Executive Summary

Undergraduate Design Team

The Georgia Institute of Technology

United States Military Academy
At West Point

40th Annual VFS Student Design Competition

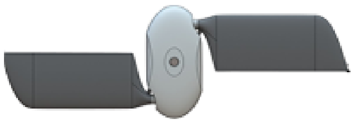
Sponsored by: Sikorsky

The Harpy

Vehicle Overview

Two 2-bladed rotors for VTOL and hover, radius of 18 ft (5.49 m) gives a maximum disk loading of 25 psf (1205 N/m^2) for takeoff on unprepared surfaces.

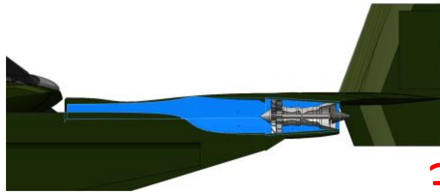
1



Blade storage vessel allows one blade to be stored during forward flight mode.

2

The two S-ducted turbofan engines utilize NASA-tested convertible engine technology to extract fan shaft power to drive rotors



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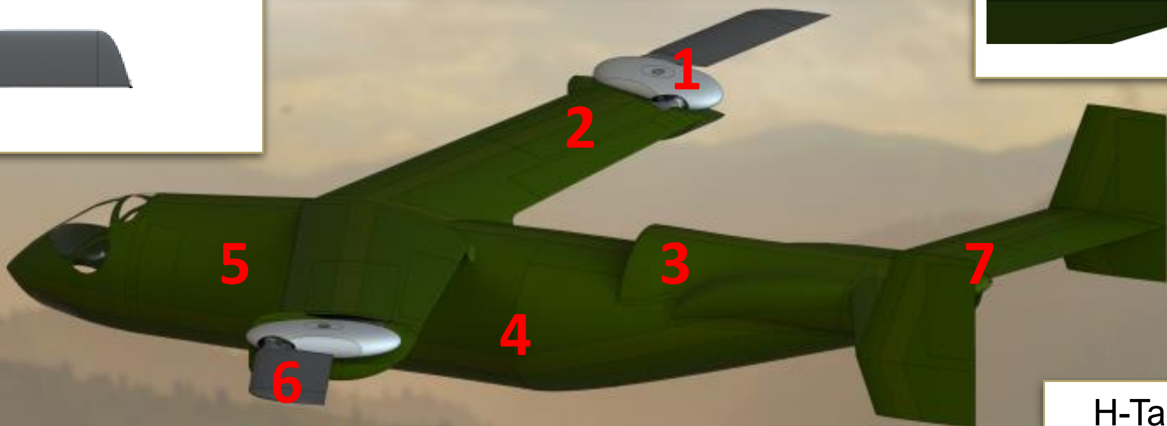
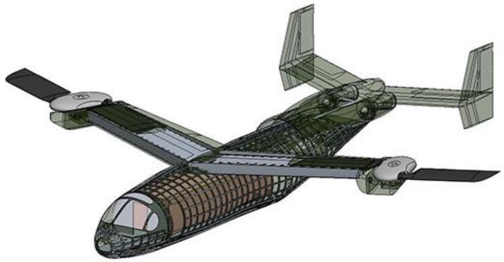


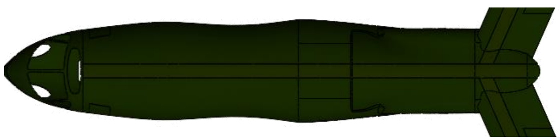
Wing and fuselage structure ensure aircraft rigidity during both 3.5g load cases and 10 ft/sec (3.05 m/s) landing with 2/3 lift.

4



Transonic fuselage design and swept wings minimize wave drag

5



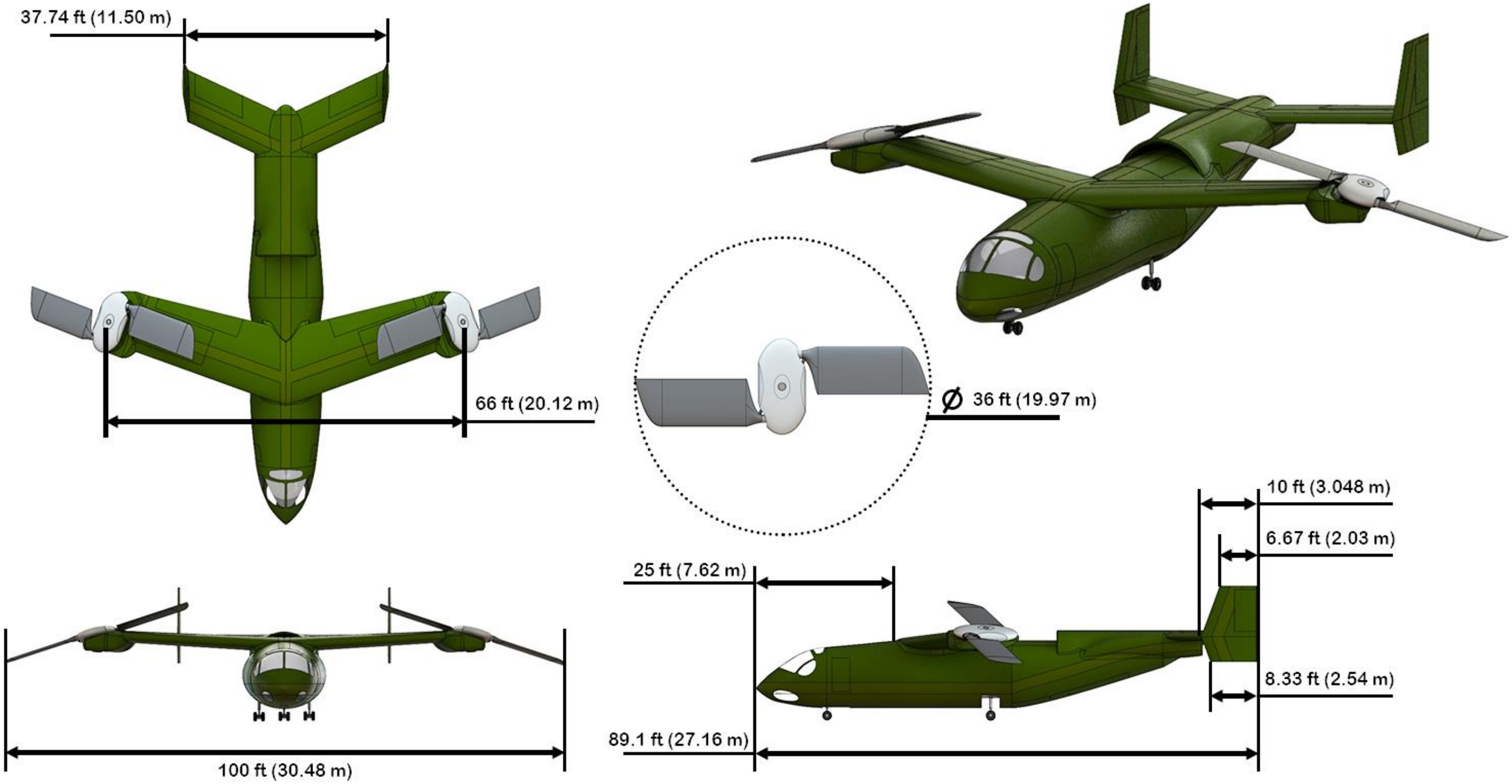
H-Tail allows aircraft mode stability that meets Military Specifications and provides ample ruder area/deflection for One Engine Inoperable situations.

