GT Angel

Innovating the future of disaster relief

American Helicopter Society International

33rd Annual Student Design Competition

Graduate Student Team Submission

Georgia Institute of Technology

2016

VEHICLE OVERVIEW

Innovative quadcopter design creates a ***stable*** UAV necessary for a range of payloads

Fully ***autonomous*** vehicle

Compact design allows two vehicles to fit inside of the C-130 cargo bay

Carries up to ***750 pounds*** of disaster relief supplies for high altitude missions

Capable of deploying from C-130 and arresting its descent ***without the use of parachutes***

Hybrid electric propulsion system allows ***rapid startup of the rotors*** upon deployment

Onboard batteries allow up to ***60 seconds of flight in the event of engine failure***

Vision-based positioning allows ***precise payload delivery***

750 lb Payload

585 hp Max Cont. Power

2234 lb Gross Weight

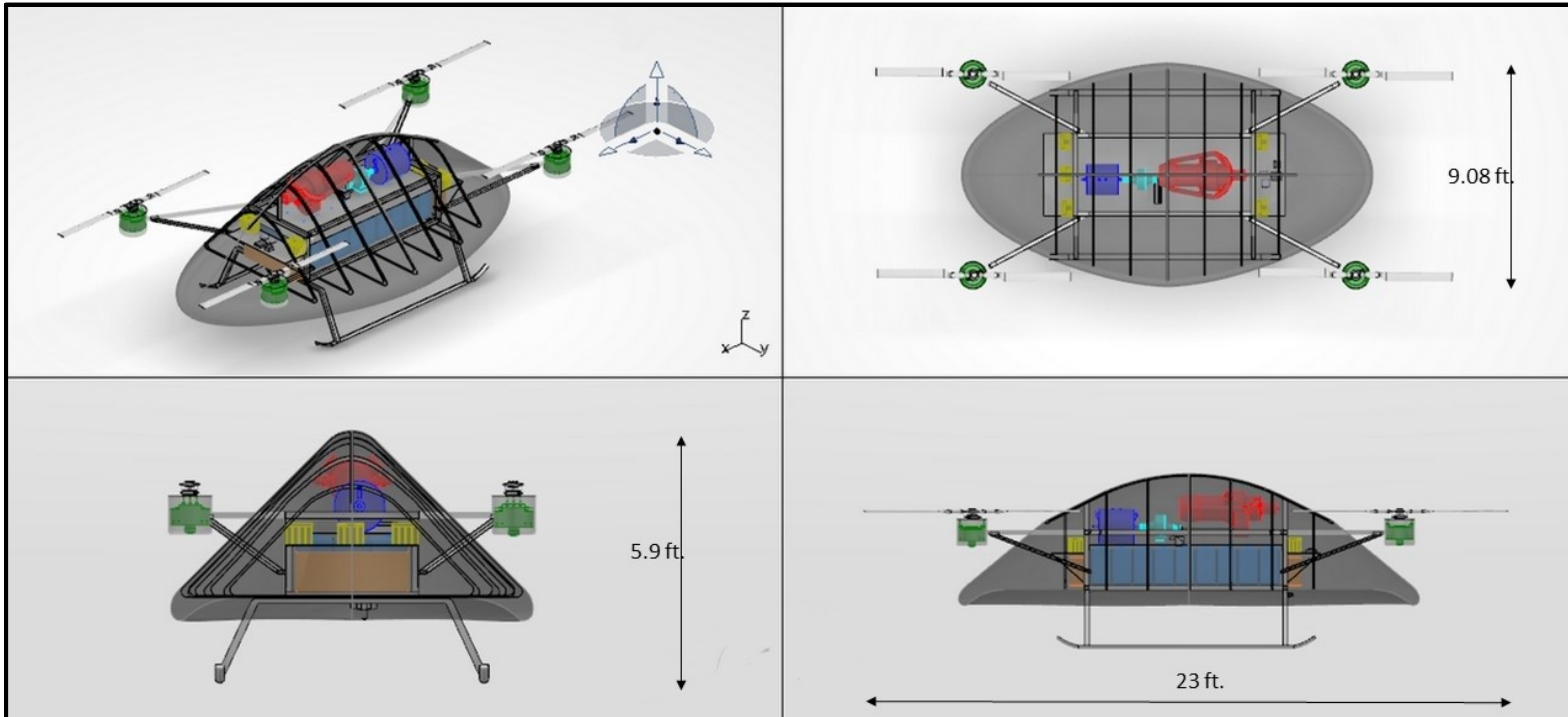
12 lb/ft^2 Disk Loading

3.85 ft Rotor Radius

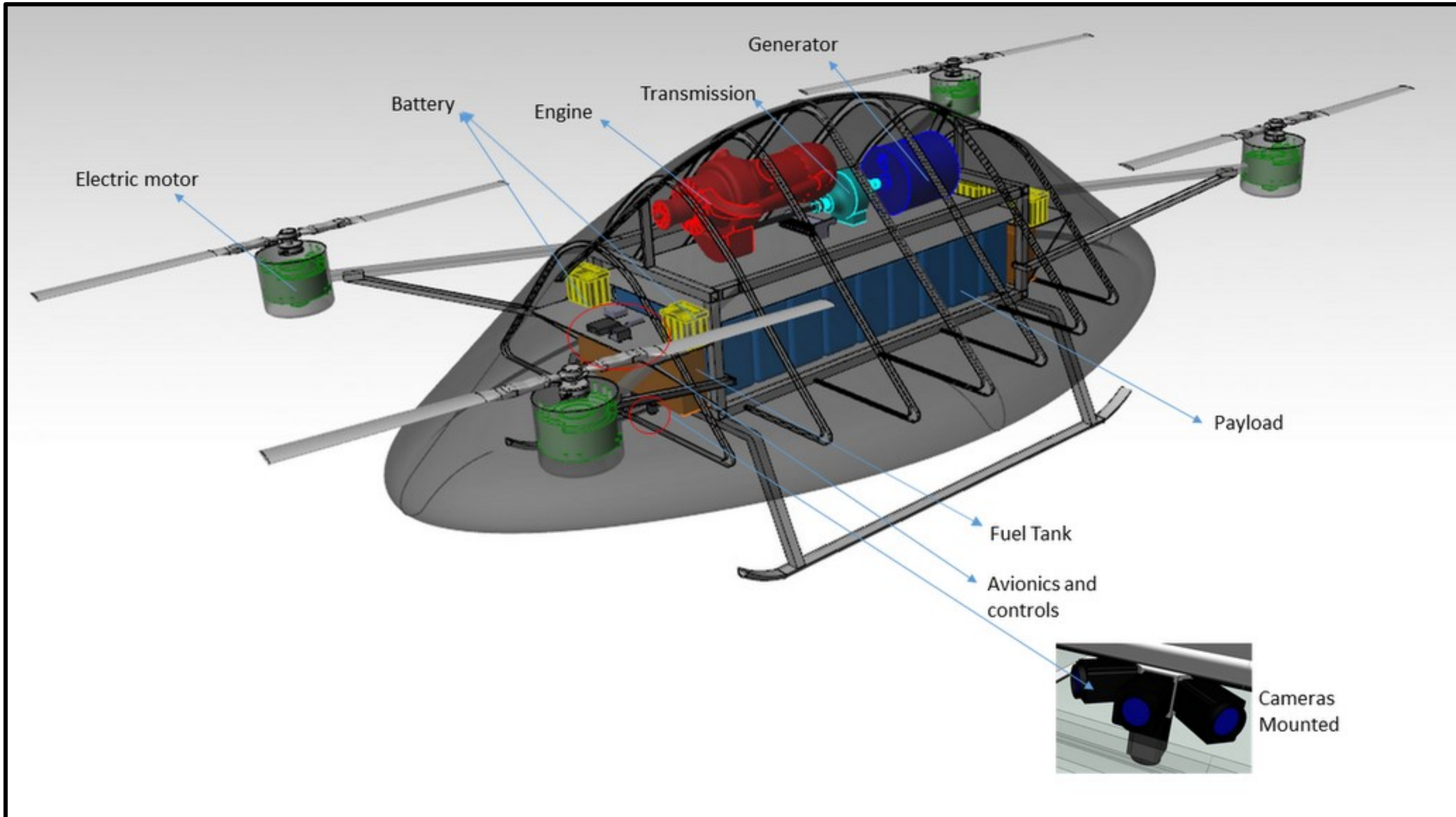
