



## Executive Summary

Undergraduate Design Team

University of Maryland – College Park

38<sup>th</sup> Annual Vertical Flight Society  
Student Design Competition

Sponsored by: The Boeing Company & Altair

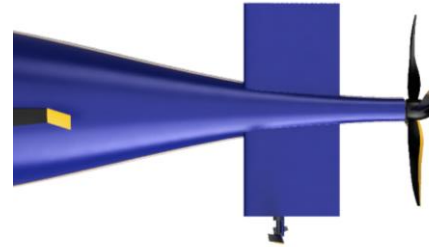


# Garra's Key Features

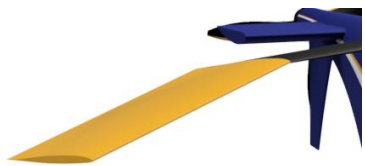
**1. Hub fairing for low drag at high speed**



**2. Tail designed for efficiency and reduced wake interaction**



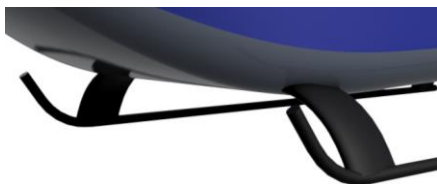
**7. Blade tip designed with 20° anhedral and 20° sweep for low noise and compressibility**



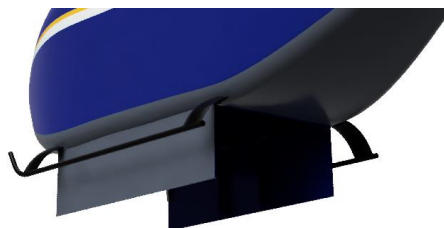
**3. Hinged doors for easy loading**



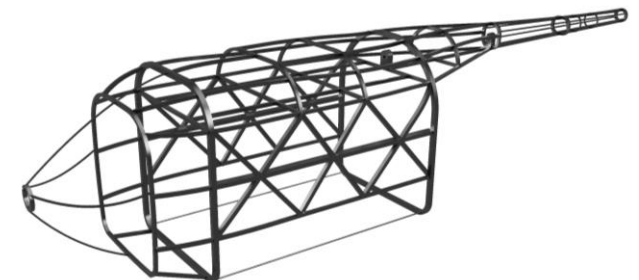
**6. Airfoil shaped skid for low drag**



**5. Bomber doors for hoisting package delivery**



**4. Lightweight bottomless structure designed for torsional stiffness**



# Garra's Safety Highlights



**1. Foldable main rotor blades for easy and safe transportation and storage**

**1. Three bladed hingeless with autorotative capability**

**2. Zero-tilt flight capability thanks to the pusher propeller**



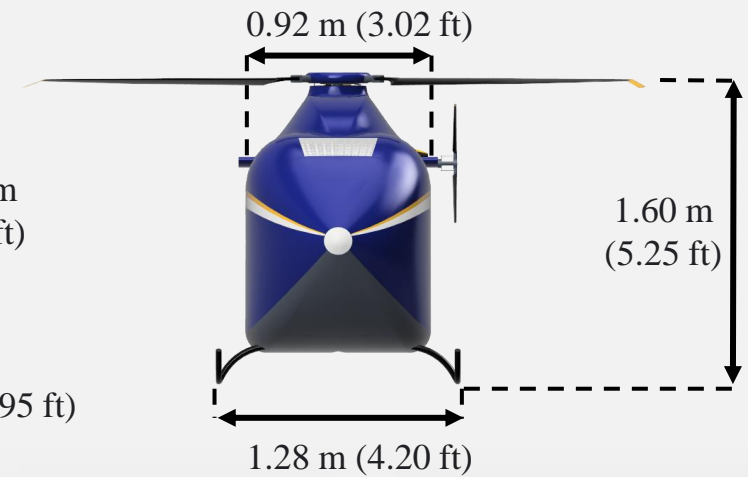
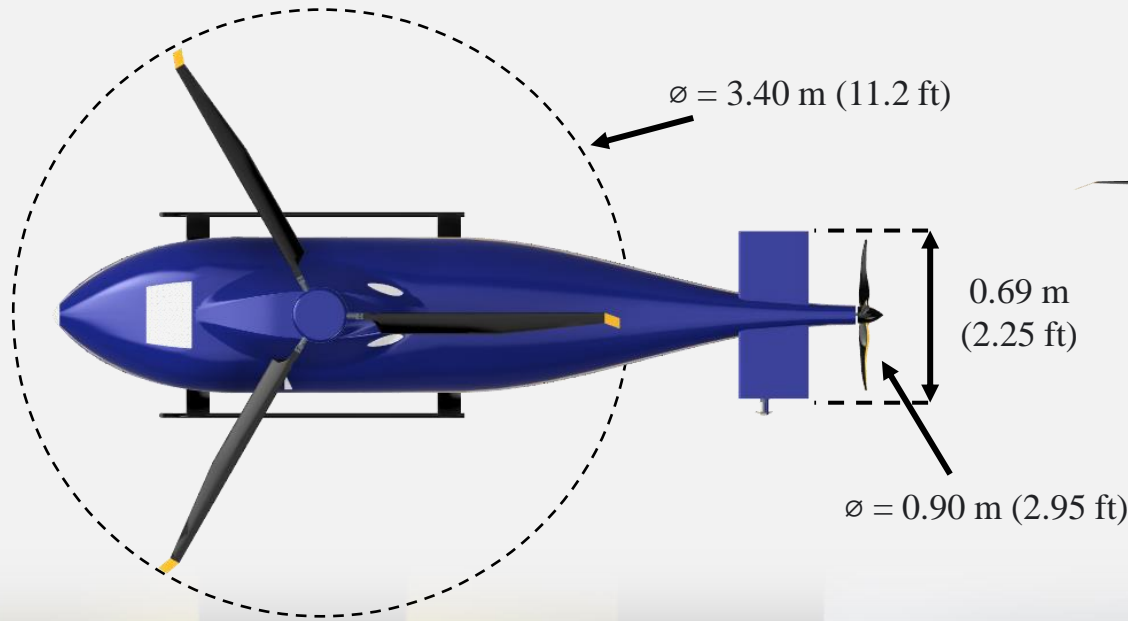
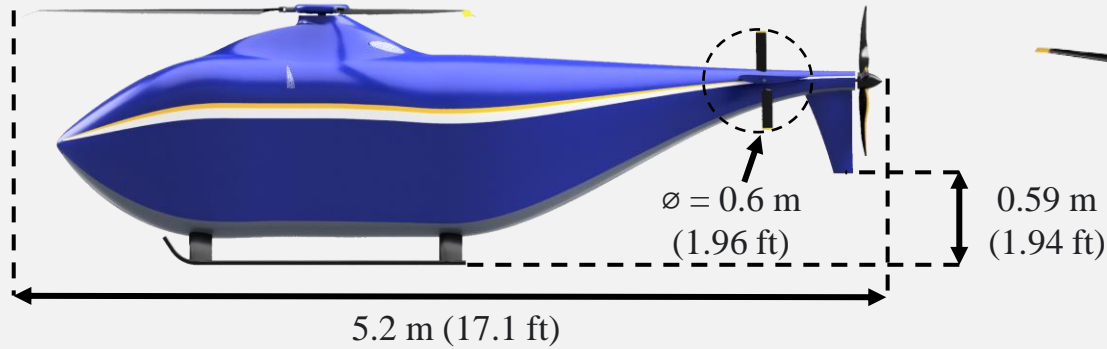
**6. Dual engines for redundancy and extra power**