7

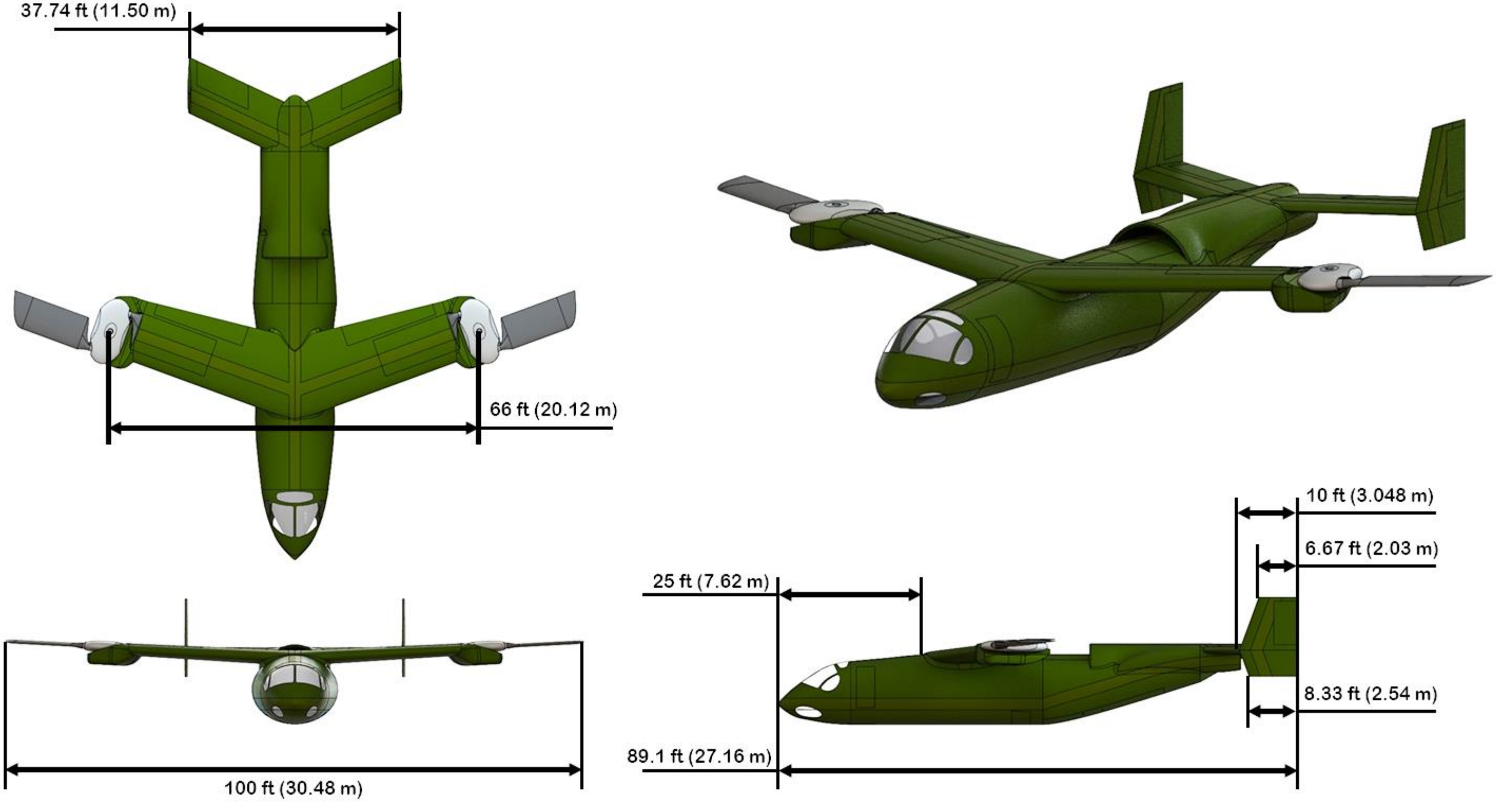
Exposed rotor utilizes Individual Blade Control to operate as a control surface in place of ailerons during forward flight, nicknamed “Rotor-ons”.

6

Hover Configuration External Dimensions



Fixed Wing Configuration External Dimensions



Introduction

To address the request for proposal put forward by the Vertical Flight Society's 2022-2023 student design competition, Georgia Tech and West Point present *Harpy*. Its name was inspired by two different sources. The first being harpy eagles which are known for being the birds that can carry the most weight, similar to how this vehicle can carry a heavy payload. The second being the harpies from Greco-Roman mythology which are half-human and half-bird, much like how this vehicle is half-VTOL and half-jet.