60 knot Cruise Speed

2 Vehicles fit in C-130

FOUR VIEW DRAWING



INTERNAL COMPONENTS



MISSION OVERVIEW

1. Deployment: The GT Angel is deployed from the C-130 using a gravity airdrop where the C-130 increases angle of attack until the Angel slides out of the cargo bay.

2. Descent Arrest: Immediately after deployment, the electric motors begin to turn the rotors. The Angel arrests its descent by using differential collective to create moments and thrust to slow the descent.

3. Transition to Level Flight: The vehicle begins a level flight, and uses the onboard GPS to navigate to the drop zone area.

4. Payload Delivery: In the drop zone area, the Angel descends and uses a vision-based system to identify precisely where the payload should be deployed. Once at 50 ft AGL above the drop zone, the bay doors open, and the payload is lowered to the ground.

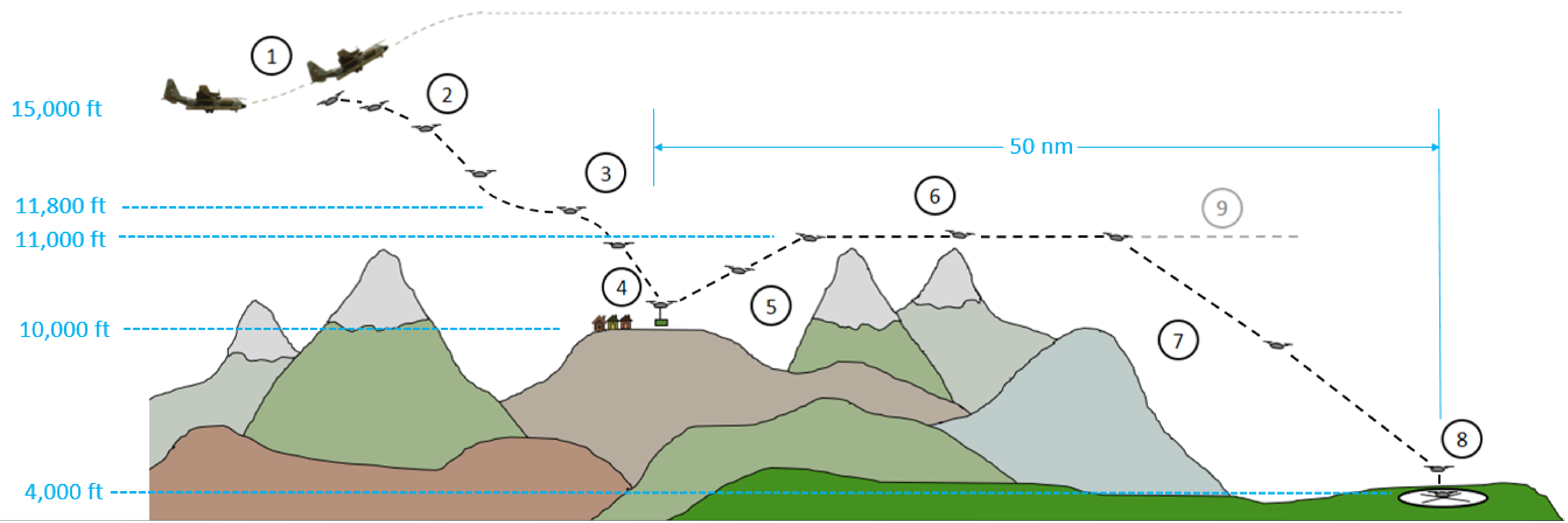
5. Cruise Climb: Once the payload has been delivered, the delivery cable is retracted and the Angel climbs to clear mountains on its return flight.

