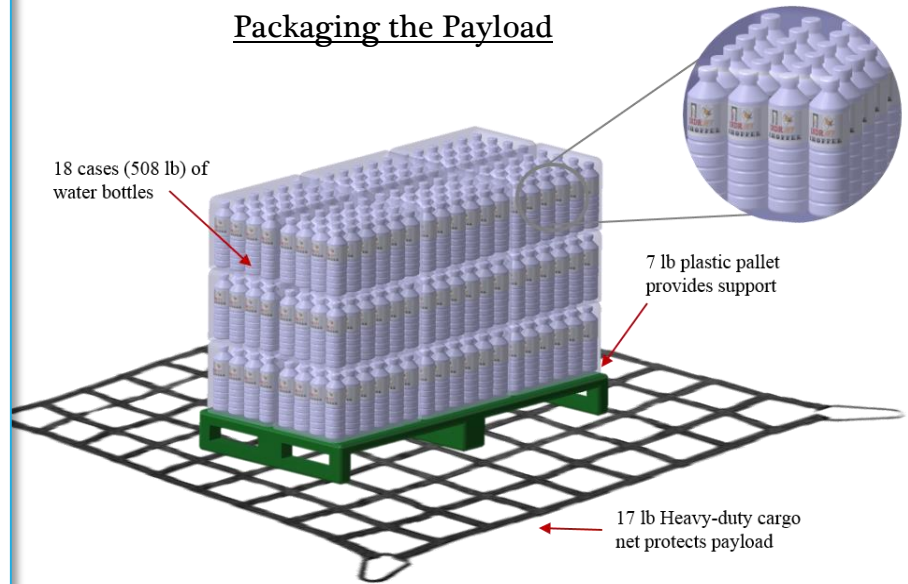


Halcyon is designed to maximize the amount of supplies delivered in one flight, increasing the impact of relief efforts in the critical hours after a disaster. One *Halcyon* aircraft can deliver over 500 lb of emergency supplies, and a C-130J transport aircraft loaded with six *Halcyon* aircraft can deliver over 3,000 lb of aid – over six times the RFP requirement – in a single C-130J flyover. *Halcyon's* lightweight, automated payload delivery system maximizes payload carrying capacity, and internal carriage of the payload protects from damage during deployment.

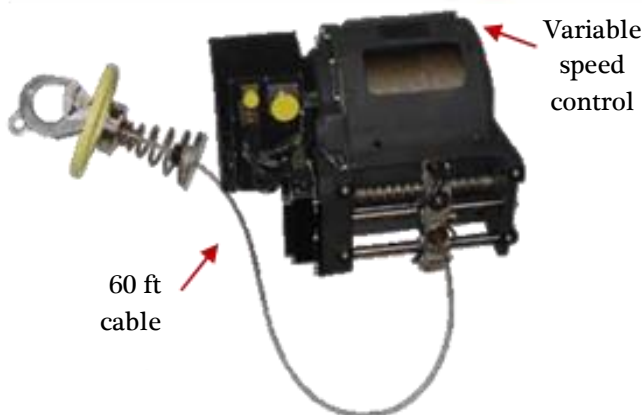
The payload is supported by a lightweight, reusable plastic pallet and wrapped in an industrial-grade cargo net to prevent damage.

Halcyon maximizes the useful payload that can be delivered by selecting the lightest possible packaging for the payload, packing 508 lb of water bottles into *Halcyon's* cargo bay.

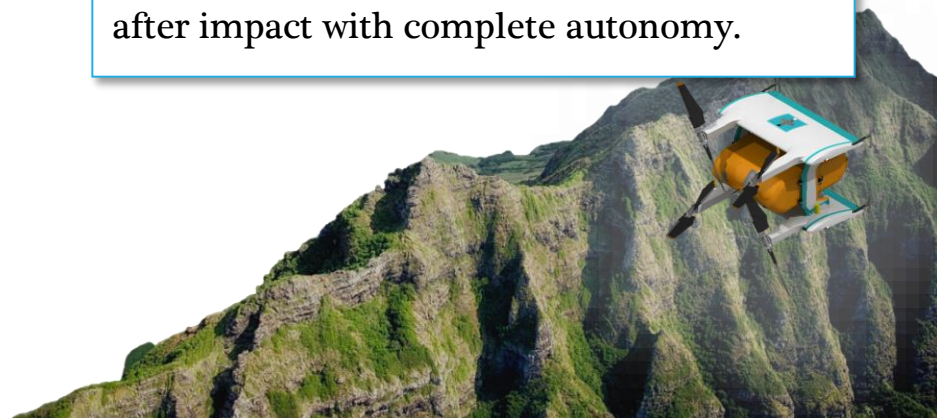
Packaging the Payload



UTC Aerospace Helicopter Rescue Hoist



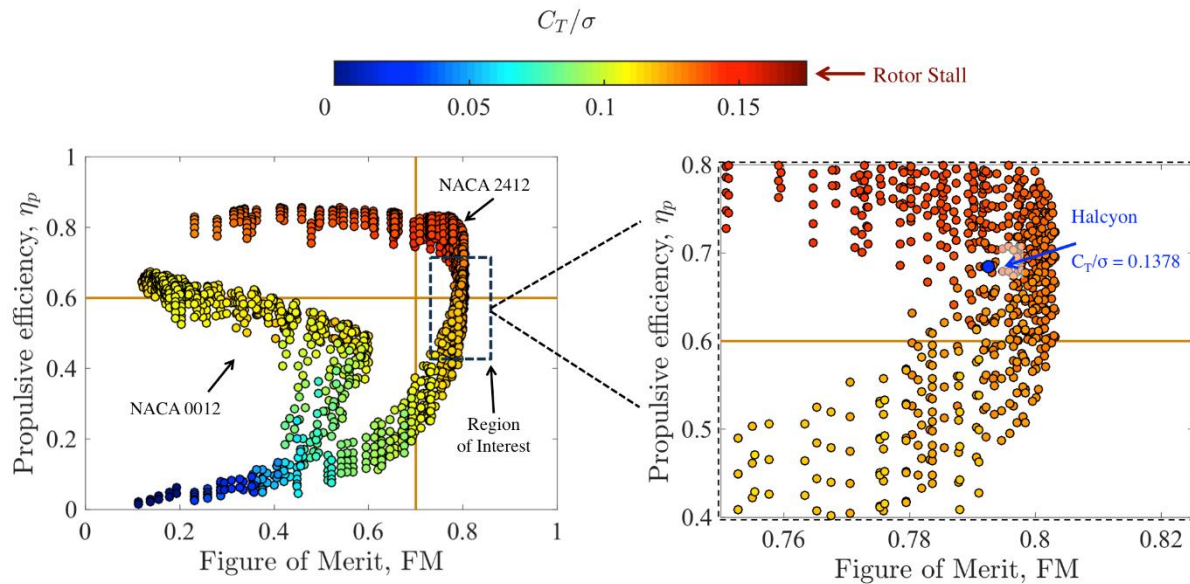
Halcyon's cargo delivery system includes a variable-speed hoist designed for helicopter rescue operations to deliver the payload within 30 seconds, well under the 60 second requirement, and an automatic pressure-sensitive cargo hook to release the payload after impact with complete autonomy.