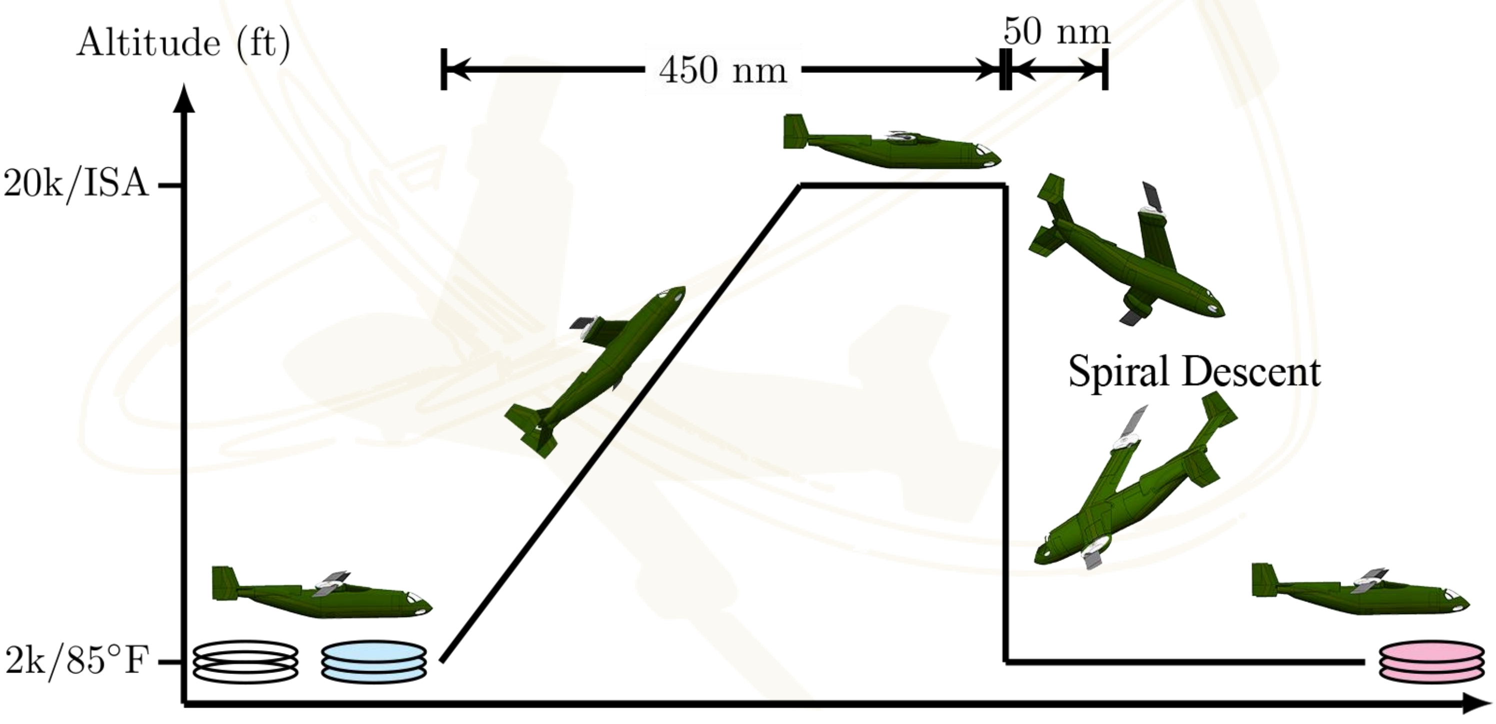
Vehicle Overview

The *Harpy* is a high-speed VTOL vehicle capable of flying in excess of 450 KTAS at 20k ft. To accomplish this, the vehicle leverages a novel rotor configuration: during vertical flight, *Harpy's* rotors are tilted outboard to provide vertical thrust. In high-speed forward flight, its retreating blades are stored in the wings to remove them from the flow. This method allows the drag to be minimized while still allowing the advancing blades to remain as a useful lifting surfaces in the flow.

Mission Operations

The *Harpy* is designed to operate for at least a 1000 nautical mile mission radius. The first half of a typical mission profile is shown below. While *Harpy* can perform well in both configurations, for any given mission profile it will be in forward flight configuration most of the time as illustrated.

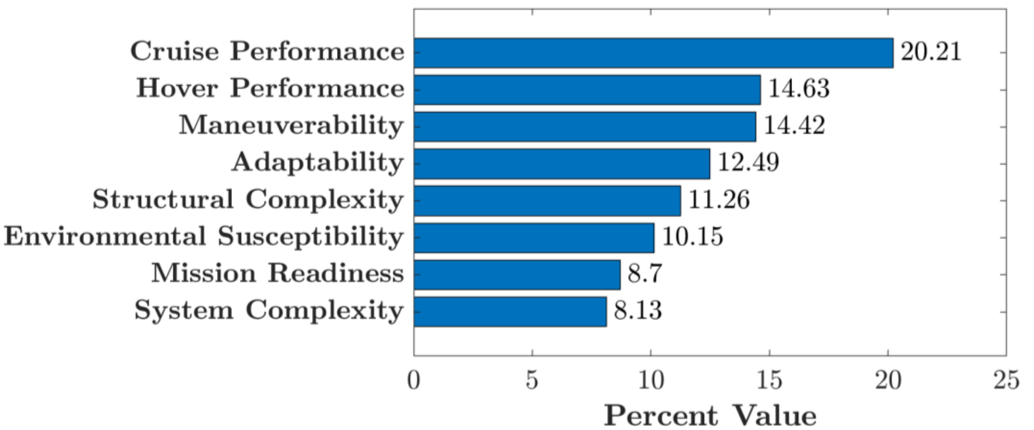
Mission Profile



Vehicle Trade Studies

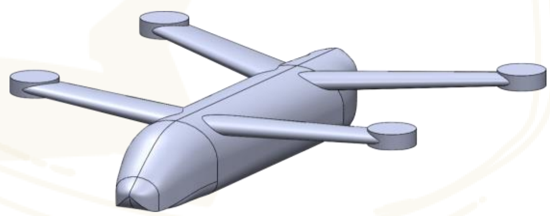
Design Drivers & AHP

The Requirements put forth by the RFP were consolidated to 8 Design Drivers that were then ranked in order of importance via the Analytical Hierarchy Process (AHP)



Configurations Considered

Down Selected Concepts



Perpendicularly Stopped Quad Rotor

Perpendicularly Stopped Bi-Rotor

Rotor Design

The rotors of the *Harpy* are designed to minimize disk loading to take off from and land on unprepared surfaces.

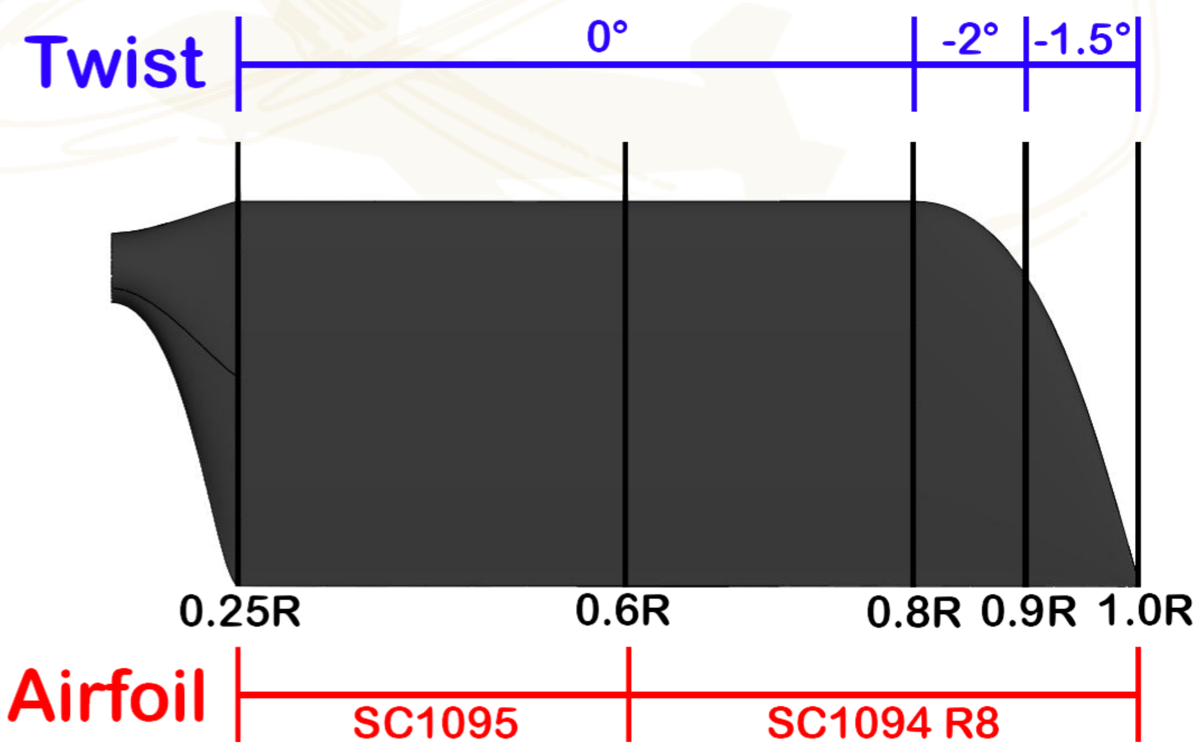
A BEMT code was created to analyze the rotor design space. This yielded the following blade design and performance results

