Executive Summary

31st Annual AHS Student Design Competition

Undergraduate Category

Andrew Aldrich
Clifford Sircar
Brett Kubica
Michael Ross
Joshua Bareket
William Keller
Brendan Haber
Mateus Pereira
Ethan Sarikas
Yuanji Zhu

AgustaWestland
A Finmeccanica Company

Georgia Institute of Technology

Project Raven

The Georgia Institute of Technology's Project Raven is the result of months of development in response to the 2013 Request for Proposal (RFP) for X-VTOL rotorcraft, sponsored by AgustaWestland.

Project Raven is a revolution in high speed, high efficiency rotorcraft. Its blended wing body design allows for forward flight speeds unmatched by any rotorcraft while its buried rotor vertical lift system provides stable and controllable hover and low speed flight.

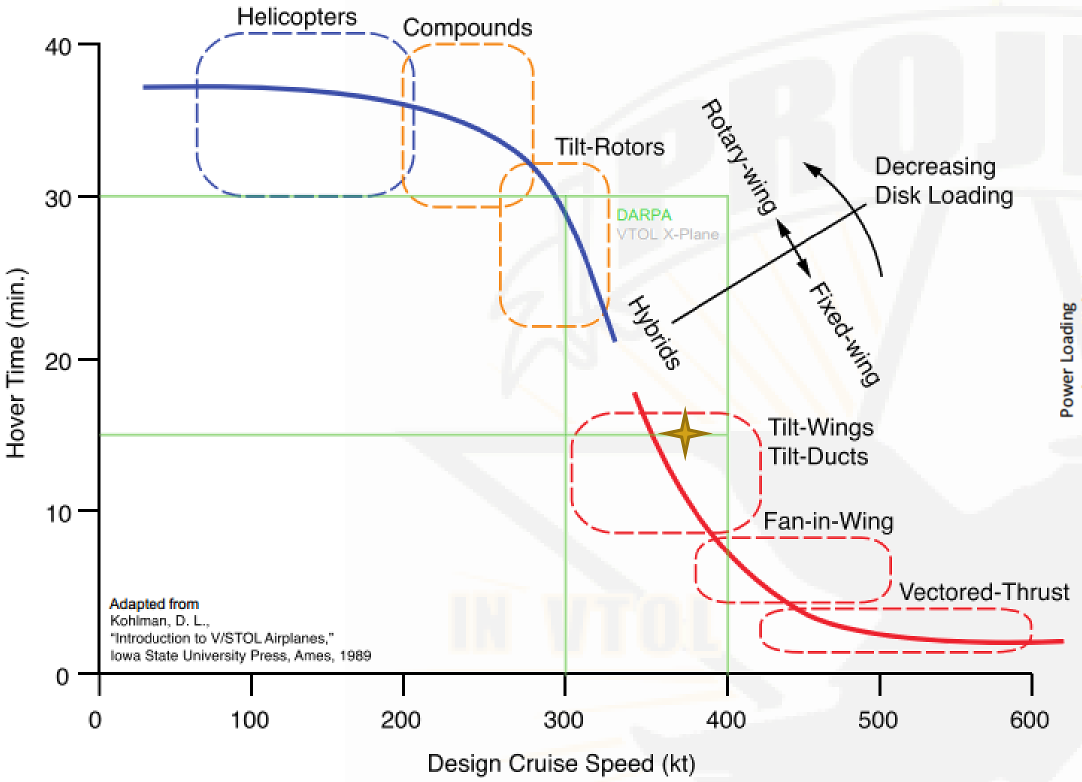
Project Raven checks all of the boxes for a successful X-VTOL concept.

- ✓ Sustained true airspeeds in excess of 400 kts
- ✓ Aerodynamic efficiency resulting in a lift-to-drag ratio exceeding 15
- ✓ 40% useful load fractions and 12.5% payload fractions
- ✓ Hover efficiency within 25% of the ideal power loading
- ✓ Flexible vehicle design allowing for broad size scalability