OPTIMIZED PROPROTOR DESIGN



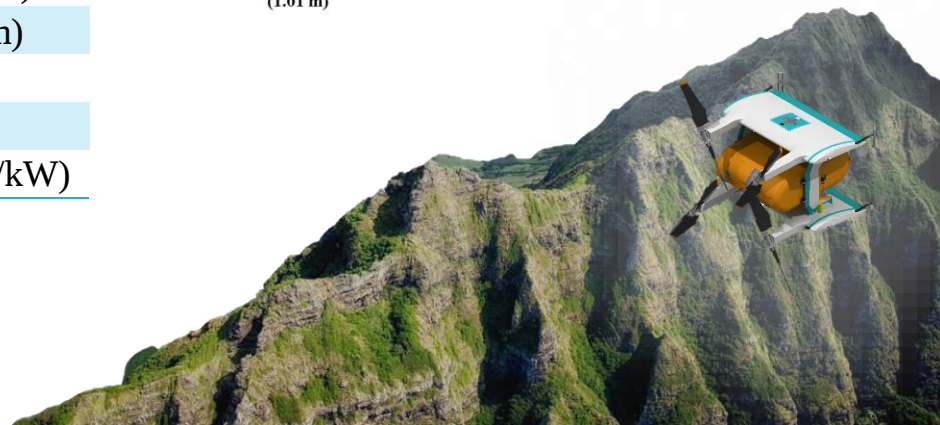
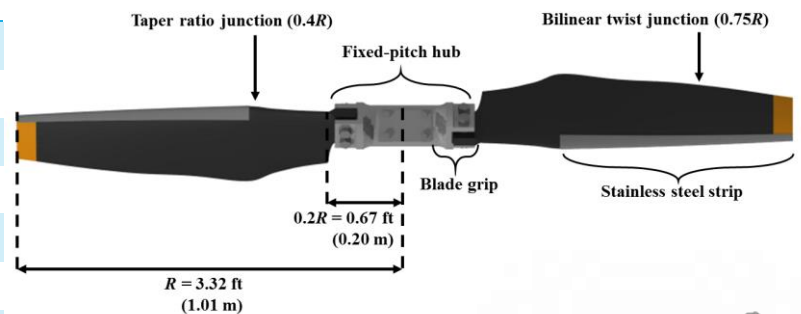
Halcyon's variable RPM rotors achieve efficient hover and minimize the weight and complexity of the rotor system. Bilinear twist proprotors yield a high stall margin and a **high Figure of Merit** of 0.79. A fixed-pitch design enables an extremely simple hub, minimizing cost and maintenance time.



Using blade element momentum theory, the performance of 5,500 independent fixed-pitch blade designs was assessed in hover and cruise modes 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.

ROTOR CHARACTERISTICS

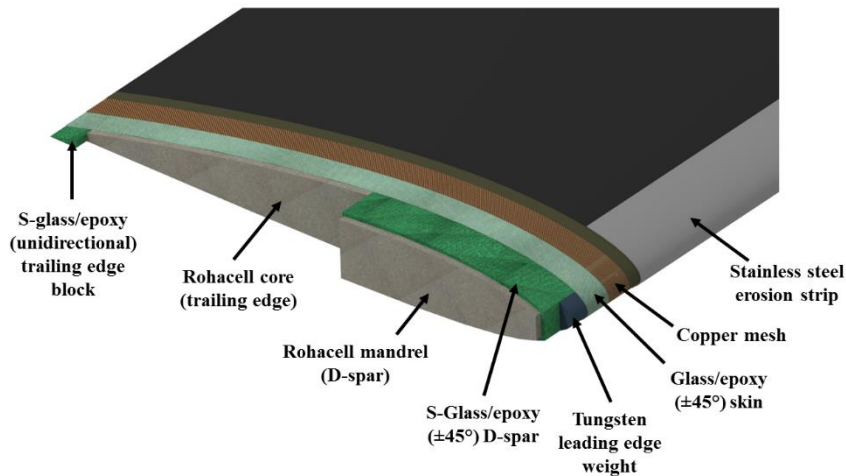
Radius	3.3 ft (1.0 m)
Blades per Rotor	2
Taper Ratio	3 : 1
Airfoil	NACA 2412
Solidity	0.11
Inboard twist	12° / ft (40° / m)
Outboard twist	3° / ft (10° / m)
Twist junction	0.75R
Root fixed-pitch	40°
Power Loading	7.5 lb/hp (4.6 kg/kW)



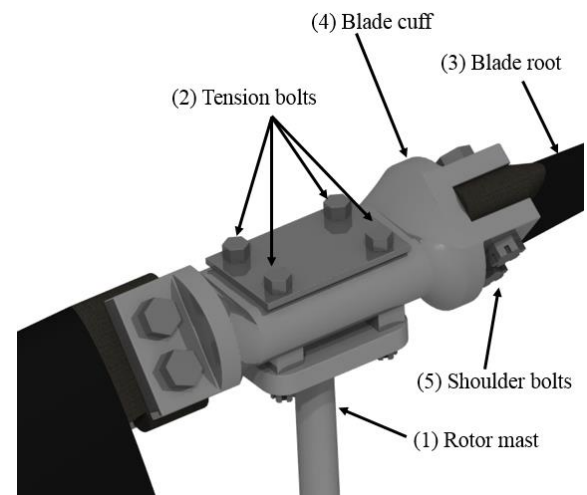
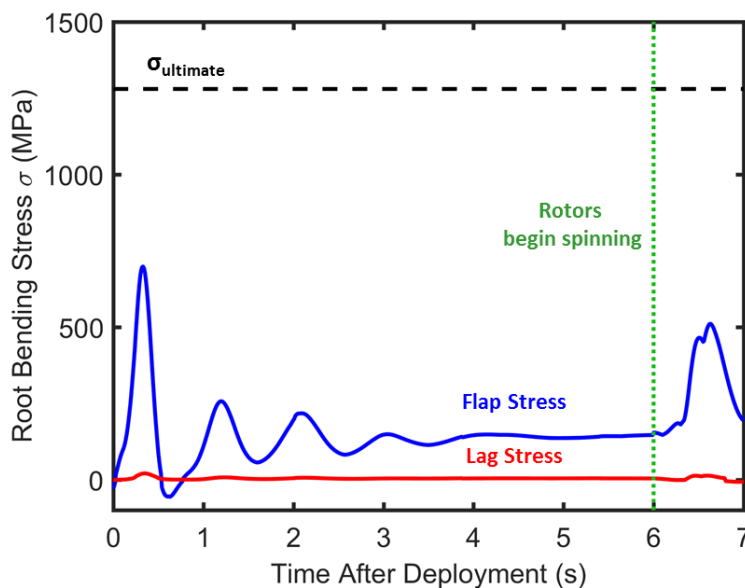
MODULAR BLADE AND HUB ASSEMBLY



Rotor blades are designed specifically to withstand the highly fluctuating loads experienced during launch from the C-130J. Fixed-pitch hubs enable easy assembly and disassembly for transport.