6. Cruise: The Angel cruises at the speed for maximum range

7. Cruise Descent: Once clear of the mountains, the Angel descents to the landing zone at 4,000 ft MSL.

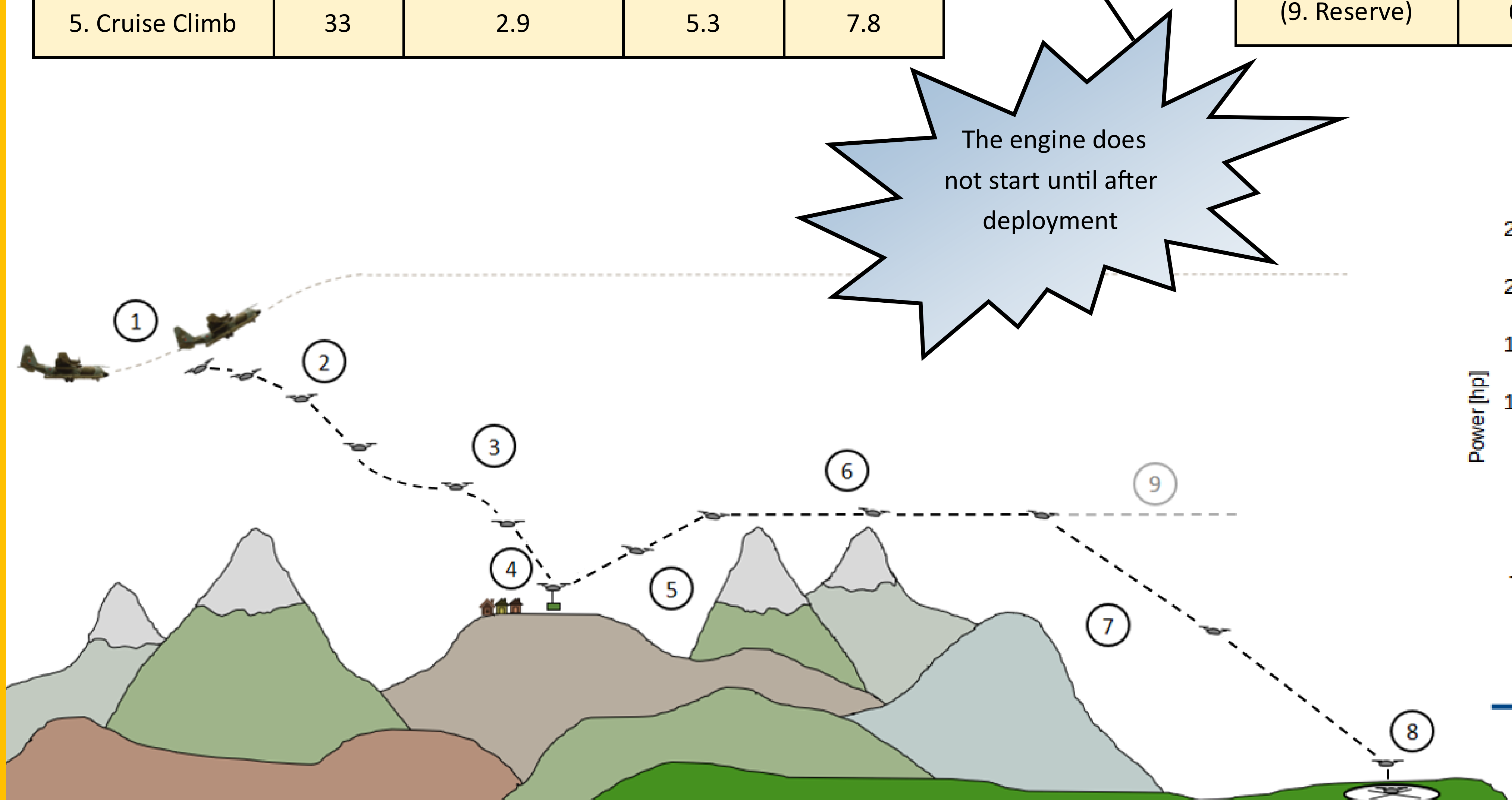
8. Landing: After using the GPS to approximately locate the landing zone, the Angel uses the vision-based positioning system to precisely land at the end of the mission.

(9). Reserve: The Angel has enough reserve fuel to travel 10 nautical miles beyond the target 50 nautical mile mission.

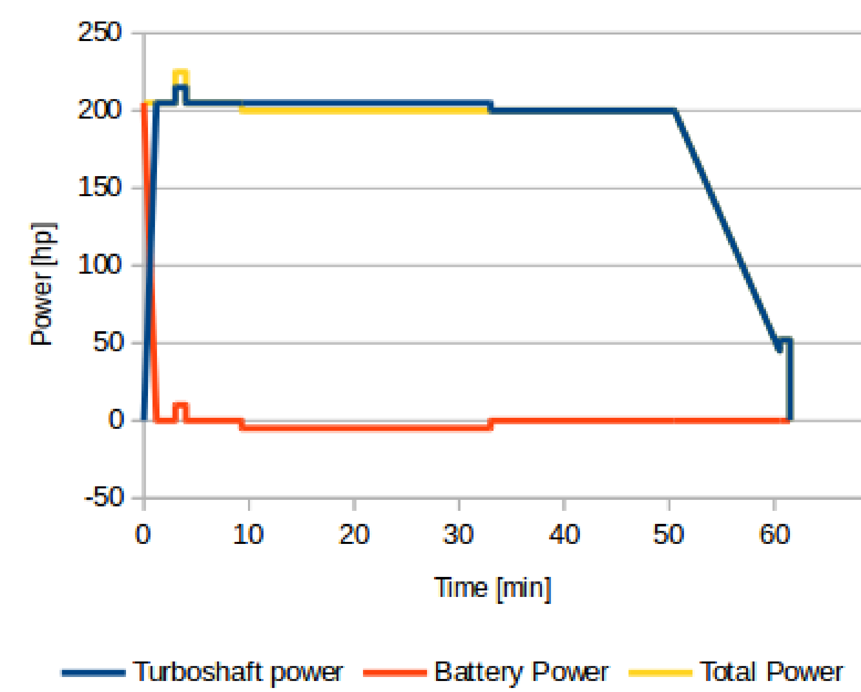


MISSION BREAKDOWN

Mission Segment	Speed [kts]	Distance Traveled [nm]	Segment Time [min]	Fuel Weight [lb]
1. Deployment	140	0	~0	0
2. Descent Arrest	90	1.8	1.2	2.2
3. Transition to Level Flight	60	1.3	1.8	3.4
4. Payload Delivery	0	0	1	3.0
5. Cruise Climb	33	2.9	5.3	7.8
6. Cruise	60	41.2	41.2	82.4
7. Cruise Descent	35.2	5.9	10	12.6
8. Landing	0	0	1	0.5
Total	**-**	**53.8**	**90**	**111.9**
(9. Reserve)	60	4.1	4.1	8.1