BEMT Performance Results

Characteristic	English	SI
R	18 ft	5.49 m
σ	0.2012	0.2012
ΩR	780 ft/s	238 m/s
DL	25 psf	1205 N/m^2
FM	0.81	0.81
C_T/σ	0.1090	0.1090
P_{HOGE}	9,193 hp	6,856 kW

The 25 psf (1,205 Pa) disk loading allows for VTOL on unprepared surfaces given possible FOD ingestion. The under 130 mph (209 km/hr) wake velocity allows for pararescuer use

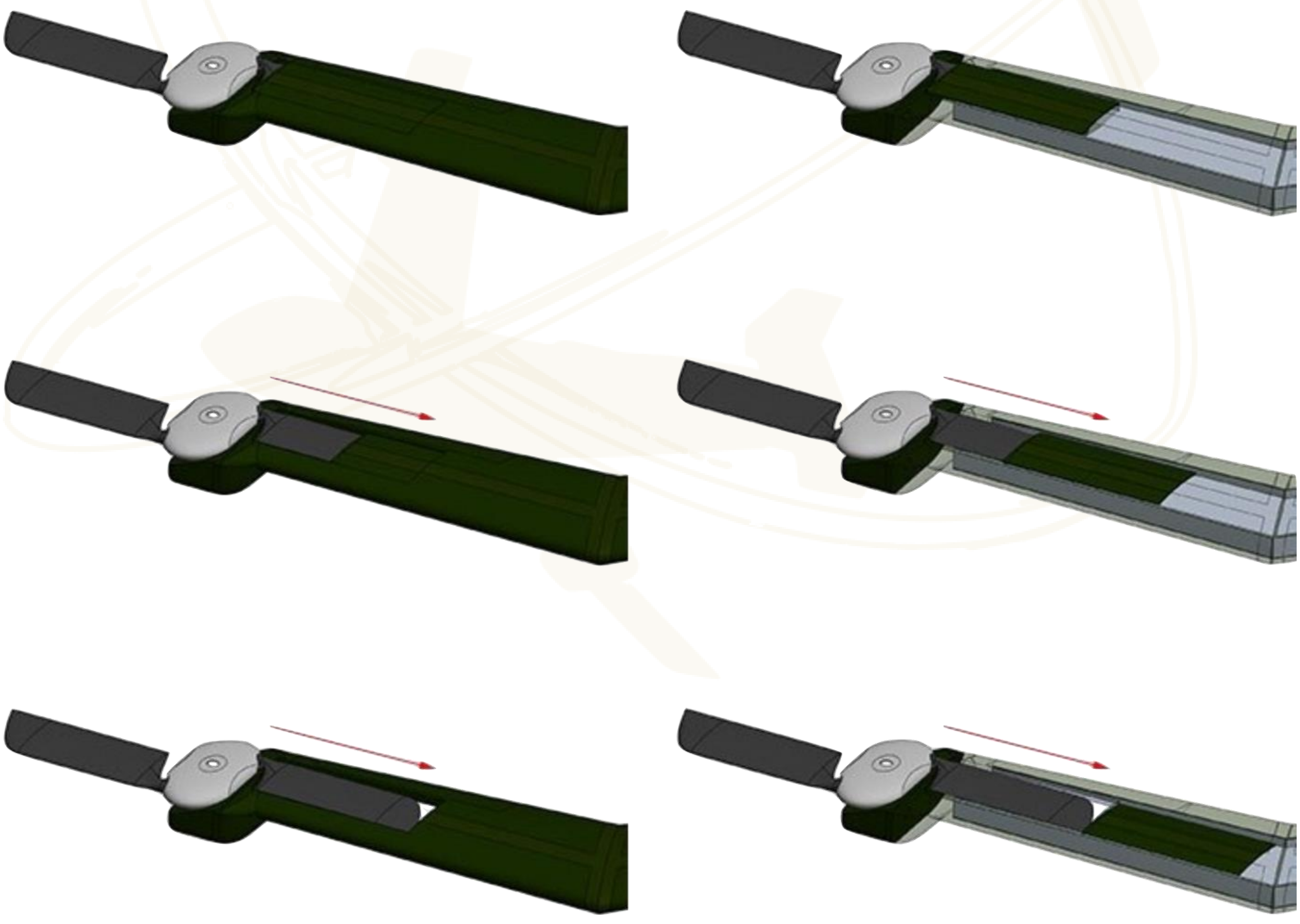
Vehicle Rotor Design



Transition Mechanics

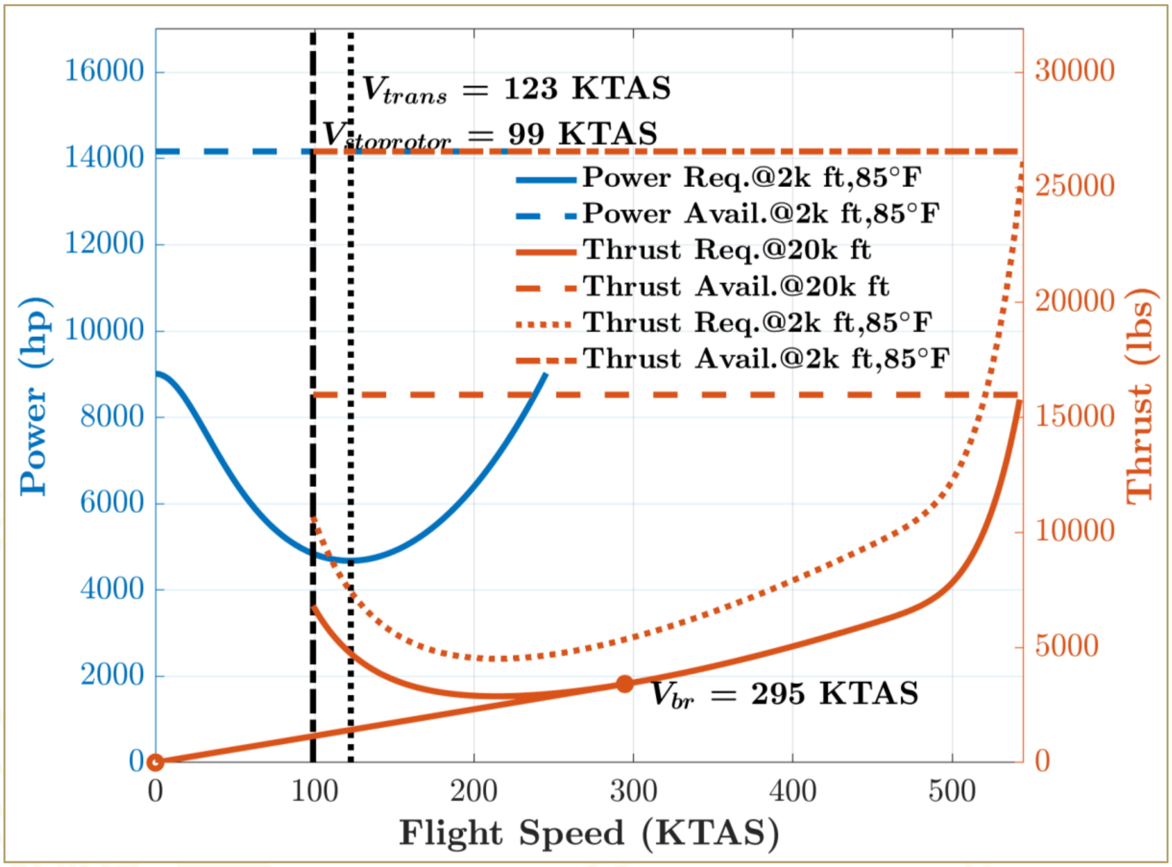
The *Harpy* can transition from hover to fixed wing once the forward flight speed exceeds 100 KTAS.
It does by slowing and stowing 1 blade from each rotor in a shrouded wing cavity. The other blade is then used to generate lift and utilizes Individual Blade Control to operate as a control surface (nicknamed "Rotor-ons").