- Fiberglass spar ensures the blades resist the high dynamic loads experienced during deployment
- Lightweight blades allow the rotors to start up more quickly after deployment
- Rotor hub design, consisting of only 5 components, is mechanically simple and easy to assemble



High strength-to-weight ratio composites enable lightweight construction and a safe launch from the C-130J cargo hold.

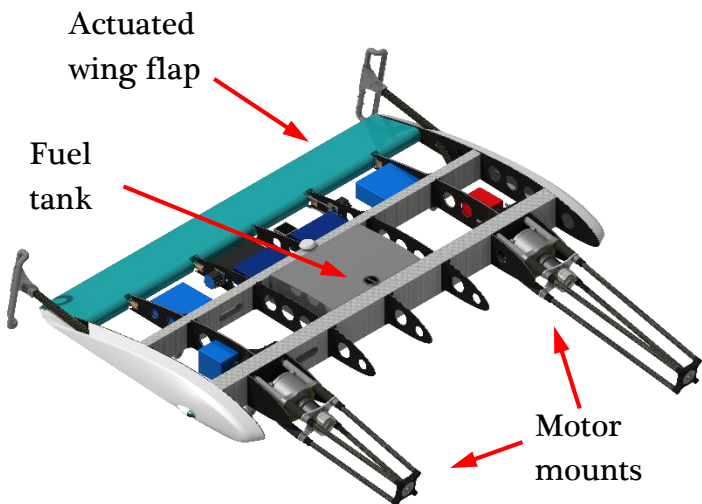
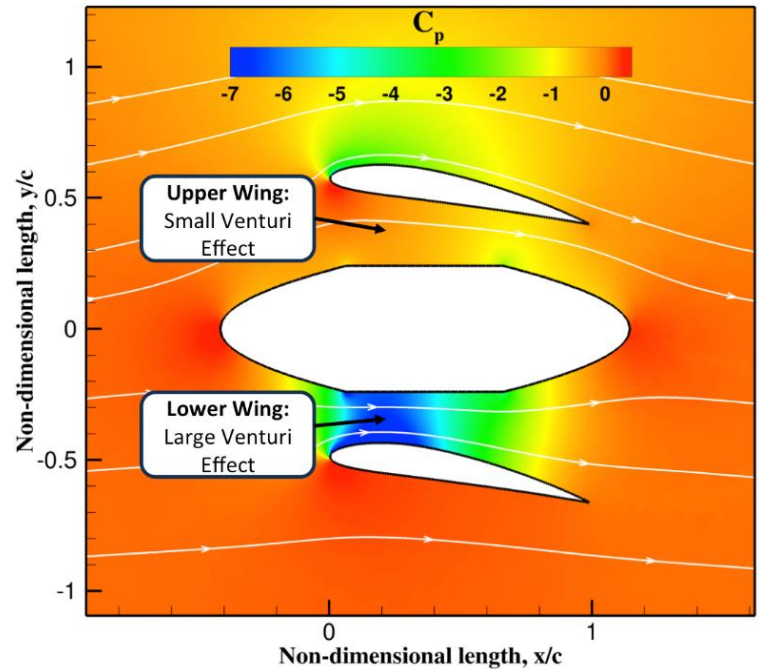


BIPLANE WING DESIGN

Each of *Halcyon's* wings feature a NACA 2412 airfoil section and are mounted at a pre-set angle of 10° . The proximity of the wings to the fuselage leads to a highly unique aerodynamic environment dominated by interaction effects.

Low aspect ratio wings enable *Halcyon* to fit within the constraints of the C-130J while providing stability during deployment and offloading the rotors in cruise.

Computational Fluid Dynamics (CFD) analysis demonstrated the need for cambered airfoils and a 10° incidence angle to provide required lift in forward flight.



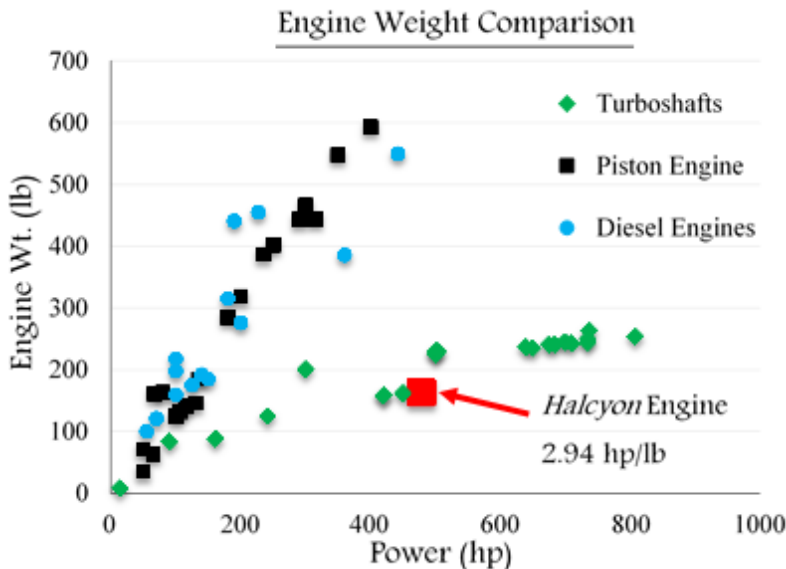
Halcyon's wings house the motors, motor mounts, fuel tanks, and wing flaps.

- **Composite** structure supports the entire vehicle weight in cruise while minimizing empty weight
- **Actuated flaps** provide pitch stability in deployment without power supplied from the rotors



SERIAL HYBRID PROPULSION

Halcyon uses a turboshaft-driven electric generator to power its electric transmission and flight control system. Capable of high altitude operation in both helicopter and airplane modes, *Halcyon's* turbo generator was selected for its high power to weight ratio and mission flexibility: *Halcyon's* range can be extended simply by carrying additional fuel tanks as the mission payload.

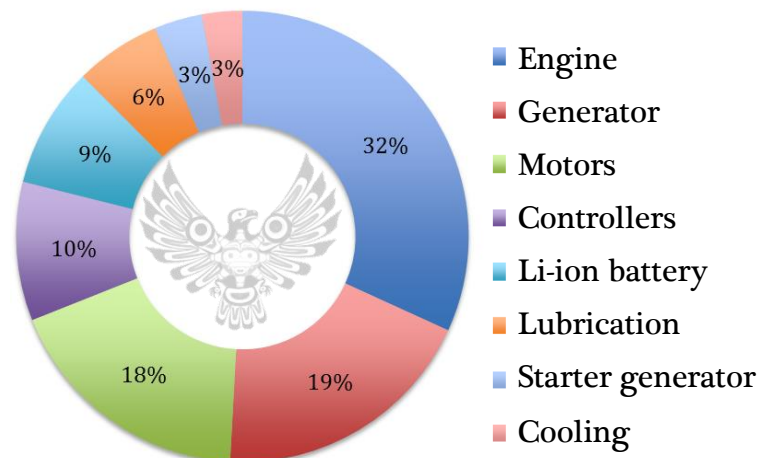


Four high-power, lightweight electric motors, monitored by four independent speed controllers, enable exceptional maneuverability using variable-RPM rotors.