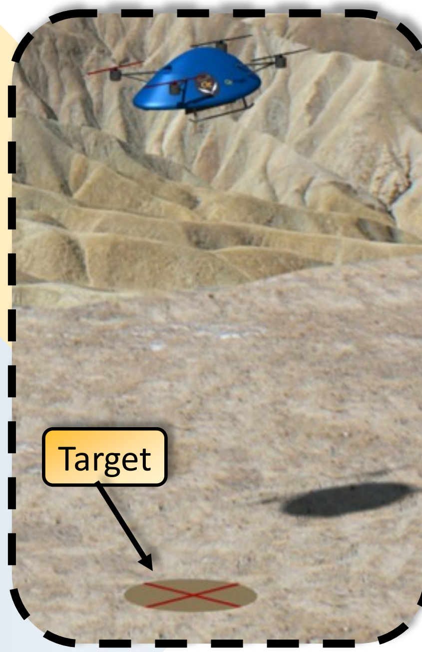


Hybrid Power Usage Breakdown



VISION-BASED NAVIGATION

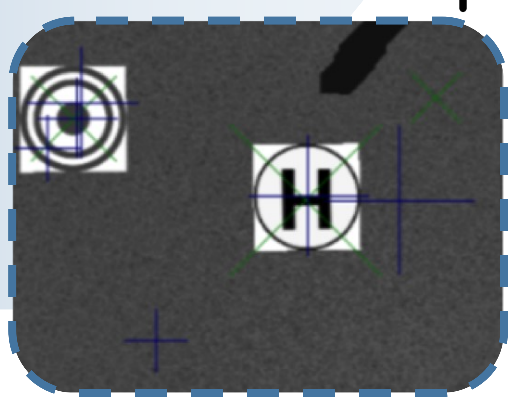
The GT Angel uses a GPS-based navigation system to reach the general area of the payload drop zone, then uses a vision-based positioning system to precisely deliver the payload.



The target location subsystem works by using a Haar-like feature detector trained to recognize target and helipad features, then uses a vision-based positioning system to precisely deliver the payload.

This navigation technique was successfully demonstrated in the 2015 AHS Micro Air Vehicle competition won by the Georgia Tech team.

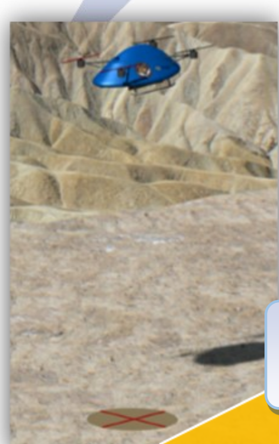
The Sony H11 camera gives the required resolution to identify the target from 200 ft above the ground.



PAYLOAD DEPLOYMENT SYSTEM

Delivery Process

Step1: Vehicle positions itself above target and opens cargo bay door.



Step 2: Vehicle lowers payload using friction brake to control impact speed.

Step 3: Payload is released upon reaching ground.

Step 4: Cable is retracted, cargo bay doors are closed and vehicle begins its return to base.

Breeze Eastern HS-5100 Winch System

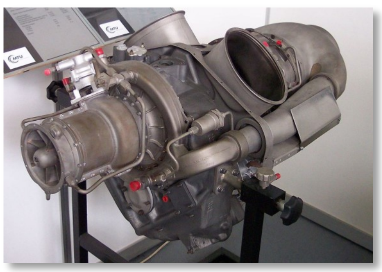
- 2000 lb Lifting Load
- 85 ft Cable Length
- Variable Speed Controller → < 5 ft/s Touchdown Speed

The large hoisting strength allows the potential to use the GT Angel in rescue operations in addition to the supply deliver mission the vehicle was designed for.

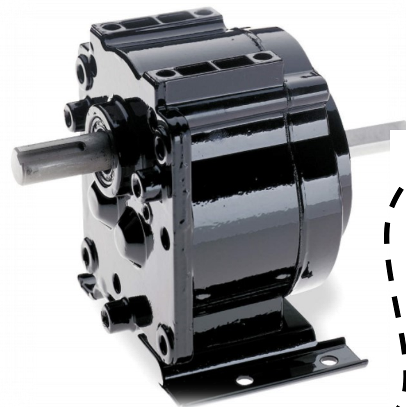
PROPULSION SYSTEM

The GT Angel uses a hybrid electric propulsion system that allows it to perform its unique deployment method. A turboshaft engine as well batteries provide power to the electric motors that drive the rotors.

Engine



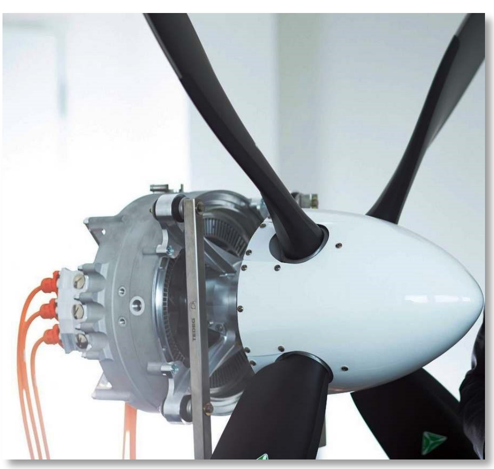
Transmission



Generator

Power Regulator

Electric Motor (x4)



Batteries

In the event of engine failure, the battery packs provide back up power for at least 60 seconds to allow the GT Angel to safely reach the ground.

PROPULSION SYSTEM

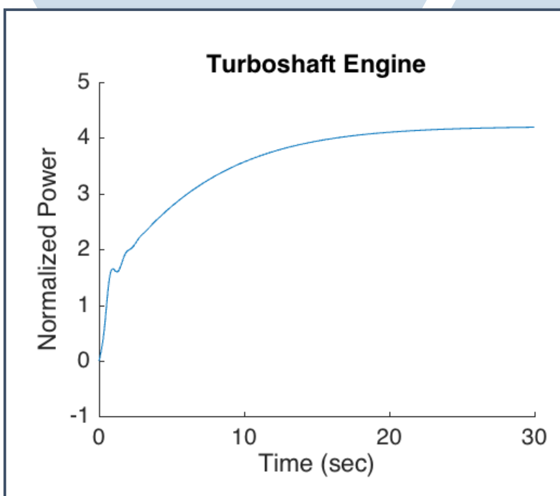
The hybrid propulsion system allows for ***electric hover assist*** where the combined power of the engine and batteries is used during the high power demand portions of the mission. The turboshaft engine is therefore sized to a smaller power which decreases the weight.

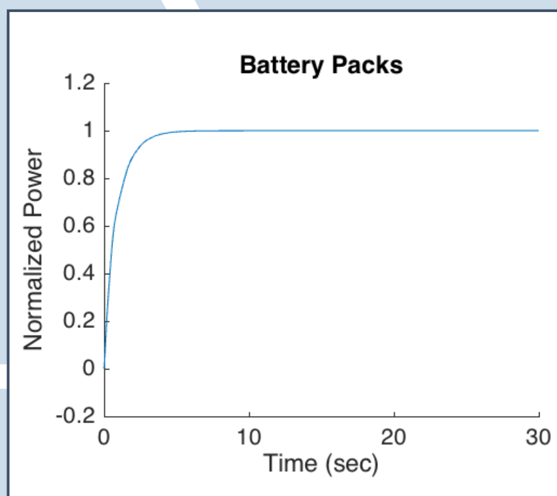
Turboshaft Engine

- Model: Allison 250-C20B
- Continuous Power: 380 hp
- Take-off Power: 450 hp

Battery Packs

- Type: $LiFePO_4$
- Output Power: 205 hp
- Energy Capacity: 18.6 hp-hr





The batteries' ability to rapidly produce power (***full power in under 4 seconds***) is critical for the arresting the GT Angel's descent after deploying from the C-130.