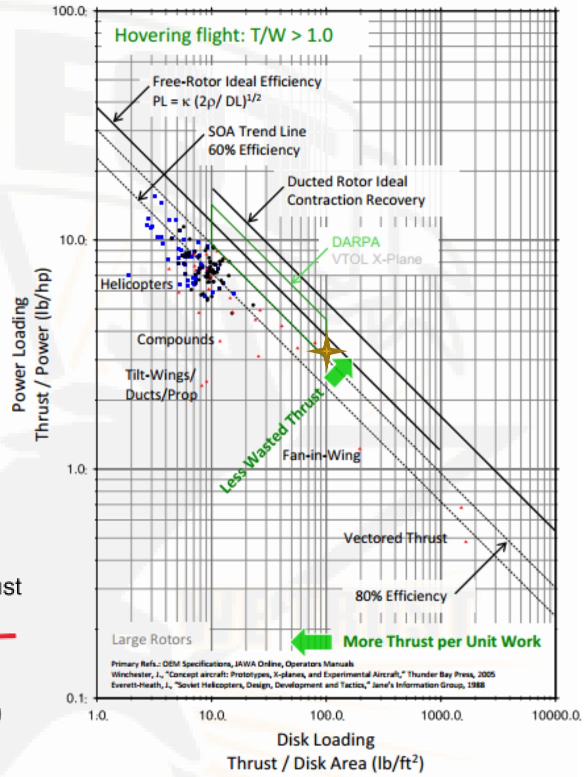
Design Summary

Weights	**Value**	**Units**
Empty Weight	6,910	lbs
Max. Gross Weight	11,522	lbs
Payload	1,441.25	lbs
Max Fuel Weight	3,170.75	lbs
Performance	**Value**	**Units**
Power Required, HOGE @ SL	3,750	HP
Hover Efficiency	0.7	-
Cruise Speed @ 35,000ft	373	kts
Dash Speed @ 35,000ft	459	kts
L/D in Cruise	16	-
Stall Speed @ SL, $\alpha = 0$	157	kts
Best Rate of Climb	78.75	ft/s
Power Plant		
Thrust Available @ SL	4500	lbs
TSFC @ Max Cruise Speed	0.67	lb/(lb*hr)
Basic Dimensions		
# of Rotors	2	-
# Blades per Rotor	11	-
Rotor Diameter	8	ft
Max Disk Loading	114.6	lb/ft^2

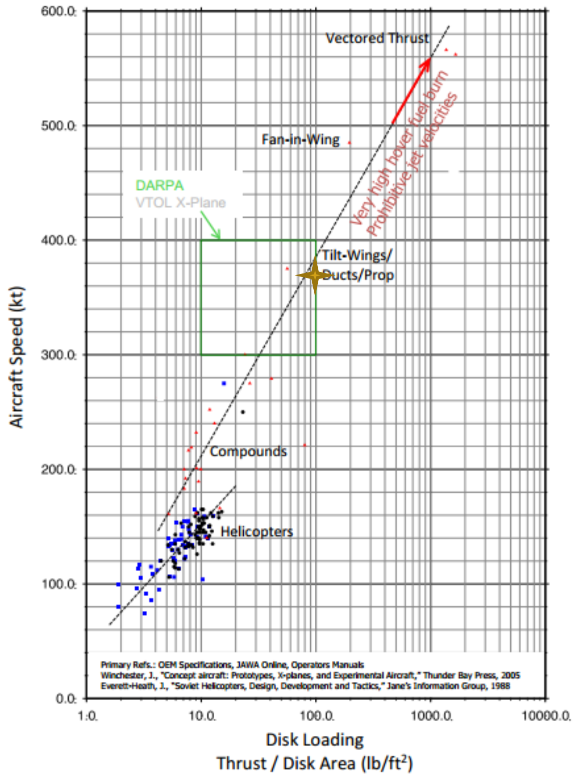
Measuring Up to the Competition



Adapted from
Kohlman, D. L.,
"Introduction to V/STOL Airplanes,"
Iowa State University Press, Ames, 1989



Primary Refs.: OEM Specifications, JAWA Online, Operators Manuals
Winchester, J., "Concept aircraft: Prototypes, X-planes, and Experimental Aircraft," Thunder Bay Press, 2005
Everett-Heath, J., "Soviet Helicopters, Design, Development and Tactics," Jane's Information Group, 1988



Primary Refs.: OEM Specifications, JAWA Online, Operators Manuals
Winchester, J., "Concept aircraft: Prototypes, X-planes, and Experimental Aircraft," Thunder Bay Press, 2005
Everett-Heath, J., "Soviet Helicopters, Design, Development and Tactics," Jane's Information Group, 1988