Electric motors provide quick response to flight commands. The simple electric transmission is also easily maintained and checked before flight in a matter of seconds.

High energy density lithium-ion batteries are used to power the aircraft's systems while inside the C-130J and in the initial moments after launch from the cargo bay. This deployment battery as well as the separate batteries used to power the avionics and flight control systems help to reduce carbon emissions and are recharged with the excess power generated in cruise.

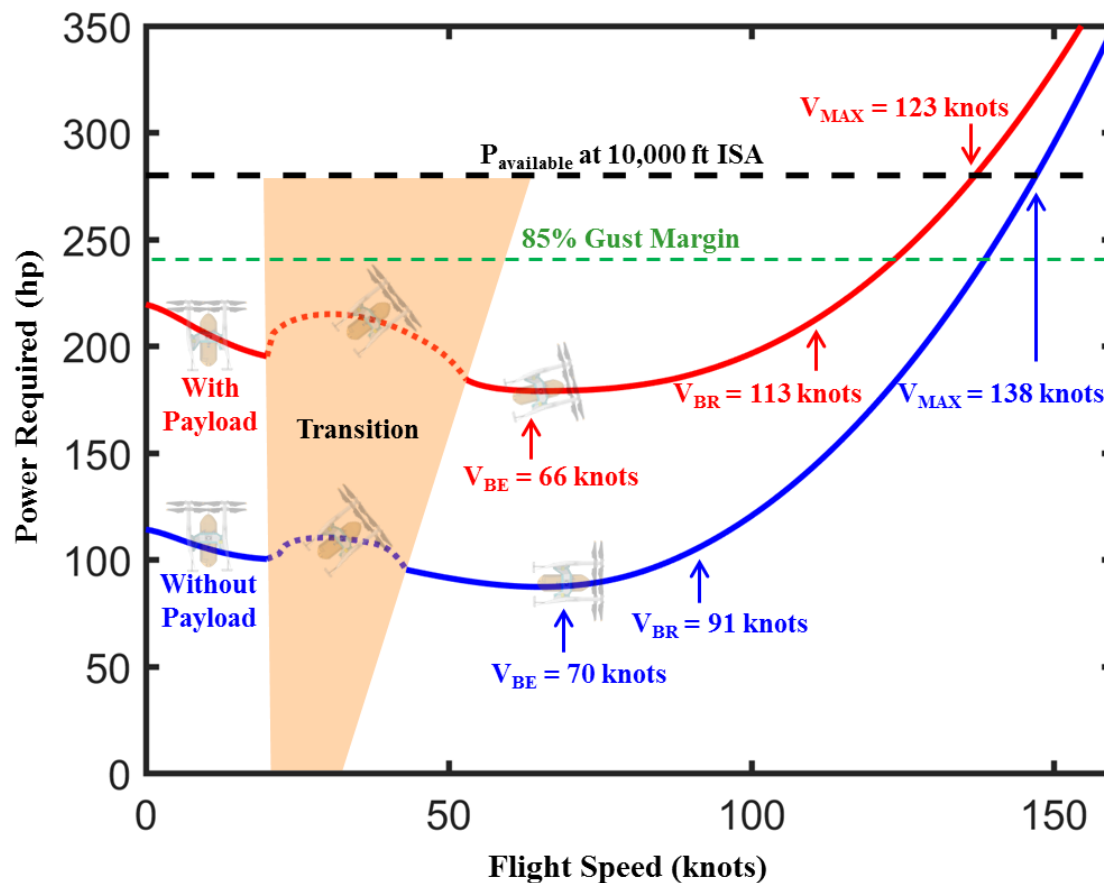
Propulsion System Weights



OUTSTANDING VEHICLE PERFORMANCE



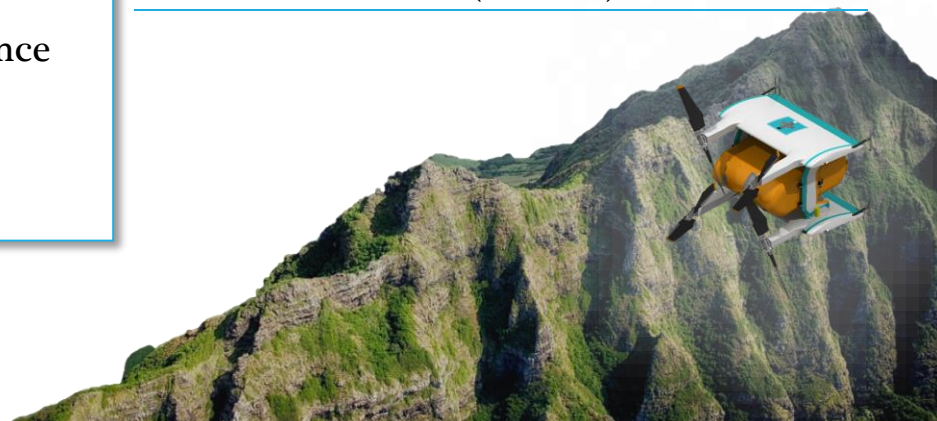
Halcyon achieves extended range and endurance by combining the exceptional hover performance of a helicopter and the range and low power cruise of a fixed-wing aircraft.



The *Halcyon* vehicle provides **unparalleled mission flexibility** for tailoring *Halcyon's* operation to the following scenarios:

- Equip and resupply
- Aerial mapping
- Search-and-rescue
- Surveillance and reconnaissance
- Telecommunications support
- Logistics support

Vehicle Configuration	Range	Endurance
With Payload	56 nm (104 km)	46 min
Without Payload	124 nm (230 km)	1 hr 19 min