FUSELAGE DESIGN

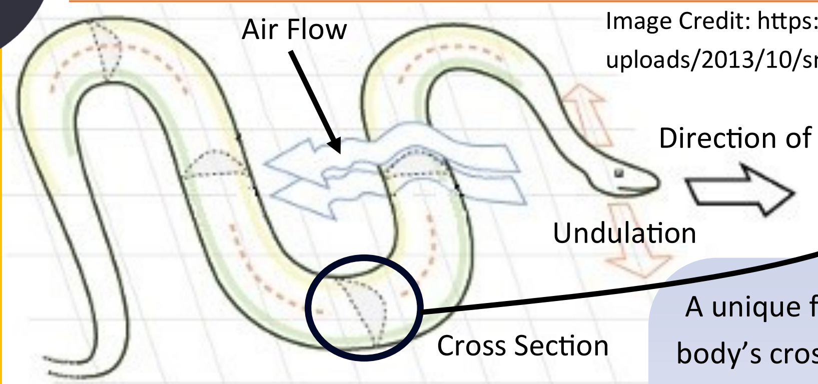
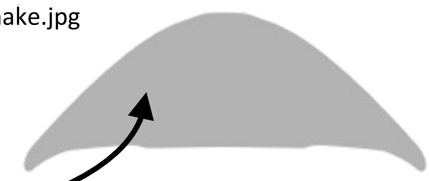
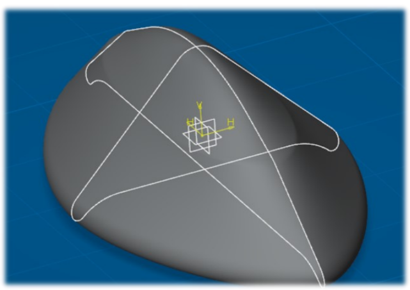


Image Credit: https://blogs.nvidia.com/wp-content/uploads/2013/10/snake.jpg

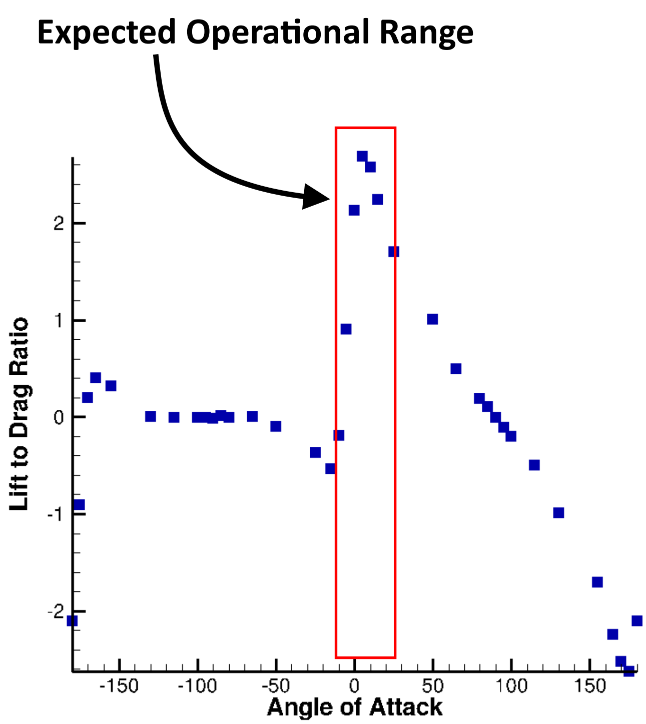


Fuselage design was ***biomimetically inspired*** by the “flying snake”, a type of snake that can glide through the air despite its lack of wings .

A unique feature of the flying snake is its body’s cross sectional shape. As it glides through the air, the snake undulates back and forth, exposing its body’s cross section to a ***vast range of orientations***, which its favorable aerodynamic shape allows it to overcome.



The fuselage was designed such that the snake's cross section was revolved elliptically about its center, resulting in a body with ***omni-directional favorable aerodynamic characteristics.***

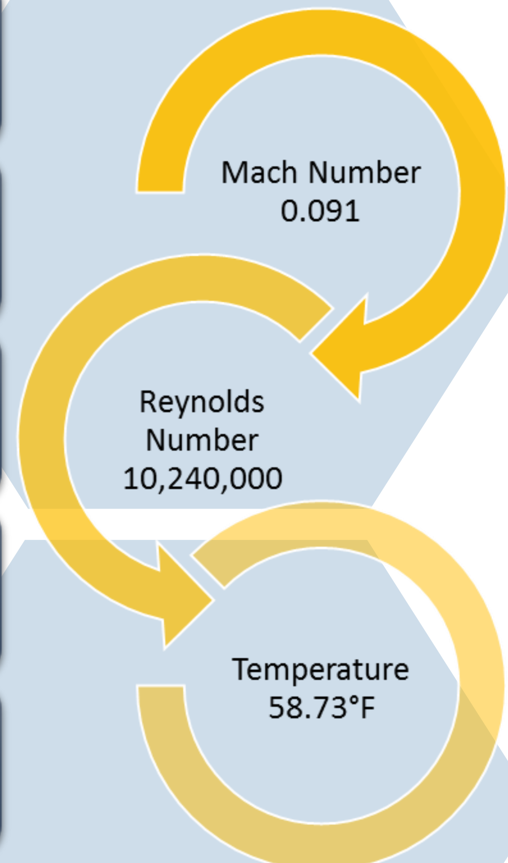


The ***fuselage serves as a lifting surface*** both inside and outside the expected operational range, including orientations where it is upside down. If the fuselage experiences unexpected orientations due to deployment mistakes, the fuselage will still provide stability to the system and increase the likelihood of a slow, controlled landing per the mission guidelines.