**3. Vertical stabilizer designed to reduce tail strikes and protect tail rotor and pusher propeller**

**5. Access panel convenient access to flight electronics**

**4. Crashworthy landing gear and fuselage design**

# Garra External Dimensions





# Introduction



In response to the Vertical Flight Society's 38<sup>th</sup> annual student design competition Request for Proposal (RFP), the University of Maryland's undergraduate design team presents Garra. The name is inspired by the Garra Rufa fish also known as the doctor fish. In nature, this fish brings wellness and joy to those around it.

## **Design Capabilities**

Garra is an innovative thrust compounded single main rotor featuring a novel open bottom structural design. The vehicle meets and exceeds all the RFP requirements in terms of safety, compactness, and block time. The SMR design has been approved by the FAA in the past, ensuring a smooth path to certification by 2025.

## **Vehicle Overview**

<b>GTOW</b>	<b>260 kg (572 lb)</b>
<b>Payload</b>	<b>50 kg (110 lb)</b>
<b>Max. Fuel Capacity</b>	<b>9.5 gal (36 L)</b>
<b>Top Speed</b>	<b>250 km/hr (135 knots)</b>
<b>Empty Weight</b>	<b>184 kg (405 lb)</b>



# Configuration Selection



To meet the challenges and safety requirements of a medical supply carrying mission, the required vehicle design needed to be innovative, safe, and realistic for operation by 2025. Based on this, the team used a four-step process to reach the desired configuration.

## Design Drivers

- Using the voice of the customer from the RFP, 8 design drivers were defined

## AHP Analysis

- The design drivers were weighted based on importance for the RFP

## Pugh Matrix

- Twelve configurations were evaluated with 4 emerging as possible contenders

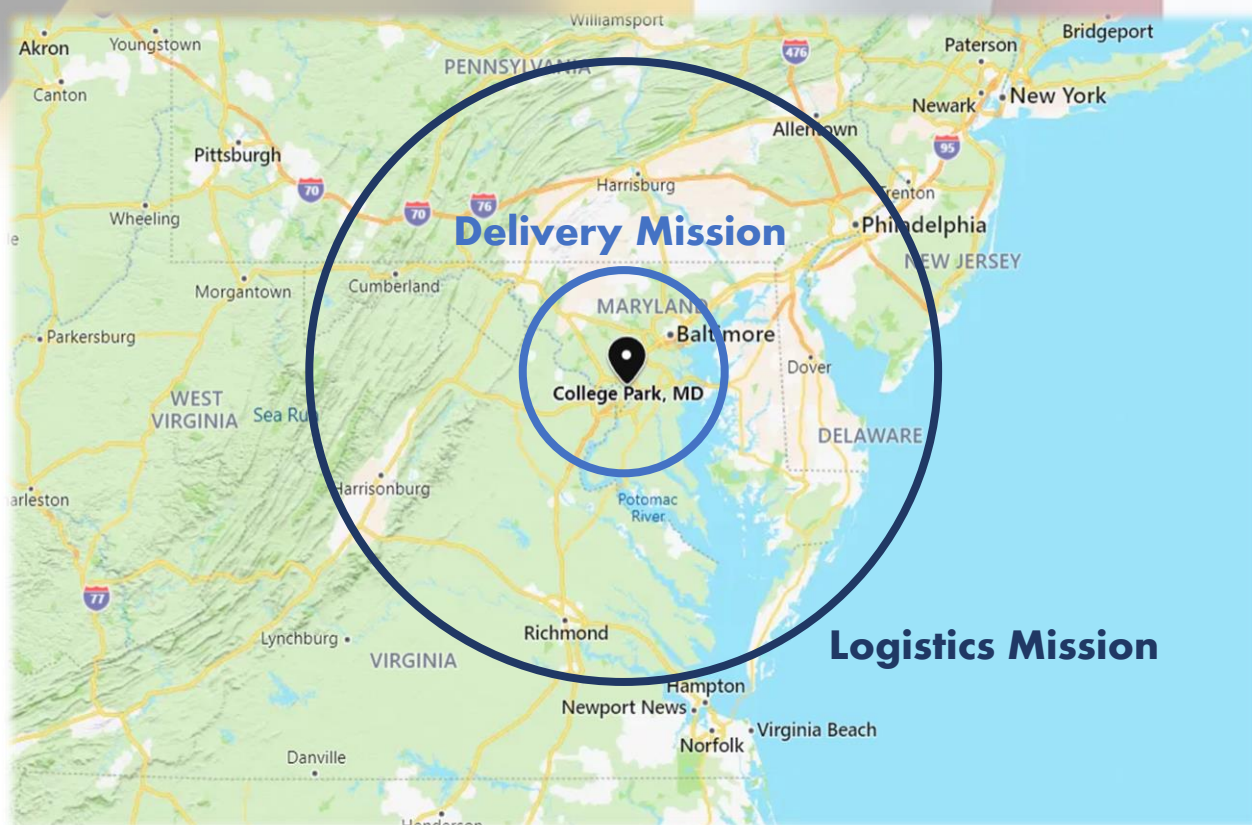
The four down selected configurations were thoroughly examined by comparing the capabilities of existing designs.



The single main rotor was selected as a baseline configuration, thrust compounding was added to achieve the required flight speeds of the mission.



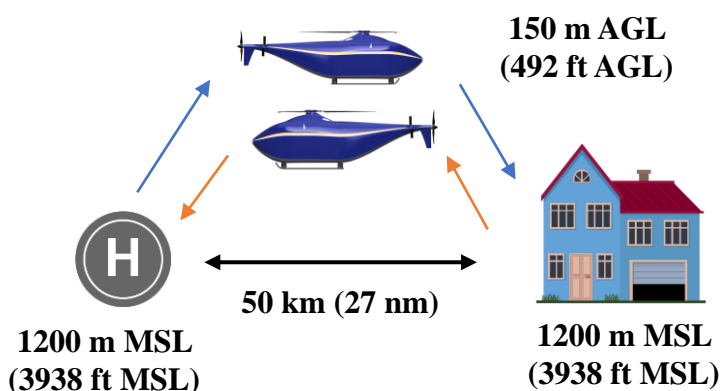
# Mission Profiles



## Description

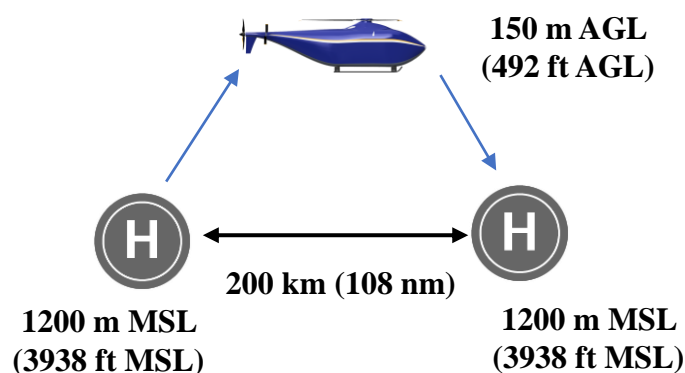
The vehicle was designed to fulfill two types of missions without reconfiguration and within a specific block time.