Speed

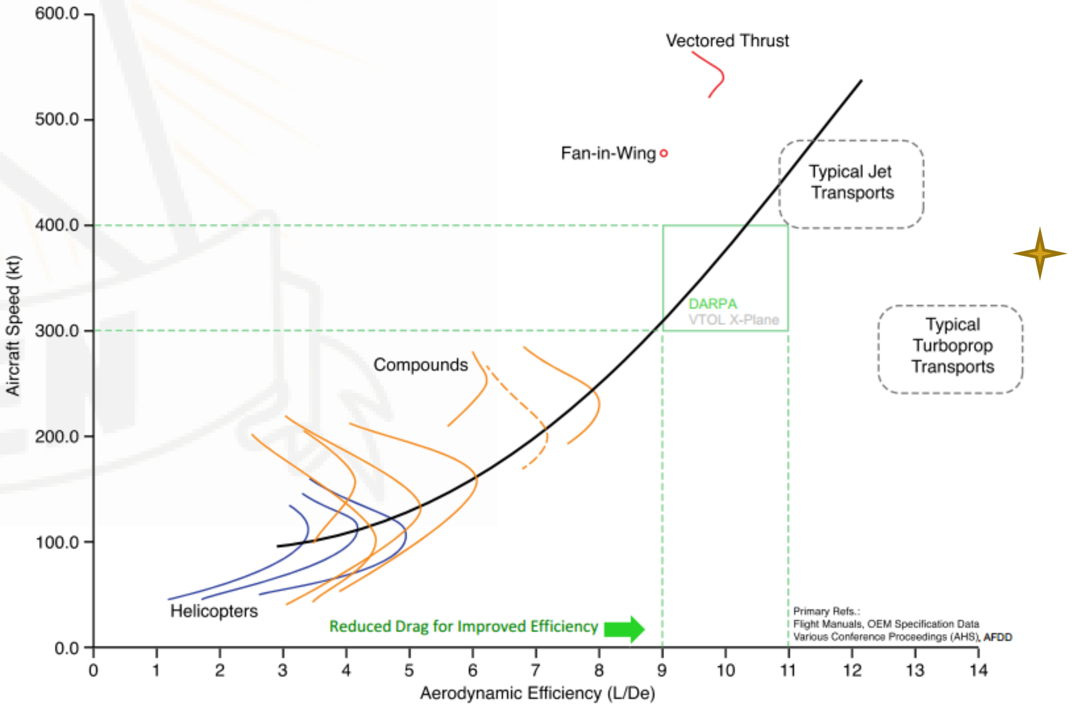
- Project Raven cruises at a cool 373 kts, enabling rapid response to any situation

Power

- Project Raven is equipped with enough power to perform steady hover in engine out situations

Efficiency

- Project Raven's aerodynamic design results in exceptional cruise, climb, and descent efficiency



Primary Refs.:
Flight Manuals, OEM Specification Data
Various Conference Proceedings (AHS), AFDD

Mission Profile

	Time (minutes)	Range (nm)	Conditions
(1) Warm up, taxi	10	0	Engine Idle, SLS
(1) HOGE take off	1	0	95% Max. Power, SLS
(2) Climb	6.35	2.1875	To best Alt, Vbroc
(3) Cruise out 1	9.26	55.875	Vbr, Best Alt. ISA
(3) Cruise out 2	15	114.75	Max Sustained speed (Dash)
(4) Descend	6.35	2.1875	To SLS, Vbroc
(5) Mid-Mission Hover	15	0	Full Payload
(6) Climb	6.35	2.1875	To best Alt
(7) Cruise In 1	15	114.75	Max Sustained speed (Dash)
(7) Cruise In 2	9.26	55.875	optimum conditions
(8) Descend	6.35	2.1875	To SLS, Vbroc
(9) HOGE Land	1	0	95% Max. Power
(9) Shutdown	5	0	Engine Idle
Overall	**105.92**	**350**	
Hours	**1.77**		
Block speed (knots)	**172.32**		