Rotor Stowing Mechanism & Video (Scan QR Code)



Vehicle Performance & Stability

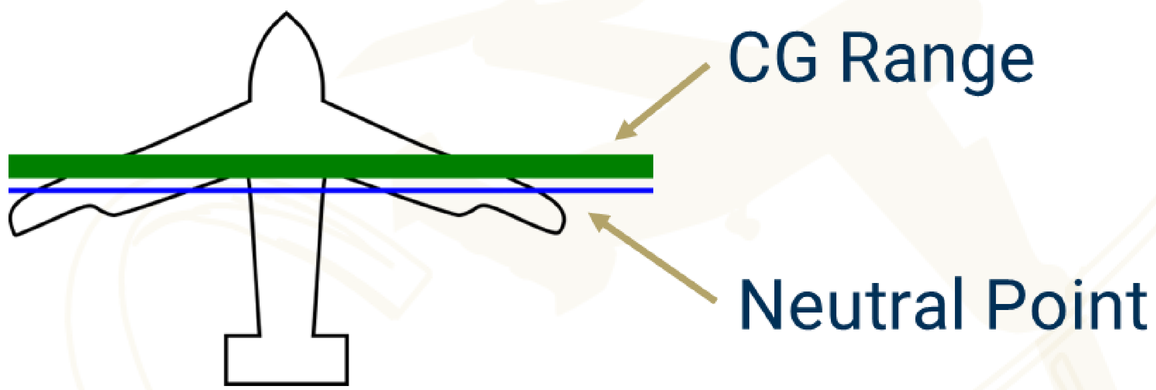
Power & Thrust Curves



Max Power	Max Thrust	Min Transition Speed	Best Climb Speed	Max Range
12,750 hp (9,378 kW)	25,455 lb (113 kN)	100 KTAS (185 km/hr)	220 KTAS (407 km/hr)	1,000 nm (1,852 km)
Hover Ceiling	**Service Ceiling (Rotor)**	**Service Ceiling (Fixed Wing)**	**Best Range Speed**	**Max Level Flight Speed**
10,791 ft (3,289 m)	27,688 ft (8,439 m)	51,600 ft (15,750 m)	292 KTAS (541 km/hr)	540 KTAS (1,000 km/hr)

Vehicle Stability Analysis

The *Harpy* maintains stability given a CG range of between 34.6 ft and 37.6 ft aft of the aircraft nose.

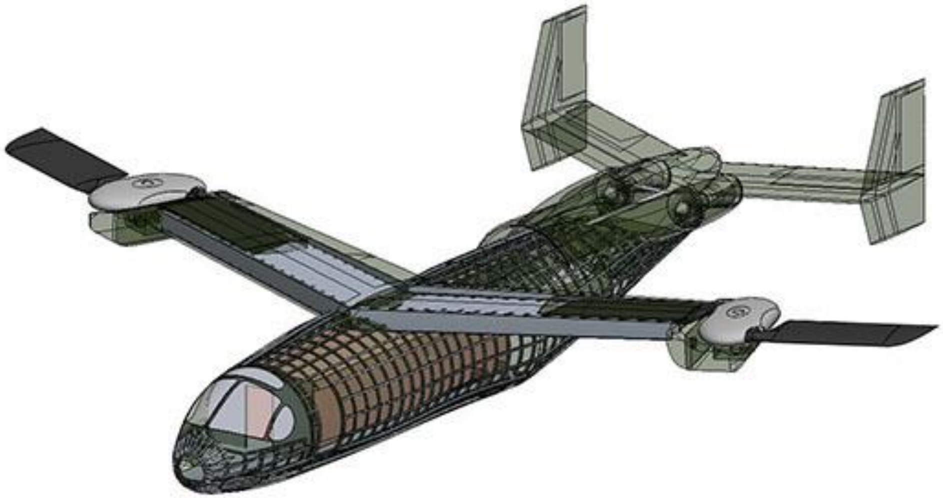


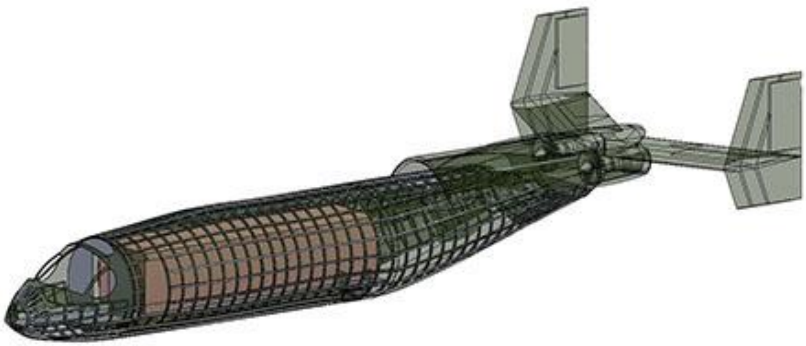
The *Harpy's* dynamic stability adheres to requirements for a Class II Aircraft as put forth by MIL-STD-1797A

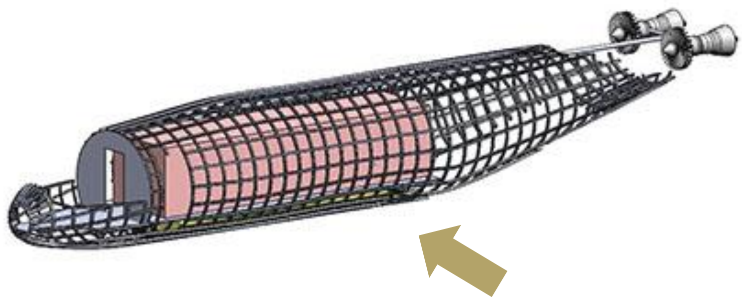
		Vehicle Mode Data	
		Damping Ratio	Half Time $T_{1/2}$
Longitudinal Modes	Phugoid	0.016	20 min
	Short Period	0.77	0.1 sec
Lateral Modes	Dutch Roll	0.036	19.5 sec
	Spiral	N/a	111 sec
	Roll	N/a	8.8 sec

Internal Structure Diagram

To satisfy the requirements put forth by the RFP, the *Harpy's* internal structure is designed to ensure aircraft integrity during both 3.5g load cases and 10 ft/sec (3.05 m/s) landing with 2/3 rotor lift.