### Delivery Mission



Allocated block time (per leg)	28 mins
Required Cruise Speed	237 km/hr (128 knots)
Garra's Cruise Speed	250 km/hr (135 knots)
Garra's time to complete	27 mins

### Logistics Mission



Allocated block time	75 mins
Required Cruise Speed	200 km/hr (108 knots)
Garra's Cruise Speed	250 km/hr (135 knots)
Garra's time to complete	63 mins



# Mission Environment



For both missions described in the mission profiles section, the vehicle performance was examined with the same mission environment and package handling qualities.

## Setting

All missions performed by the Garra will be set in a suburban or rural setting at 1200 m (3937 ft) MSL

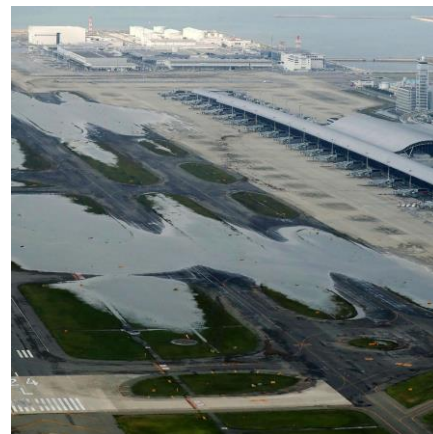


## Weather

The temperature will be at most 35°C (95°F), and the conditions will be always VFR. This means good visibility and no flying in clouds.

## Landing Zones

Even though the RFP states that the vehicle will land at a prepared surface, history has shown that after a natural disaster prepared surfaces are never a reality. Considering this, the Garra is equipped with multiple package delivery techniques.



Tokyo Narita airport after typhoon



San Juan, PR after 5.8 earthquake



# Package Description



Garra is capable of carrying payloads of two different volumes. This can be done without any reconfiguration to the vehicle when changing mission, and its handling has been designed to always ensure the safety of its contents.

## Package Dimensions

Regardless of the change in volume, the package is assumed to have an overall weight (including handling materials) of 50 kg (110 lb).

Two possible dimensions:

- 70 cm x 70 cm x 70 cm  
( 2.3 ft x 2.3 ft x 2.3 ft)
- 140 cm x 50 cm x 50 cm  
( 4.6 ft x 1.64 ft x 1.64 ft)



## Package Handling Qualities

As the package may contain sensitive materials such as vaccines or medical equipment, it must be handled with the utmost care. Having this in mind, the Garra always features a **zero-tilt flight mode** to ensure that the package never experiences any extreme attitudes during loading, cruise, and unloading.



# Package Handling



For increased versatility and safety, the Garra has two forms of package unloading and a loading procedure that only requires one operator.

## Loading

The package is loaded through the back of the vehicle by one operator with the help of a commercially available variable height cart. If the cart is not an option, the package can be loaded by two operators.



## Deployment

Natural disasters can make landing zones inaccessible, and from a mission perspective landing is inefficient. The Garra exhibits **two methods of deployment**: hoisting from hover (autonomous) and ground deployment (assisted by operator).

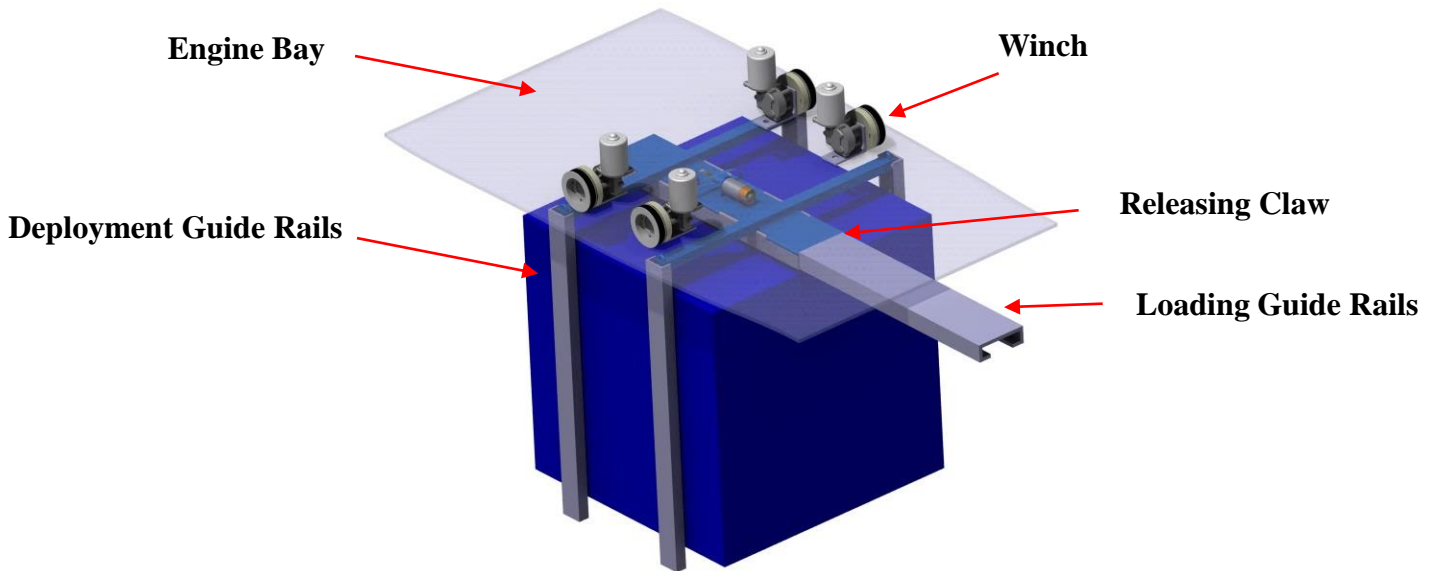
Hoisting deployment:

- The package is connected to four independent ropes to avoid spin
- Vehicle will hover at 3 m (10ft) to protect the package and any operators on the ground.
- Package is deployed autonomously