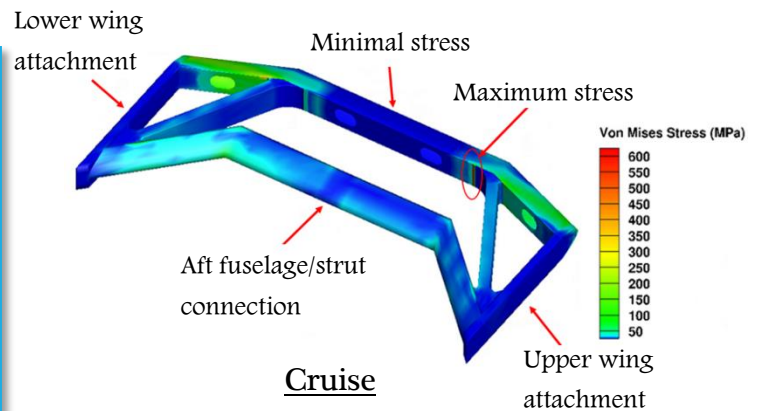
LIGHTWEIGHT AIRFRAME DESIGN



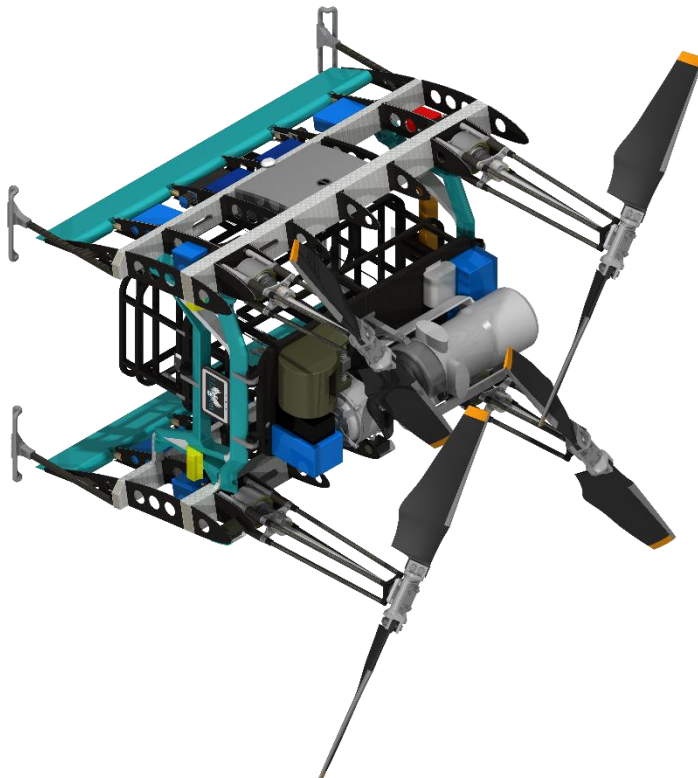
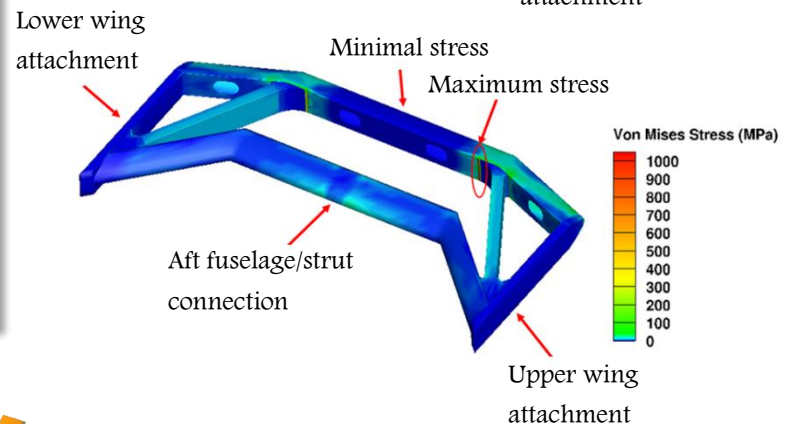
To withstand the loads experienced during deployment, a carbon fiber and Rohacell sandwich composite is utilized throughout *Halcyon's* airframe to maximize strength and stiffness while minimizing the aircraft empty weight.

- Composite structure is designed for strength and maintainability
- Fiberglass layer between fasteners and the carbon fiber skin prevents corrosion
- *Halcyon* is easily assembled within minutes using only five standard tools and press-fit pin joints
- The structural response to various flight load cases in hover and cruising flight was examined using X3D Finite Element Analysis

Hover



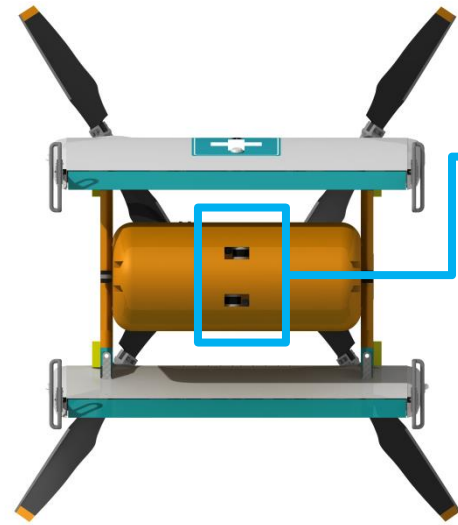
Cruise



- Quick-release bump stops within the fuselage secure the payload in flight
- Box beam network in the bulkhead distributes the weight of the equipment or supplies being delivered regardless of payload size

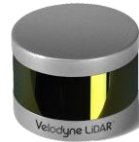


Halcyon Avionics Suite



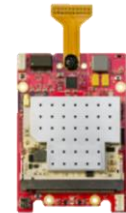
2x LIDAR

- 3D mapping with 300,000 points per second
- 100m range and 30° horizontal field of view



2x Autopilot

- Fully autonomous operation
- Redundant CPU
- Inertial navigation system integrated