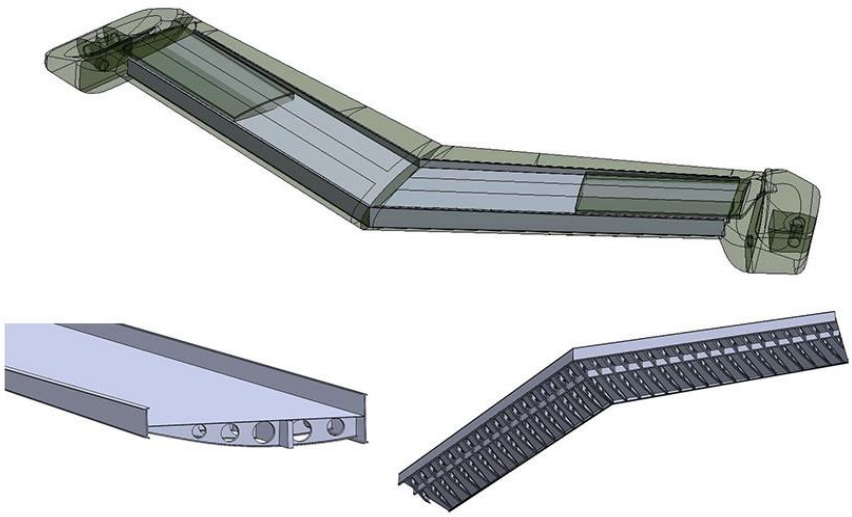






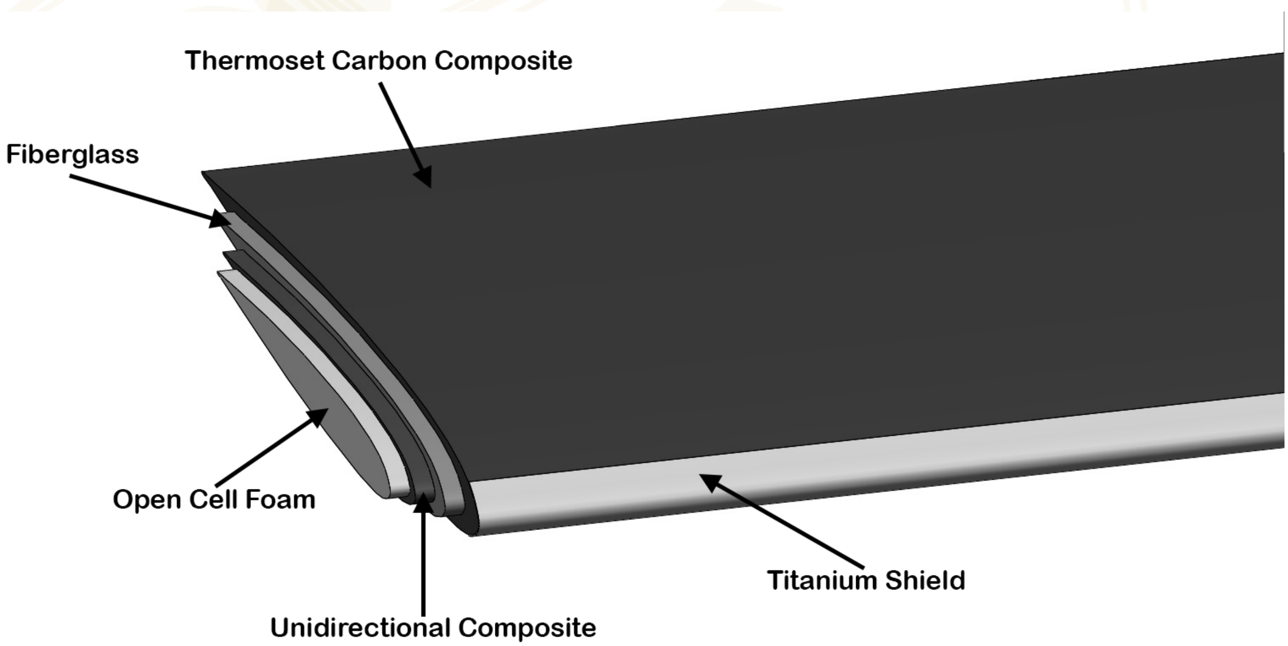
Cargo Showed in Pink

Wing & Rotor Structure



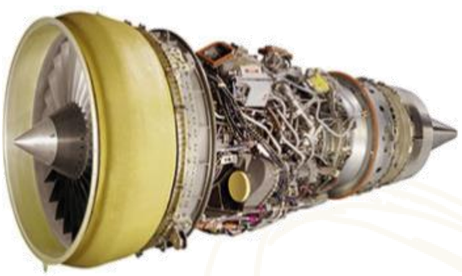
The *Harpy's* Wing Structure utilizes Webbed Ribs and 3 Spars to Stand the 3.5g Load requirements while being able to accommodate a cavity to house the rotor blades.

The *Harpy's* Rotor structure utilizes a thermoset carbon composite to minimize weight while also having the rigidity to provide lift for the aircraft in fixed wing mode.