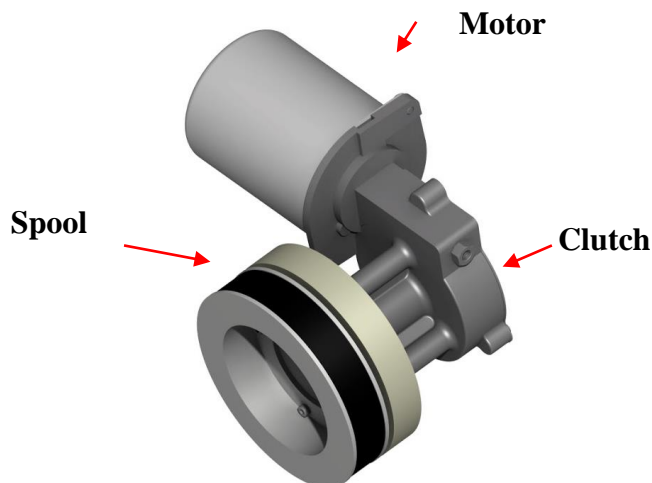
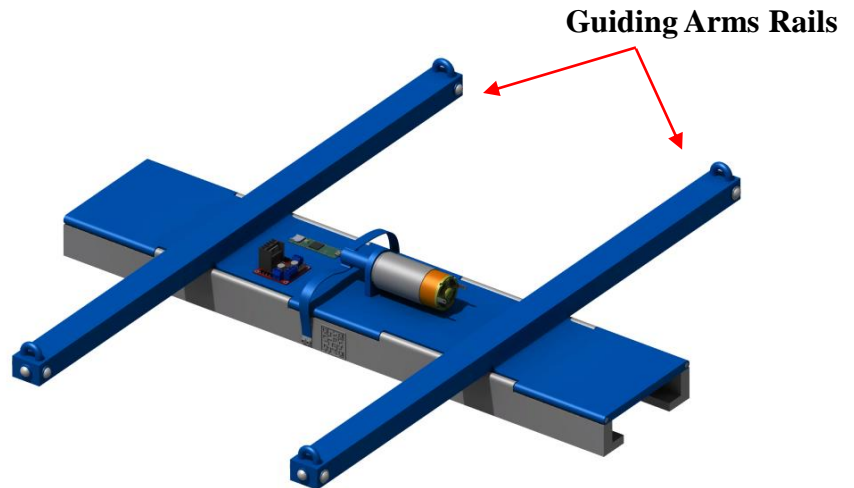
# Hoisting Mechanism

To conduct the autonomous hoist delivery, Garra depends on an independent hoisting mechanism. The mechanism is fully built in-house with commercially available materials.



## Releasing Claw Design

- The claw is hoisted down with the package and returned to the vehicle for the next mission
- Sensors on-board the claw used to monitor and deploy the package



## Winch Mechanism

Built in-house with off-the-shelf materials. Equipped with clutch system as a safety feature to ensure safe delivery in the event of an inoperable winch.



# Package Delivery Concept of Operations



(1) Vehicle is prepared for mission



(2) Package is loaded using the variable height cart



(3) Package is engaged in the low-friction rail and pushed inside by the operator



(4) Back door is closed, and Vehicle start up



(5) Vehicle reaches destination and opens its bottom doors autonomously during hover

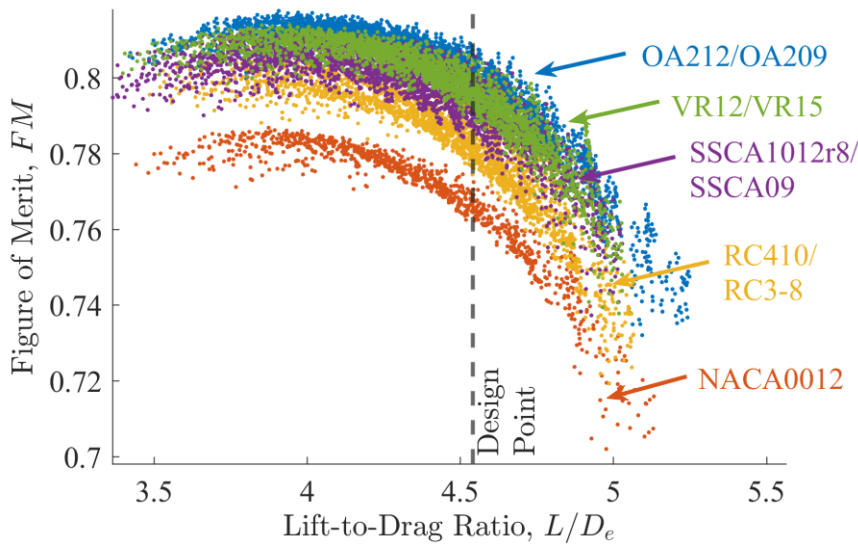
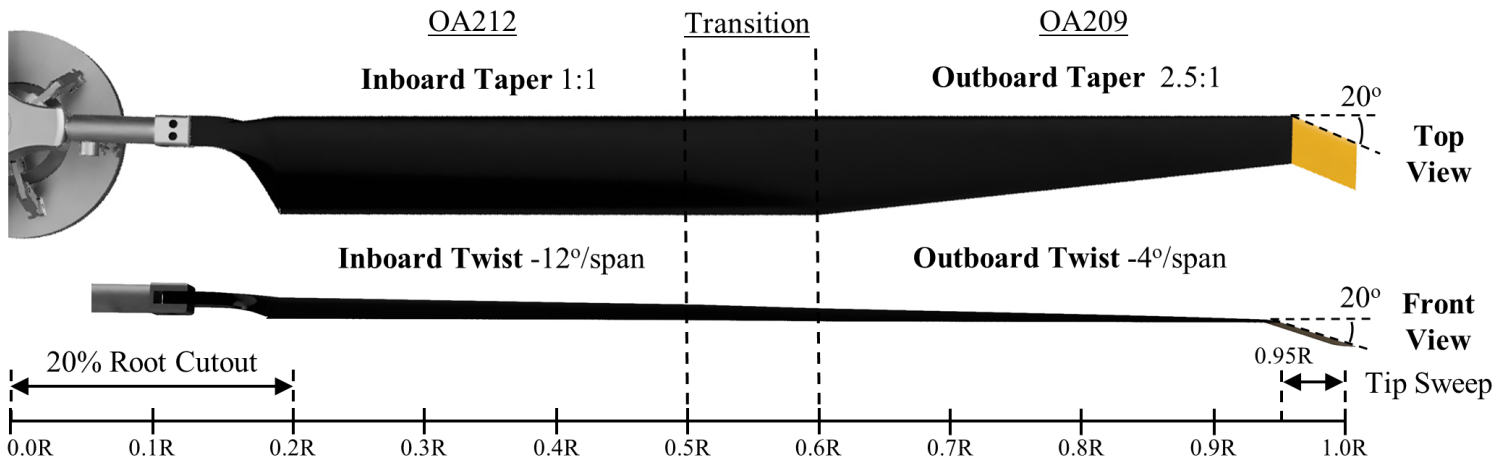


(6) Package is hoisted down

# Highly Efficient Blades

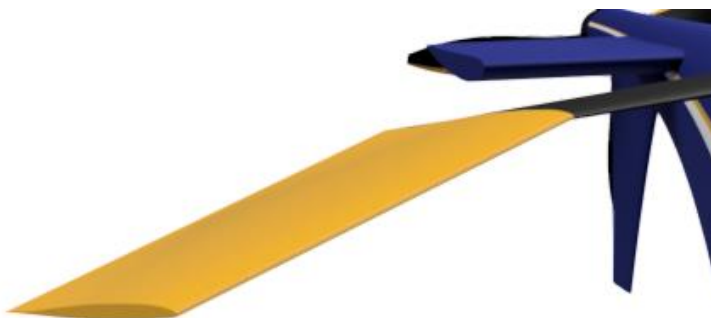


Garra's main rotor blades are designed for low-noise and enhanced cruise performance.