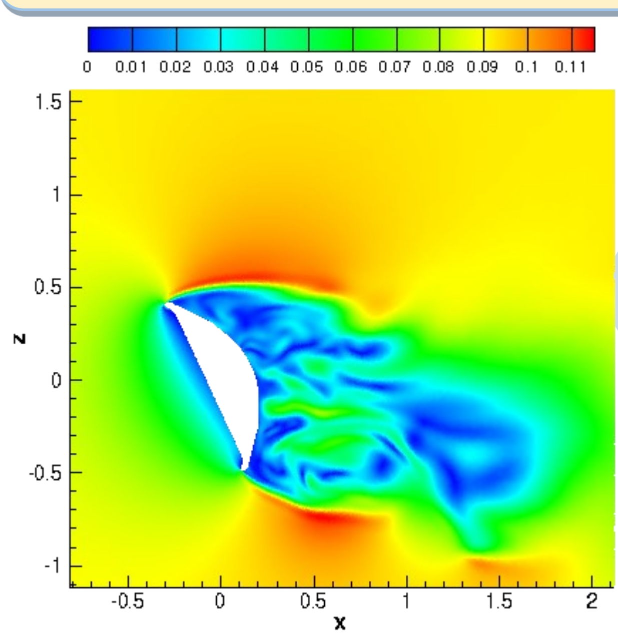
See the flying snake in action by clicking [here].

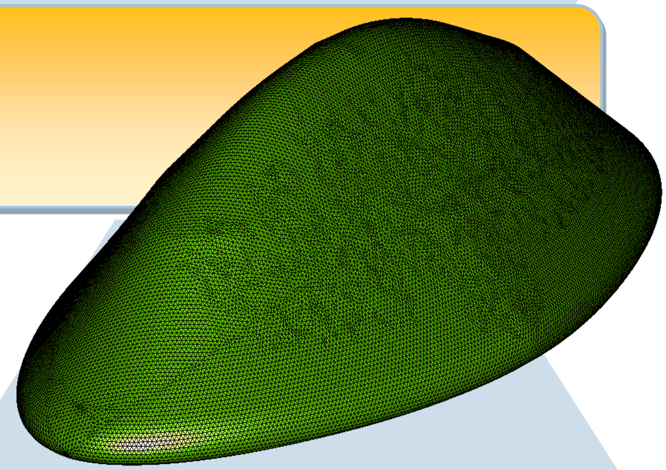
AERODYNAMICS

- State-of-the-art CFD analyses using NASA's Fully Unstructured Navier-Stokes Solver for 3-Dimensions (FUN3D)
- High fidelity grid with 53,000 surface nodes and 8,700,000 volume nodes.
- 48 Steady state runs using second order differencing and k-ω two-equation turbulence model.
- Aerodynamic coefficients from angle of attack and angle of sideslip sweeps used to populate GTABB descent model.
- State-of-the-art analyses at 65° angle of attack using Hybrid RANS-LES (HRLES) turbulence model to study massively separated wake.



Wake from unsteady HRLES simulation



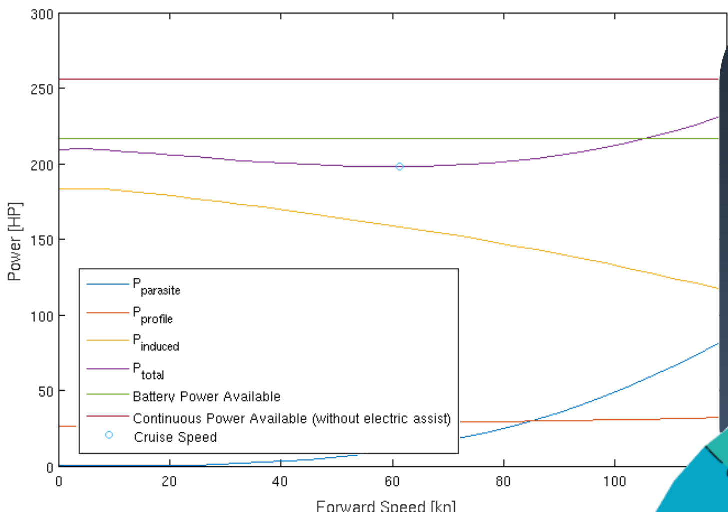


Animation of Unsteady wake from HRLES Simulation:

(click here)

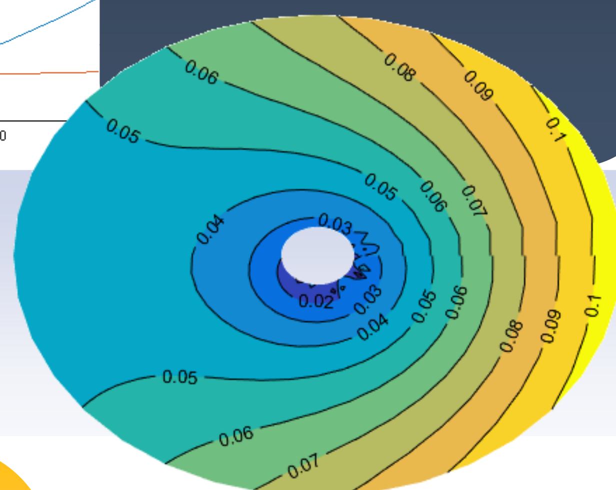
PERFORMANCE

A ***blade element momentum theory (BEMT) code*** was developed to determine performance characteristics of the rotor blade. Results from the BEMT code were ***verified using RotCFD***, a widely used design tool developed by SukraHelitek.

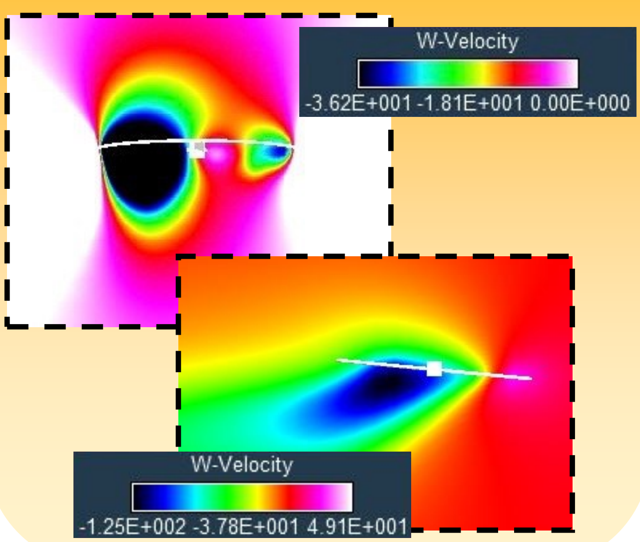


The ***electric hover assist*** allows for a hover ceiling of 25,000 ft, an increase of 11,000 ft over the hover ceiling that could be achieved by the turboshaft engine alone.