Convertible Engine

The *Harpy* is powered by two GE CF34 turbofan engines. Each turbofan can provide the required power for the mission profile, allowing for One Engine Inoperable vehicle operation



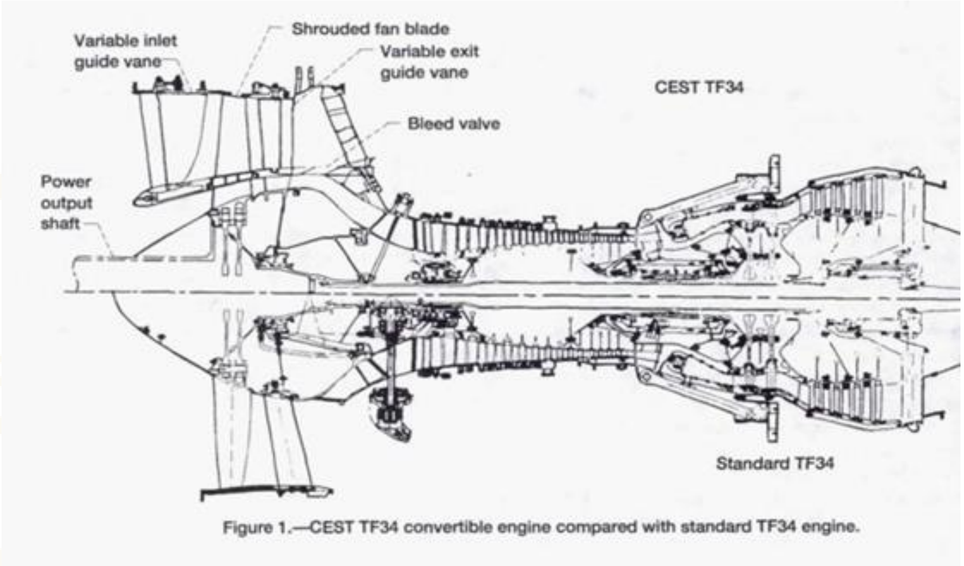
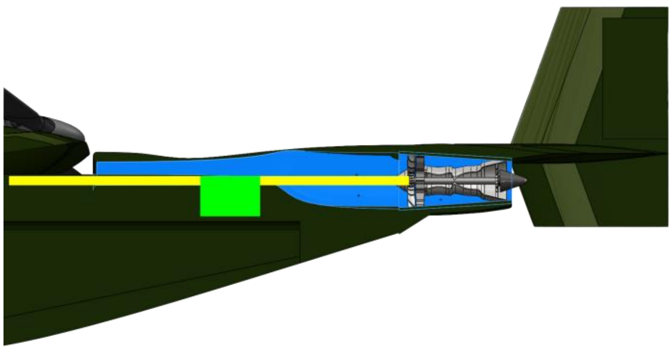


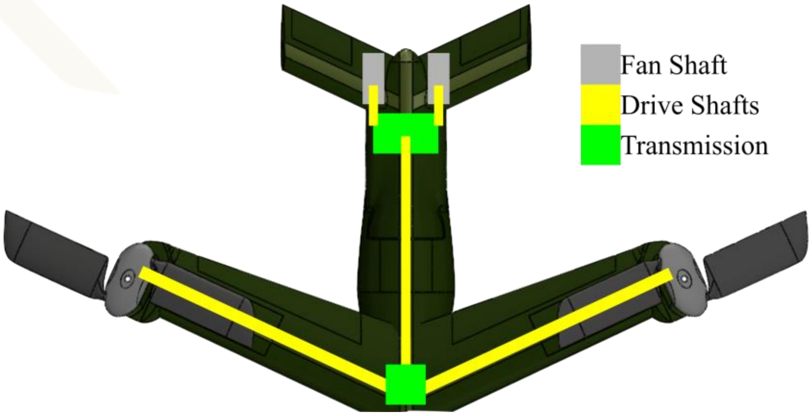
Figure 1.—CEST TF34 convertible engine compared with standard TF34 engine.

In place of Turboshaft Engines, it utilizes NASA-tested Convertible Engine Technology to extract power from the fan shaft using inlet guide vanes.

Vehicle Drive Shaft & Transmission System

The *Harpy* utilizes a series of drive shafts and transmission boxes, to supply the required power to the rotors

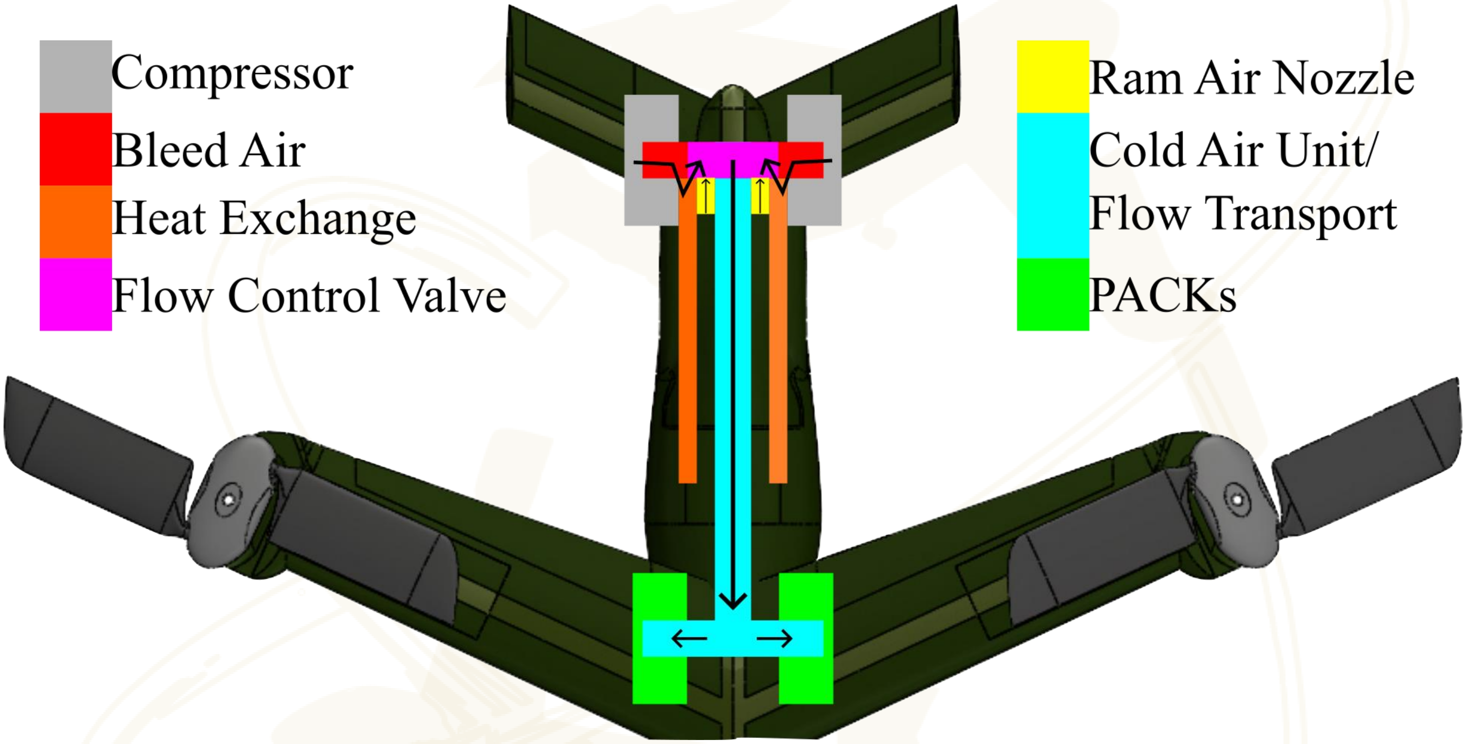




Installed Engine Performance

Cabin Management System

The *Harpy* utilizes a cabin management system that extracts bleed air from the engine compressors to pressurize and condition the cabin up to 8,000 ft (2438.4 m).