Pareto: over 30,000 configurations studied

<b>Selected Configuration</b>	OA212/OA209
<b>Disk Loading</b>	277 N/m <sup>2</sup> (5.78 lb/ft <sup>2</sup> )
<b>Power Loading</b>	46.6 N/kW (7.76 lb/hp)
<b><math>C_T/\sigma</math></b>	0.112
<b><math>L/D_e</math></b>	4.54
<b>FM</b>	0.807



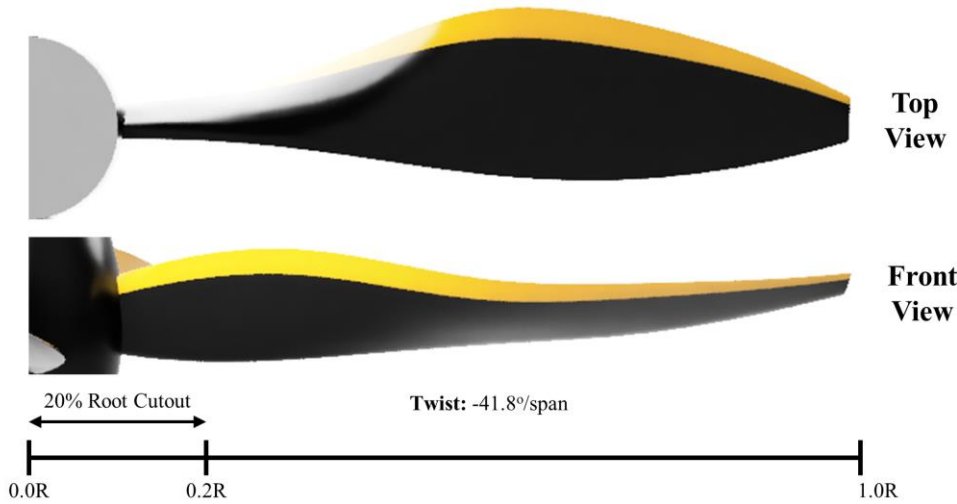
Blade tip with 20° anhedral and 20° sweep for:

- Low noise
- Low vibrations
- Reduced compressibility

# Empennage Rotary Systems

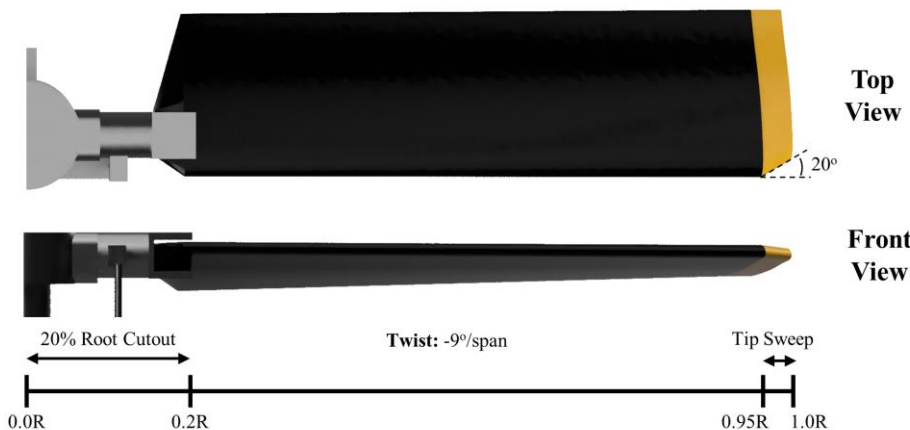
Garra achieves high cruise speed and the signature zero-tilt flight through the use of a highly efficient pusher propeller. For safety, Garra can sustain up to 48 km/hr (26 knots) cross wind component.

## Pusher Propeller



No. Blades	4
Solidity	0.212
$C_{Tprop}$	0.137
$J @ V_{cruise}$	0.883
$\eta$	<b>0.803</b>

## Tail Rotor



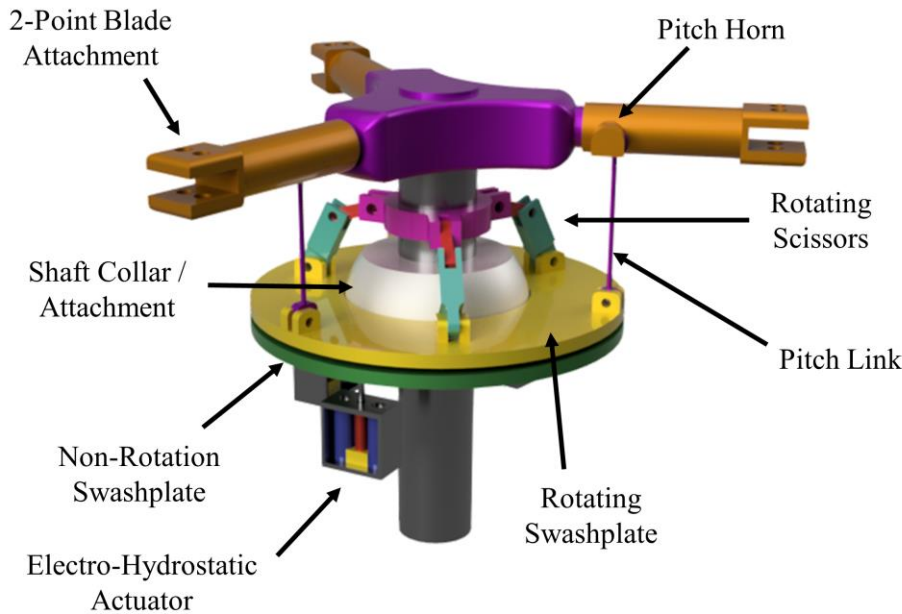
No. Blades	2
Solidity	0.141
$C_T/\sigma$	0.0814
FM	<b>0.768</b>
Power Ratio	8.2%



# Rotary System Hubs

Safety and simplicity are the main design drivers for all the rotary system hubs. This ensures smooth operation and drives down maintenance time and cost.