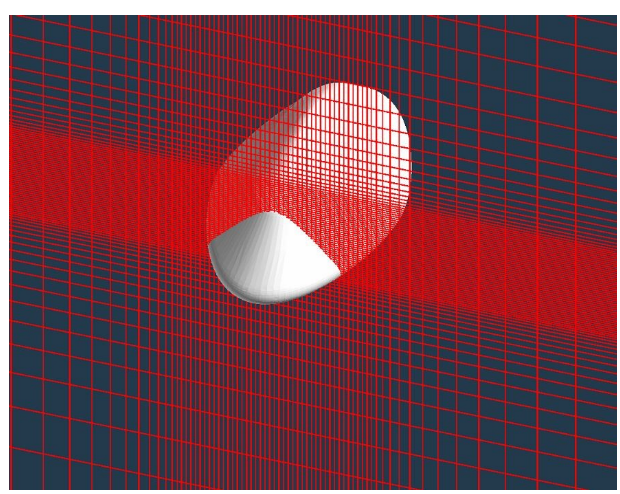
The nondimensional rotor inflow distribution of rotor was achieved using ***Castle and Dee Leeuw's linear inflow approximation***.



Downwash contours for rotor in hover and in forward flight.



Grid used for RotCFD analysis



ARRESTING THE DESCENT

The GT Angel's fuselage design is inspired by the cross-section of the flying snakes of Southeast Asia, which are known for superior gliding characteristics with smaller surface area than other gliding animals.

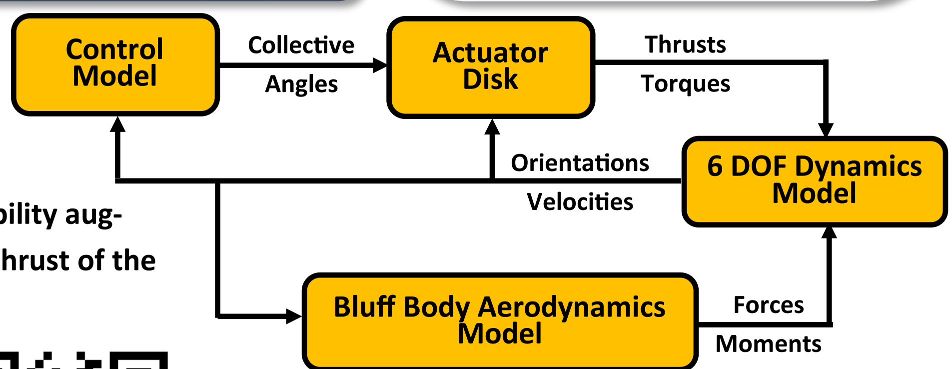
The hybrid electric propulsion allows the rotors to begin immediately after exiting the C-130.

The arresting of the descent was modeled using a state-of-the-art bluff body aerodynamic model for the fuselage aerodynamics with a full six-degree-of-freedom dynamics model. A set of PID controllers determine the response of the rotor to stabilize the vehicle.

Simulation videos of :

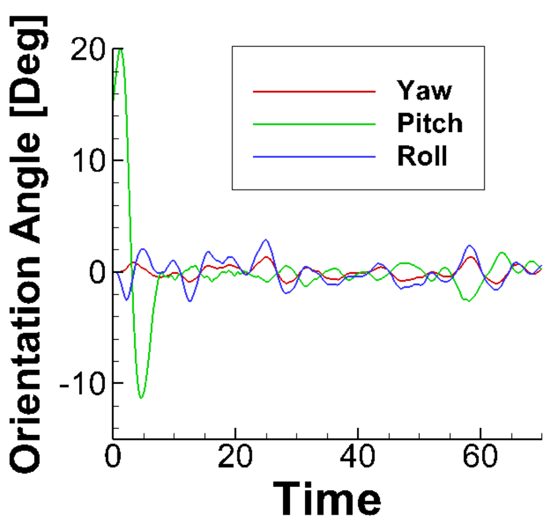
1.) The vehicle in free-fall (click here).

2.) The vehicle with stability augmented by differential thrust of the rotors (click here).

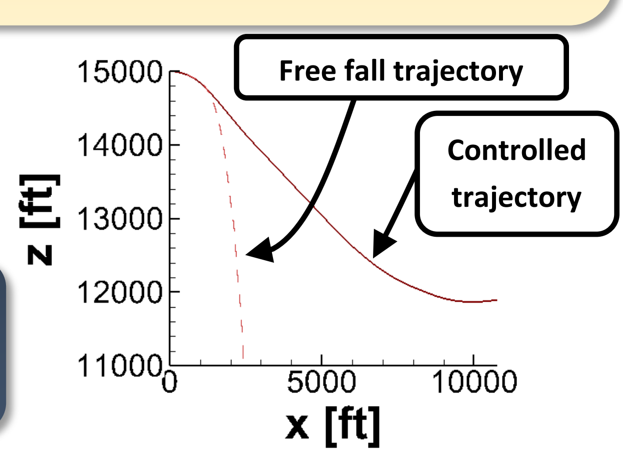


With the additional stability from differential thrust of the rotors, the GT Angel can perform a controlled descent in severe turbulence.

During the descent, the GT Angel maintains forward speed which avoids the potential dangers of vertical descent such as the vortex ring state. It recovers and achieves controlled level flight by 11,800 ft.