Installed Engine Data

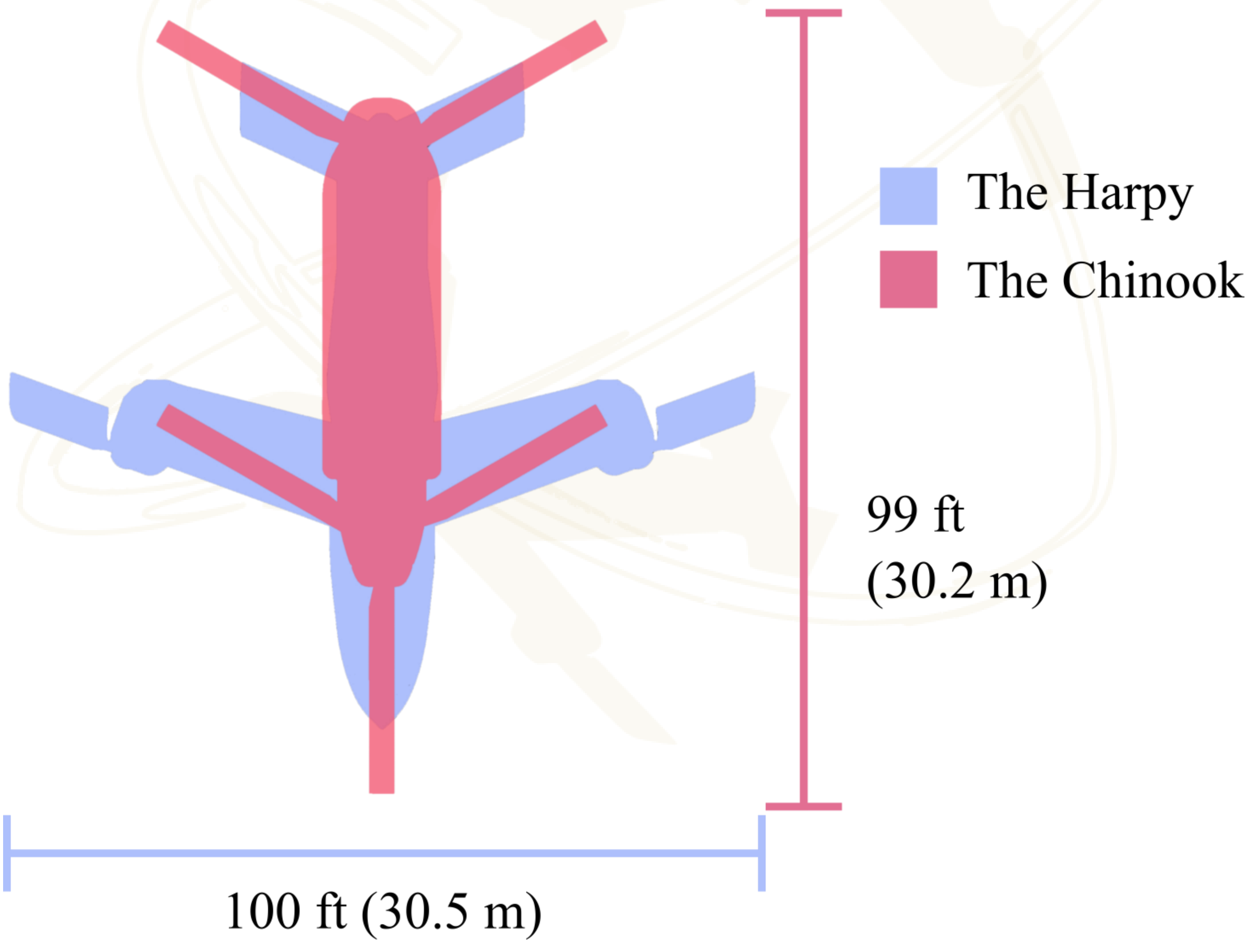
The bleed air losses in conjunction with the airframe losses comprise the uninstalled versus installed engine data, shown below.

Engine		Weight (lb)	Max Thrust (lb)	TSFC (1/hr)
CF34	Uninstalled	2,000	15,000	0.346
	Installed	2,000	14,350	0.360

Vehicle Footprint

Comparison - Chinook

Below is a full-scale footprint overlay of the *Harpy*, in blue, and the Chinook, in red. While the *Harpy's* lateral footprint is larger in comparison to the Chinook, it should be noted that its longitudinal footprint is smaller, putting the *Harpy* at comparable sizes to in-use VTOL vehicles. This allows the *Harpy* to land in the same areas the Chinook can.



Cost and Weight Breakdown

SAWE RP8A Part I was used to generate the group weight statement. The *Harpy's* weight breakdown is shown below.

Component	Weight (lb)
Wing	3,465 (1,572 kg)
Rotor	4,960 (2,250 kg)
Horizontal Tail	825 (374 kg)
Vertical Tail	547 (248 kg)
Fuselage	3,325 (1,508 kg)
Landing Gear	1,220 (554 kg)
Engine Structure	260 (118 kg)
S-Duct	140 (64 kg)
Total Structure	**14,742 (6,687 kg)**
Engines	6,231 (2,828 kg)
Controls	2,400 (1089 kg)
Equipment & Furnishings	2,355 (1,069 kg)
Hydraulics	650 (295 kg)
Electrical	500 (227 kg)
Weight Contingency	1343.9 (610 kg)
Total Empty Weight	**28,222 (12,801 kg)**

Component	Weight (lb)
Load Condition	5,000 (2,268 kg)
Crew – Qty: 3	750 (340 kg)
Mission Equipment Packaging	1,000 (454 kg)
Trapped Fluids	130 (59 kg)
Zero Fuel Weight	28,222 (12,801 kg)
Usable Fuel	16,390 (7434.5 kg)
Gross Weight	**51,492 (23,356 kg)**

Production Cost

- *$37,900,293 USD/unit*

Operational Cost

- *$11,000 USD/hr*
- *$44,020 USD/mission*

Summary

In response to the 2022-2023 VFS Student Design Competition, the Georgia Institute of Technology and the United States Military Academy at West Point proudly presents the *Harpy* an innovative and versatile convertible rotorcraft design.

With its exceptional maneuverability and power, the Harpy can access and navigate challenging environments with ease. The *Harpy's* VTOL capability on unprepared surfaces and FOD resistance in conjunction with its high service ceiling and transonic speeds is "groundbreaking". This allows for rapid deployment and personnel extraction in rugged and contested locations. These capabilities are certain to solidify the *Harpy* as an indispensable asset in critical military operations.

Furthermore, the *Harpy* incorporates state-of-the-art materials and cutting-edge technologies, ensuring optimal efficiency, durability, and vehicle survivability.

Combining the grace and agility of the harpy eagle with the strength and adaptability of the mythical creature it is named after, we are confident that the *Harpy* will revolutionize military rotorcraft operations, providing unmatched capabilities and contributing to the success of any CSAR mission it undertakes.