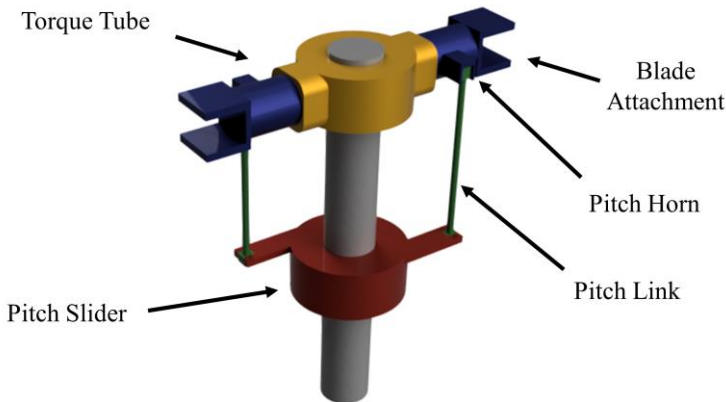
## Main Rotor Hub



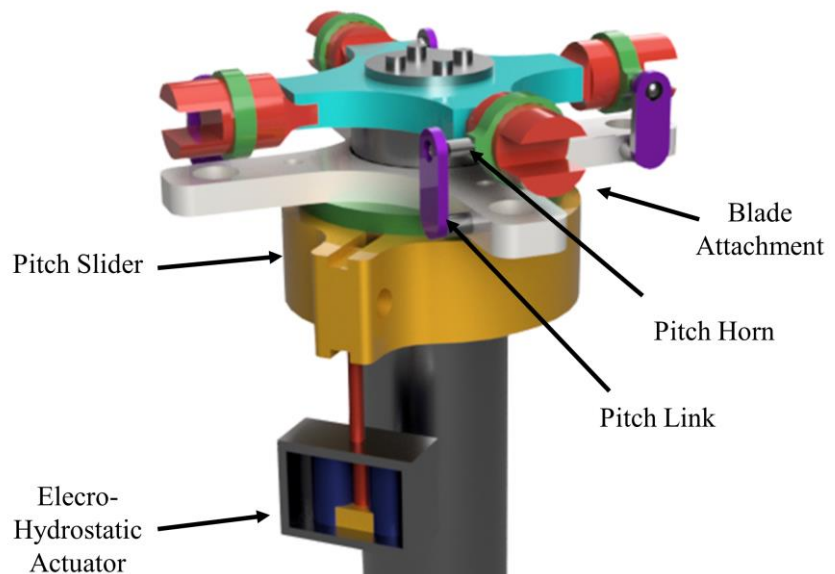
Hingeless hub designed for

- Low drag profile hub
- Low part count
- Ease of operation
- Flap freq: 1.08/rev

## Tail Rotor Hub



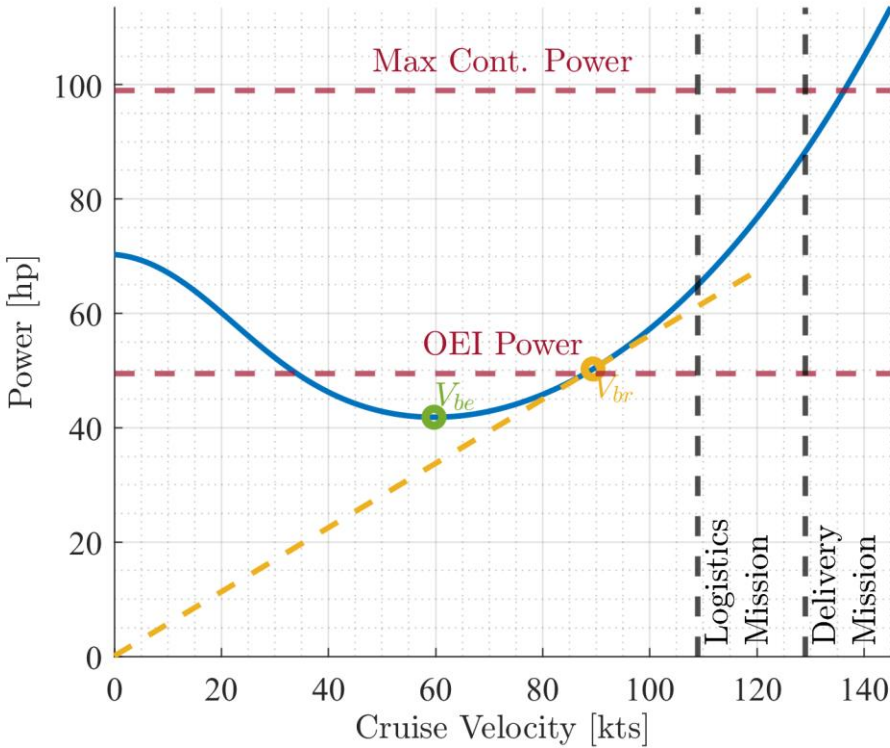
## Pusher Propeller Hub



# Vehicle Performance



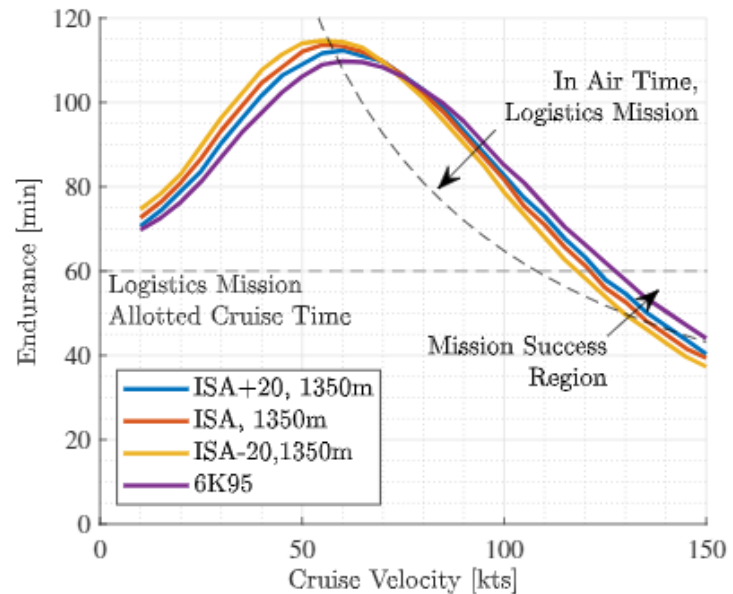
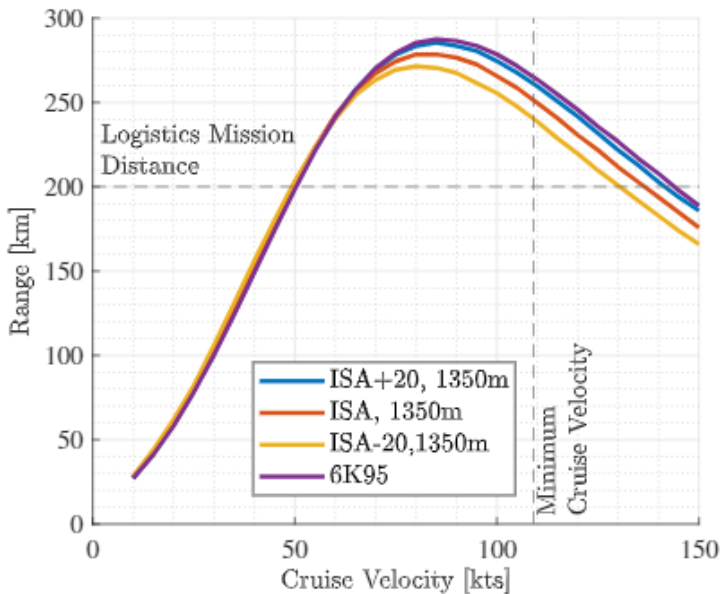
The Garra's performance is able to achieve and exceed the mission requirements using its proven configuration and efficient design.