Datalink

- Communicates with ground control station at up to 108 nmi
- Live video feed

Electronic Circuit Breaker

- Fully programmable
- Remote sensor power up



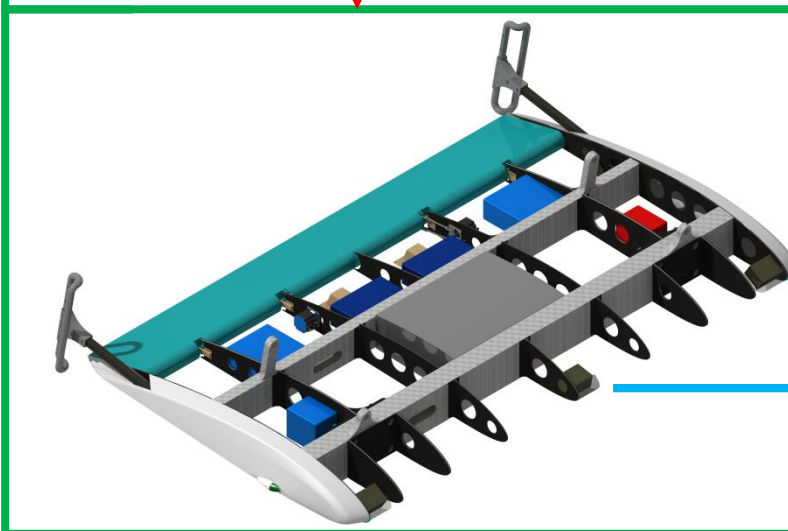
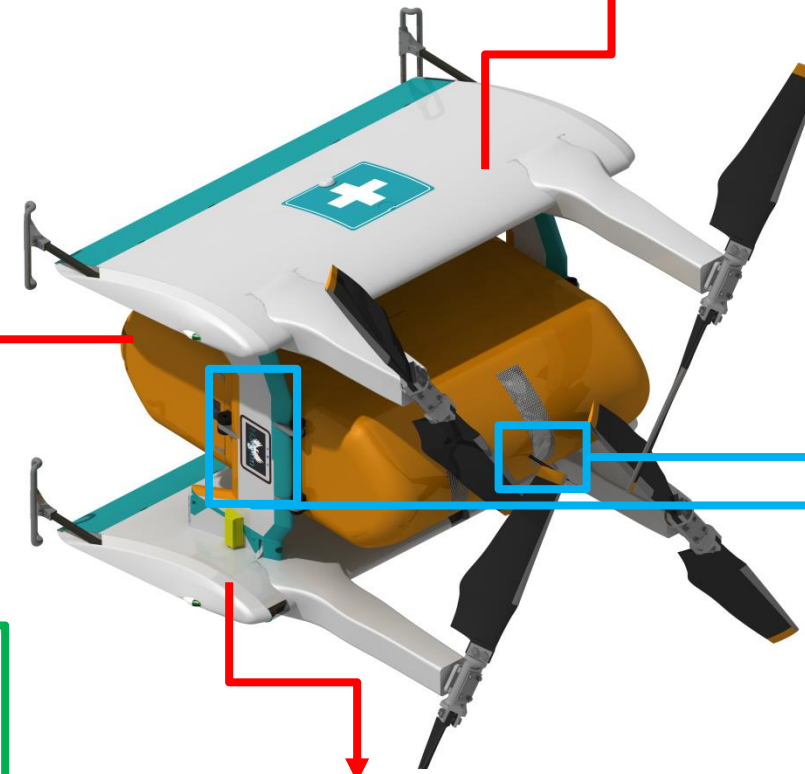
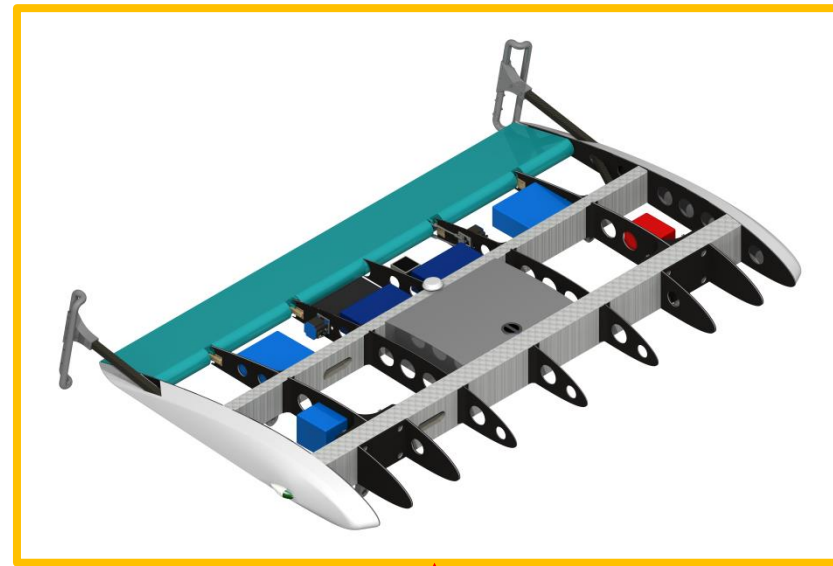
Traffic Collision Avoidance System

- Detects aircrafts and obtains location and flight path trajectory



RADAR Altimeter

- Altitude above ground level up to 2550 ft.



Rugged Mini PC

- Intel i7 processor for 3D mapping
- Delivery & landing zone assessment software
- Obstacle avoidance software



GNSS Antenna and Receiver

- 2 cm Location Accuracy

Omni-Probe

- Air data inputs at up to 165 degrees from axis



Touchscreen Display

- Interactive display for Halcyon preparation
- Sensor diagnostics display



Laser Rangefinder

- Obstacle detection at up to 8.63 nmi (16 km)



6x IR Camera

- 1080p/30fps video
- Motion detection
- 90° field of view



6x Visual Camera

- Detects people at up to 935 ft (285 m)

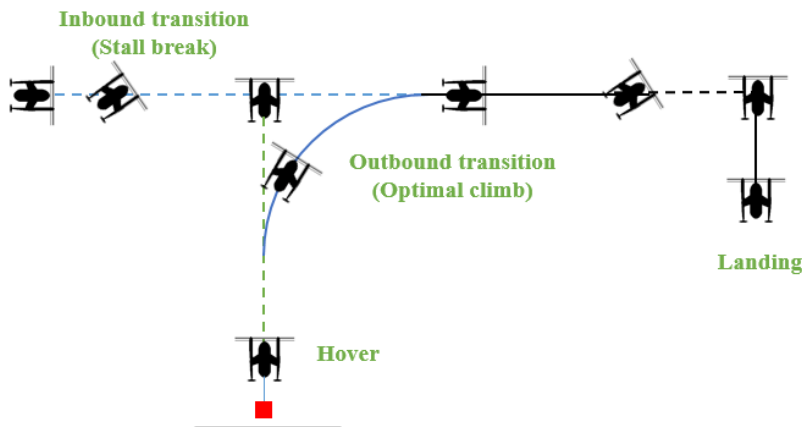
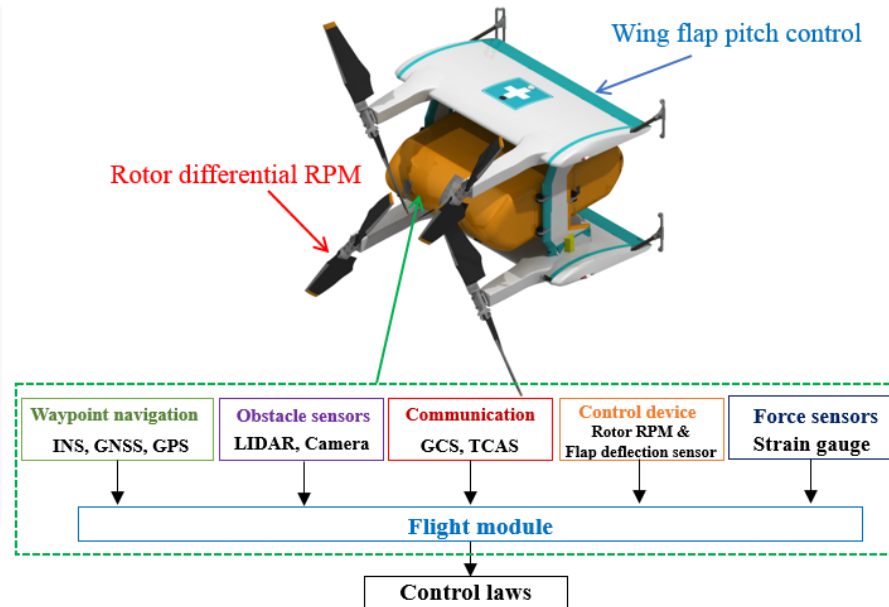


EXCEPTIONAL CONTROL AUTHORITY



Halcyon's quadrotor design features four-point control for exceptional agility and maneuverability.