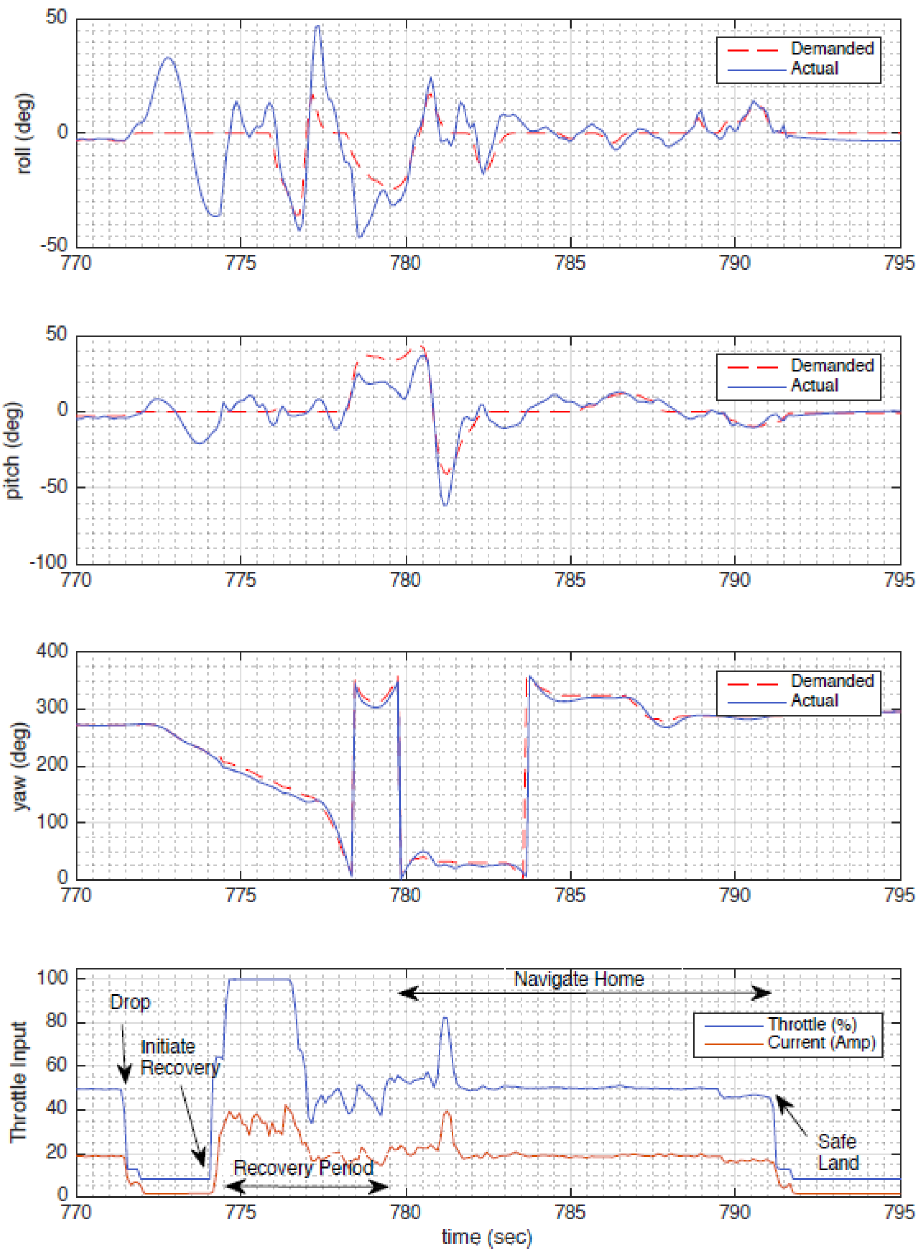


Orientation angles of the GT Angel during descent modeled with severe turbulence from the Dryden turbulence model



EXPERMENTAL DESCENT TESTING

The descent method was inspired by real test data from scaled experiments



IMU data from a 100 ft drop, demonstrated the phases of the GT Angel's descent:

1) Initial drop before the vehicle has control

2) Recovery of the descent using differential thrust

3) Controlled flight to the target location

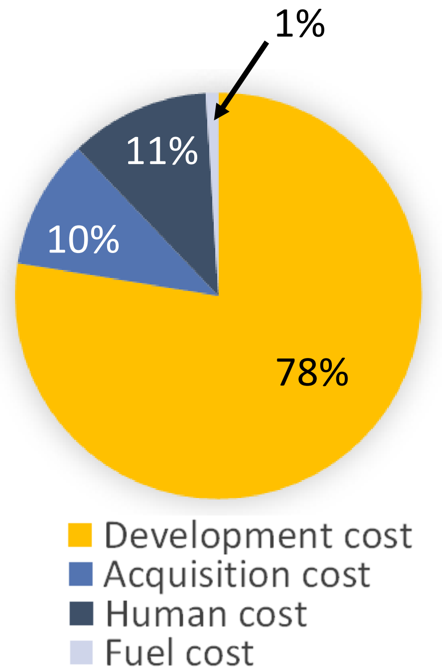
Video from the experimental recovery testing

(click here)

COST

SINGLE UNIT COST BREAKDOWN

Total Unit Cost: $4,588,458



Acquisition cost:

- Tooling, manufacturing labor, engineering, and quality cost based on parametric equations widely used in industry
- Material cost based on CATIA model material volumes and current cost per volume of each material
- Avionics and power plant cost based on component research survey

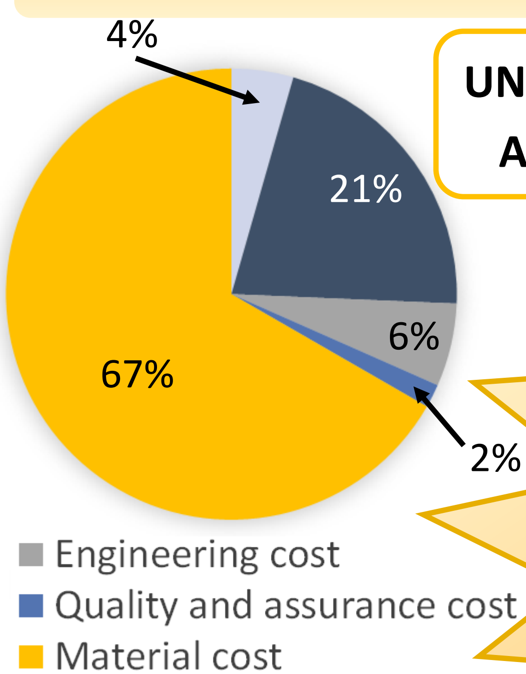
Human cost : Accounts for human intervention in disaster relief missions, assuming 35 disasters per year (includes a factor of 5 in estimating disaster relief need).

Fuel cost: Based on 120 pounds per fuel each mission, assuming 8 missions per day for 3 years

Development cost : Estimated at $1500 per pound of empty weight

UNIT ACQUISITION COST BREAKDOWN

Acquisition Cost per Unit: $472,598



Cost per unit for 100 Units Over 3 Year Period: $812,552.67

SUMMARY OF REQUIREMENTS

Requirement	GT Angel
The UAV must be able to carry a minimum payload weight of 500 pounds.	GT Angel can support a payload weight of 750 pounds.
The UAV and payload must fit in the cargo bay of a C-130.	Two GT Angel UAVs can fit in the cargo bay of a C-130.
The UAV must be able to deploy from the cargo bay of C-130.	GT Angle deploys from the C-130 cargo bay using a gravity airdrop.
The UAV must arrest its descent and transition to autonomous flight no lower than 1000 ft AGL.	GT Angel arrests its descent and transitions to autonomous flight at 1800 ft AGL.
The payload must be delivered from a precision no wind hover tha places the payload at precise GPS coordinates.	GT Angel uses a joint GPS and vision-based navigation system to achieve precise payload delivery.
The payload must touch the ground at a speed < 5 ft/s	GT Angel uses a variable speed controller to ensure a touchdown speed < 5 ft/s.
The delivery in hover must take no longer than 1 minute.	GT Angel completes its delivery in under 1 minute..
The UAV must travel a minimum distance of 50 nm to return to base.	GT Angel carries reserve fuel so that it can travel more than 50 nm to return to base.

GT Angel

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