<b>V<sub>cruise</sub></b>	250 km/hr (135 knots)
<b>V<sub>br</sub></b>	165 km/hr (89.2 knots)
<b>Range</b>	252 km (136 nm)
<b>V<sub>be</sub></b>	110 km/hr (59.6 knots)
<b>Endurance</b>	111 mins (1.85 hours)

Performance Metric	
$\zeta_{\text{Logistics}}$	10.3 m/s (20 knots)

Performance Metric	
$\zeta_{\text{Delivery}}$	6.16 m/s (12 knots)



# Propulsion System Overview



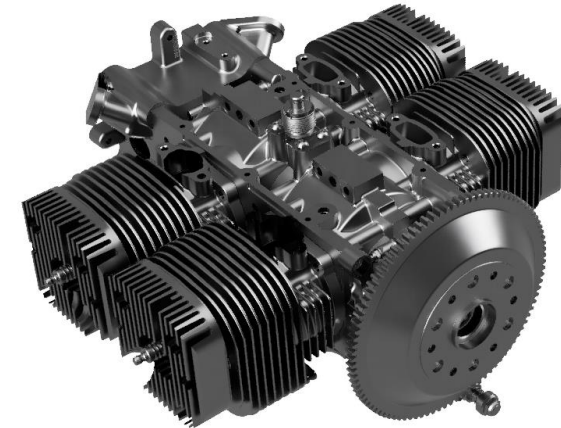
## Main Gearbox



## Tail Gearbox



## Limbach 550EF



Designed with ATI Allvac X-2M Steel and operated with MIL-PRF-23699 oil for enhanced performance

4-cylinder, 2 stroke piston engine with **power to weight ratio of 2.5**

## Tail Transmission Analysis

**Fully Electric Drive Tail**  
Weight: 40.5 kg (89.1 lb)

**Electric Tail Rotor +  
Mechanical Pusher Prop**  
Weight: 32.7 kg (72.1 lb)

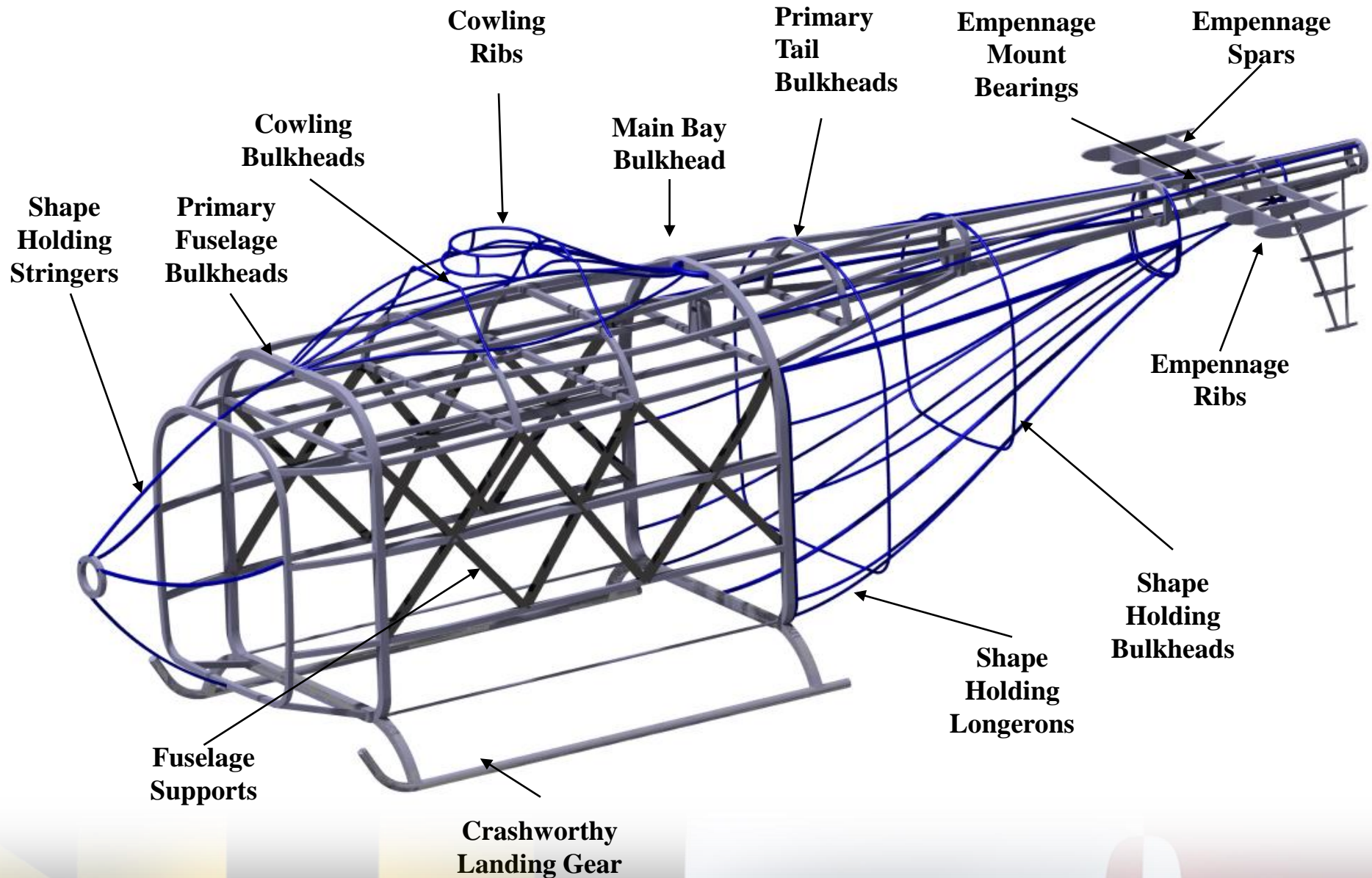
**Mechanical Tail Rotor +  
Mechanical Pusher Prop**  
Weight: 5.3 kg (11.7 lb)

Fully mechanical transmission design presented an **87% weight decrease** and an **increase of 20% efficiency**