- *Halcyon* naturally pitches nose-down in unpowered descent after launch
- Electrically-actuated wing flaps achieve favorable pitch attitude and permit safe rotor start-up
- Differential rotor RPM enables roll, pitch and yaw control in hover and forward flight mode



- *Halcyon* uses rotors and wings to rapidly decelerate during inbound transition ("stall brake") to hover
- *Halcyon* transitions from hover to cruising flight using an optimized flight profile for efficient climb

Halcyon delivers the payload within the 60-second requirement and with an impact velocity of less than 5 ft/s following gusts up to 20 ft/s



SYSTEM of SYSTEMS DESIGN



The *Halcyon* system is the complete solution for disaster response, designed for all aspects of the mission including preparation, execution, and reloading.

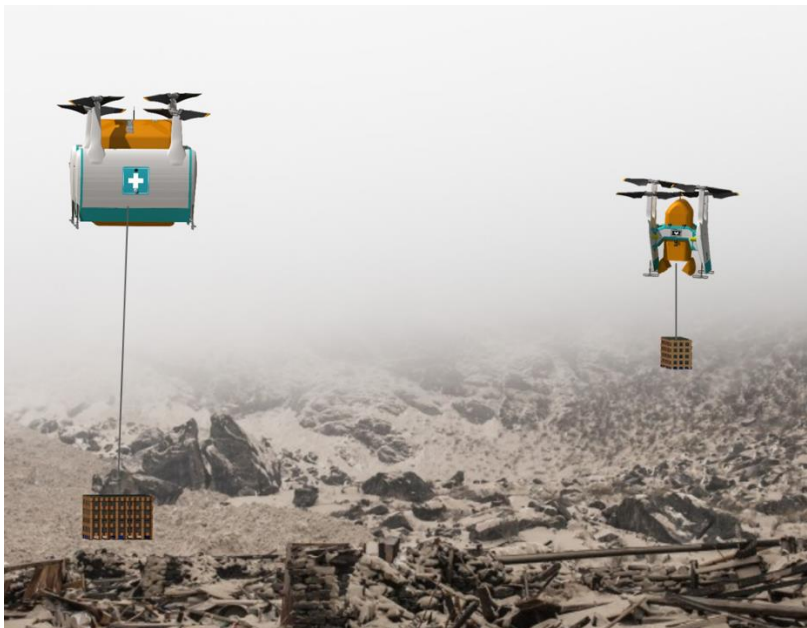
Preparation

- *Halcyon* assembly kit requires just five tools for easy assembly at the disaster site
- Three-person crew required to load *Halcyon* into the C-130J per OSHA regulations
- For safety, rotor blades are 7.5 ft high, leaving sufficient clearance above crewmember head height



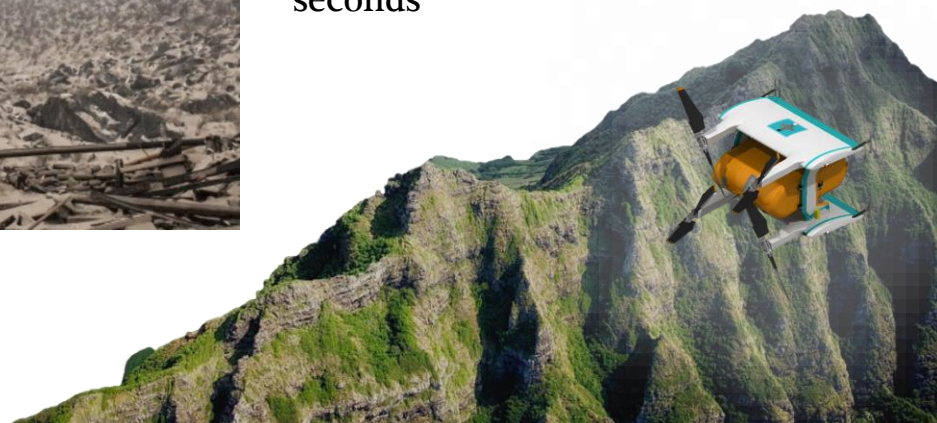
Execution

- Navigate rough terrain and sense-and-avoid obstacles
- Maintain communication with other *Halcyon* units and nearby aircraft for multi-vehicle mission coordination and flight safety



Reloading

- Batteries recharge during flight to minimize turnaround time between missions
- *Halcyon's* two 8-gallon fuel tanks are filled by a standard pump in 90 seconds

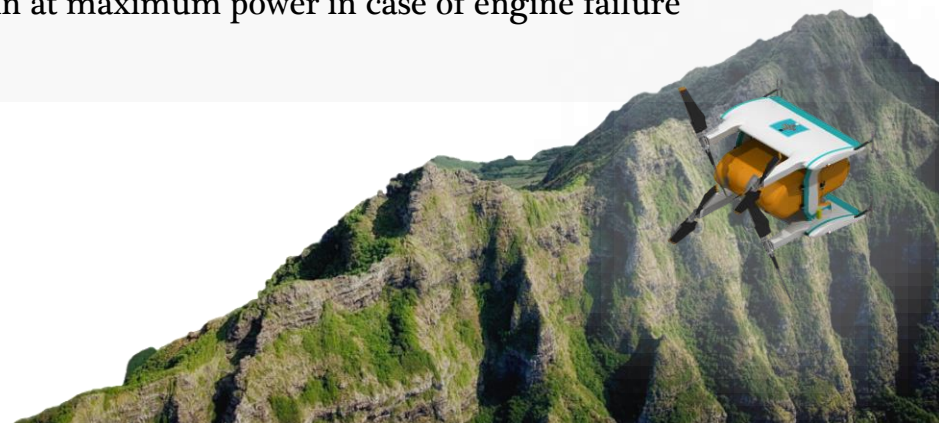


SAFETY FEATURES



Maintaining operational safety in every phase of the mission is a key aspect of *Halcyon's* design.

Staging	• Internal payload carriage protects against damage • Complies with all C-130J regulations • Loading procedures comply with OSHA regulations
Deployment	• No power supplied to rotating components while inside the C-130J • LED touchscreen panel performs pre-flight system check before deployment: indicator light turns a solid green if ready for launch, turns white if an error occurs during the system check, and flashes if a problem is detected • Even in turbulence, <i>Halcyon's</i> skids prevent the aircraft from striking the C-130J interior during deployment • Achieves controlled flight at 3,000 ft AGL, well above the RFP requirement of 1,000 ft AGL
Delivery	• From a 50 ft hover (15 rotor radii above the ground), <i>Halcyon</i> demonstrates a low rotor downwash of 35 ft/s • <i>Halcyon</i> effectively stabilizes the underslung payload using rapid-response electric motors and an anti-swing controller, even in gusts up to 20 ft/s
Cruise	• Three-tier redundancy in <i>Halcyon's</i> navigational and obstacle sense-and-avoidance systems ensures uninterrupted control during flight • Backup batteries and four independent motors provide redundancy in case of power failure
Landing	• Capable of landing on uneven terrain with up to 31° inclination (36° with payload) • Wing and battery-powered flaps allow for emergency landings from cruise • Backup battery sustains one min at maximum power in case of engine failure



Disaster Relief



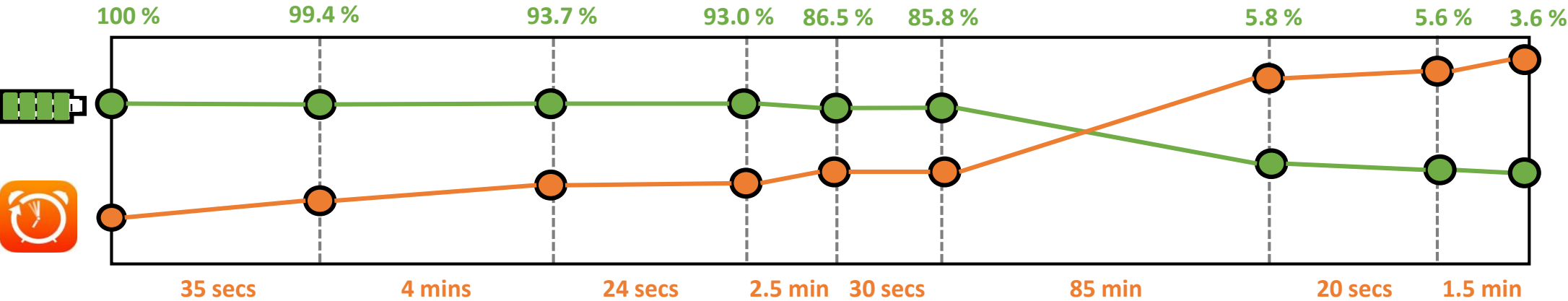
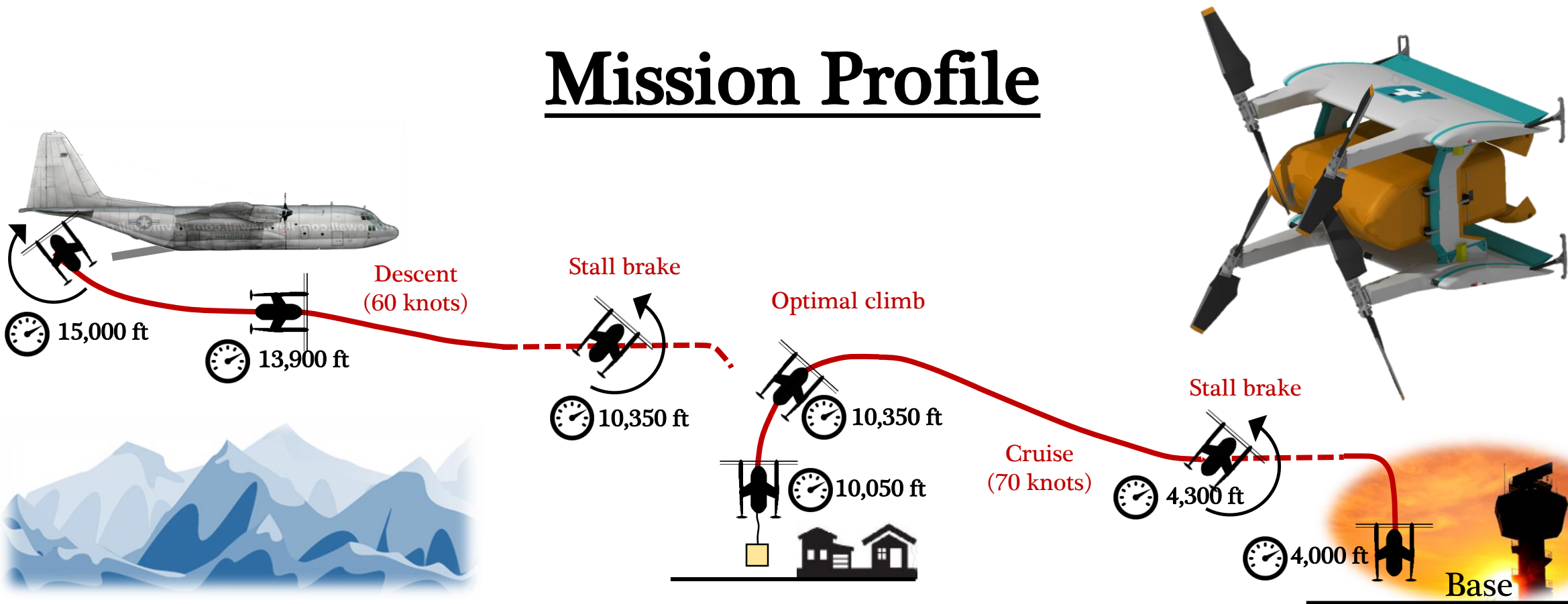
City	Total payload (lb [kg]) (# of Halcyon)		Distance from base
Cajamarca (8,900 ft)	1,000 [455]	2	60 nm [111 km]
Huaraz (10,013 ft)	1,500 [682]	3	95 nm [176 km]
Bambamarca (8287 ft)	500 [227]	1	50 nm [93 km]

The ability to deploy 6 fully equipped *Halcyon* vehicles with every C-130J deployment allows for disaster relief over a wide geographical region.

Over 3,000 lb of relief supplies are delivered to this affected region in South America.



Mission Profile



- Air launch** High-speed air launch naturally stabilized using wings with sufficient safety margins on all components
- Safe** Flight paths chosen from set of possible maneuvers based on fuel efficiency and environmental constraints
- Efficient** Fuel efficient descent angle based on target range
- Autonomous** Multiple navigation and obstacle sensing avionics suite
- Precise** Feedback hover control with gust tolerance

SUMMARY



Developed in response to the Request for Proposal for the 2015 AHS Student Design Competition, *Halcyon* is a complete system of systems solution that is versatile, efficient, and designed specifically for a resupply mission. Guided by a comprehensive analysis of flight mechanics, aerodynamics, structural integration, and logistics modeling developed at the University of Maryland, the *Halcyon* system both meets and exceeds the requirements specified in the RFP.

- Biplane wings sized to support **high speed, low power cruise**
- Quadrotor chosen to provide **exceptional control** authority and **outstanding hover efficiency** with variable RPM for **simple, low maintenance** rotor system
- Compact tailsitter configuration delivers **6 times the payload** specified in the RFP
- **Tailored disaster response** with a network of *Halcyon* UAVs for mission flexibility
- CG positioned to provide **passive stability**, enabling parachute-free deployment
- **Serial hybrid propulsion** is simple, quick to respond, and capable of extended range
- Modular kit aids efficient transport and **rapid on-site assembly**
- Designed for **safe operation** in all mission phases, costing \$1.05 million per unit