# Structure Highlights

Structure was optimized using Altair's Hyperworks and SimSolid



## Obstacle Detection (Cruise)

- Voxel Stereo Sensor (Cruise Stereo Camera)
- Velodyne Puck Lite (Lidar)
- Sharp Patch Radar

## Takeoff & Landing Operations

- Lightware SF30-D Laser Rangefinder (altimeter)
- mvBlueCOUGAR-X102fc (landing camera)
- PX4flow Smart Camera (Optical flow hover camera)
- RADAR Altimeter

## Navigation

- XPG-TR Mode S Transponder (GPS and Transponder)

## Communications (pilot in the loop)

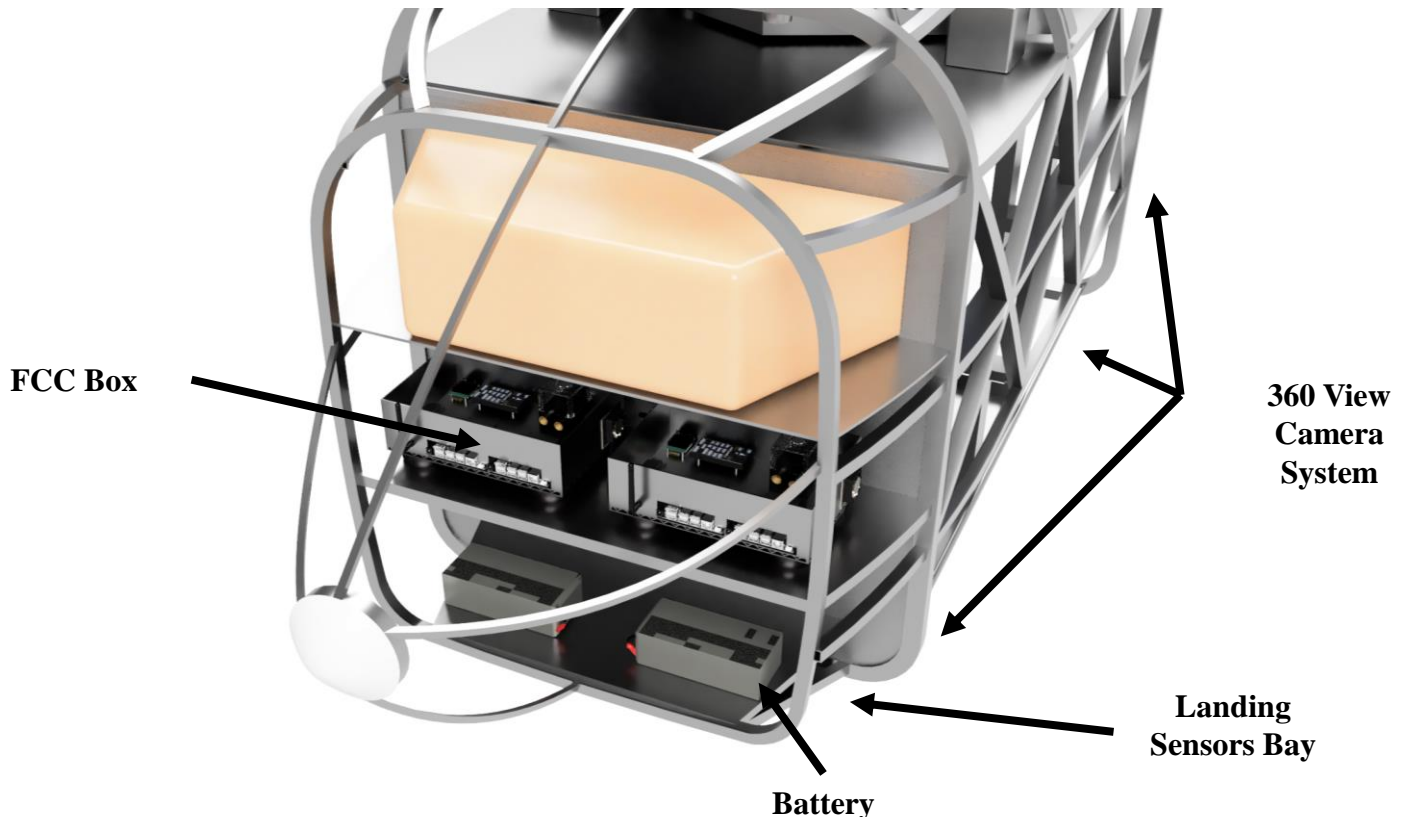
- Aviator UAV 200 (satellite communication)

## Stabilization & Processing

- Pixhawk PX4 (Flight controller)
- NVIDIA AGX Xavier (Flight Computer)

## Supporting

- Navigation Lights
- Landing Lights
- Anti-collision lights
- Fuel Sensor
- Battery
- Oil Sensor



# Cost & Weight Breakdown

Propulsion		
Item	Weight (kg)	Weight (lb)
Main Gearbox	11.05	24.30
Engines	30.00	66.00
Starter	2.30	5.06
Main Shaft	3.00	6.60
Fuel Pump	1.00	2.20
Generator	2.00	4.40
Pusher Shaft	0.26	0.57
TR Gearbox	1.60	3.52
TR Shaft	0.50	1.10
Bearings	1.00	2.20
Flex Couplings	0.40	0.88
Fuel Tank	4.00	8.80
Intake Fans	0.50	1.10
Avionics		
Avionics Package	7.10	15.62
Structures		
Structures (Primary)	36.14	79.51
Skids	2.10	4.62
Secondary X's	3.40	7.48
Structures (Secondary)	3.01	6.62
Skin	24.43	53.75
Nose Ballast	10.00	22.00
Deployment Mechanism		
Winch	5.20	11.44
Rails	2.50	5.50
Claw	3.60	7.92
Aerodynamics		
Blades and hubs (MR)	15.00	33.00
Blades and hubs (TR)	2.50	5.50
Pusher Prop	3.00	6.60
Horizontal Stab	2.96	6.51
Vertical Stab	0.72	1.59
<b>Total Empty Weight</b>	<b>179.27</b>	<b>394.40</b>
Loading		
Package	50	110
Max. Fuel	28.8	63.36
<b>Total Weight</b>	<b>258.07</b>	<b>567.76</b>

Garra offers an affordable option for an overall Cost of Purchase **\$220,000.00**

Cost of operation per hour **\$72.98**

Garra's design permits for an Empty/GTOW ratio of **0.69**





# Summary



In response of to the RFP for the 2020-2021 VFS Student Design Competition, sponsored by the Boeing Company, the University of Maryland's undergraduate team presents the Garra. Garra finds the balance between safety, compactness, and speed. With a top speed of 135 knots, the Garra can complete any mission outlined with stellar performance.

Garra is the dream of any operator, its autonomous capability lets the vehicle operate on its own at all times. With safety in mind, the Garra also includes the capability to add a pilot for control. While this vehicle is designed for natural disasters or future pandemics, Garra will be able to operate at any time that is needed. Its proven SMR technology and off-the-shelf materials will ensure that the Garra is operational by 2025.