Primary Missions

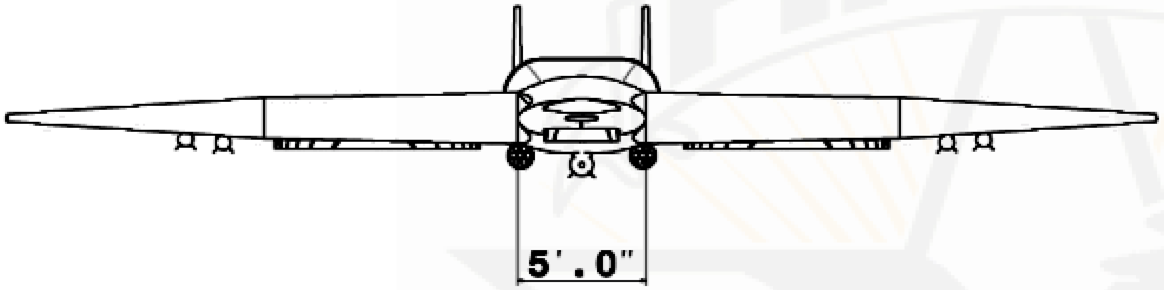
Attack Mission

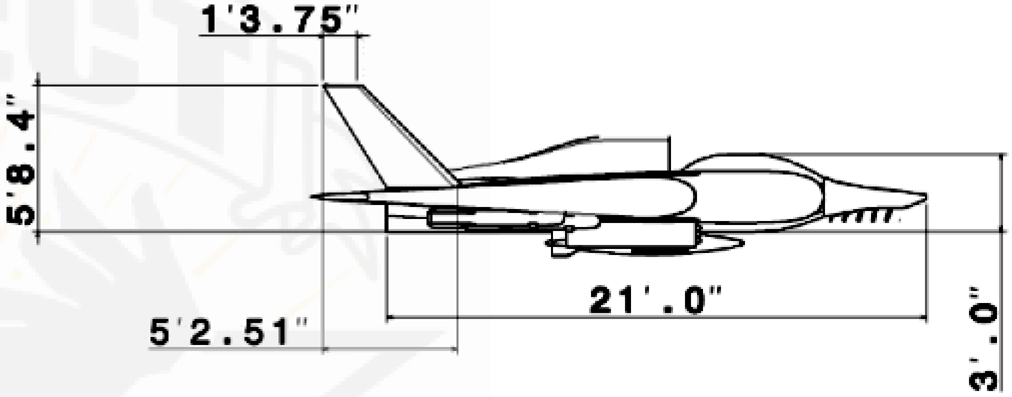
- Destroy enemy forces and supporting systems
- Acquire and engage targets

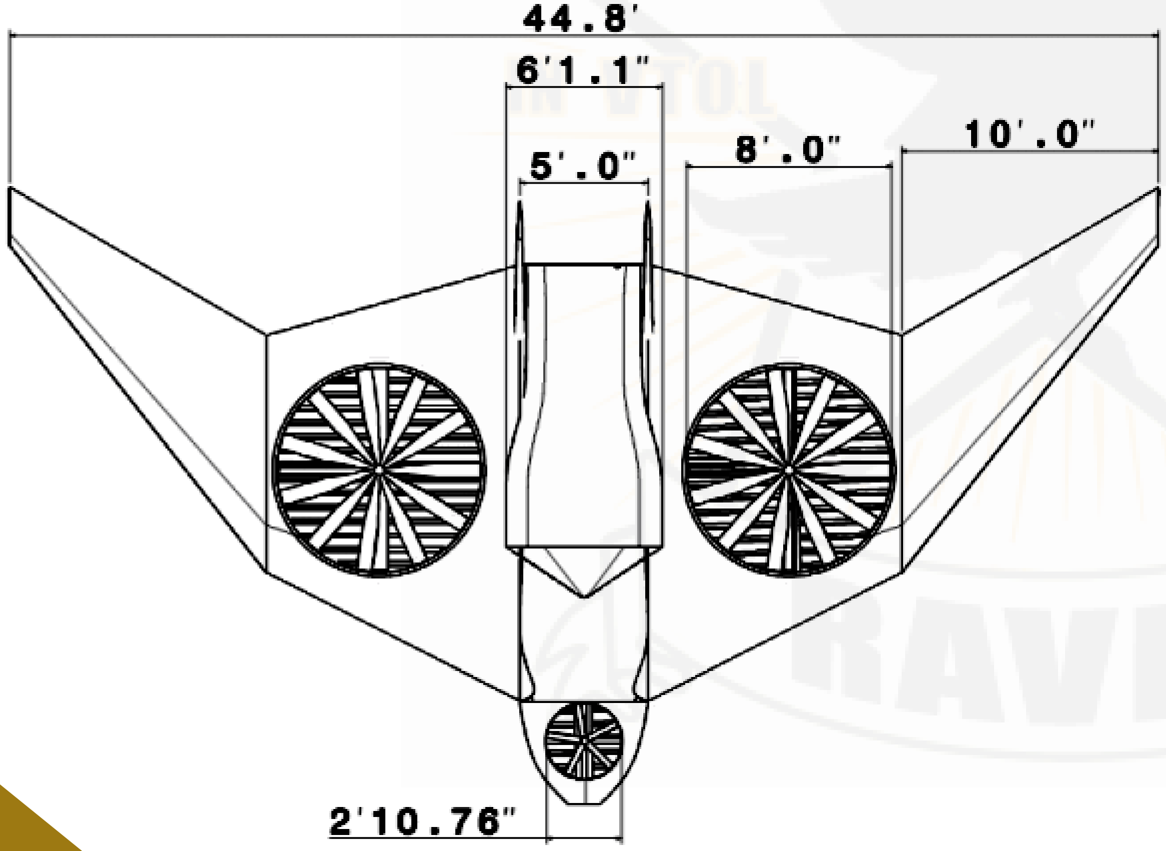
Close Combat Attack (CCA) / Quick Reaction Force (QRF) Mission

- Respond to troops in contact in shortest time possible
- Maneuvers and fires in direct support of ground forces
- Deliver payload on target to neutralize the enemy

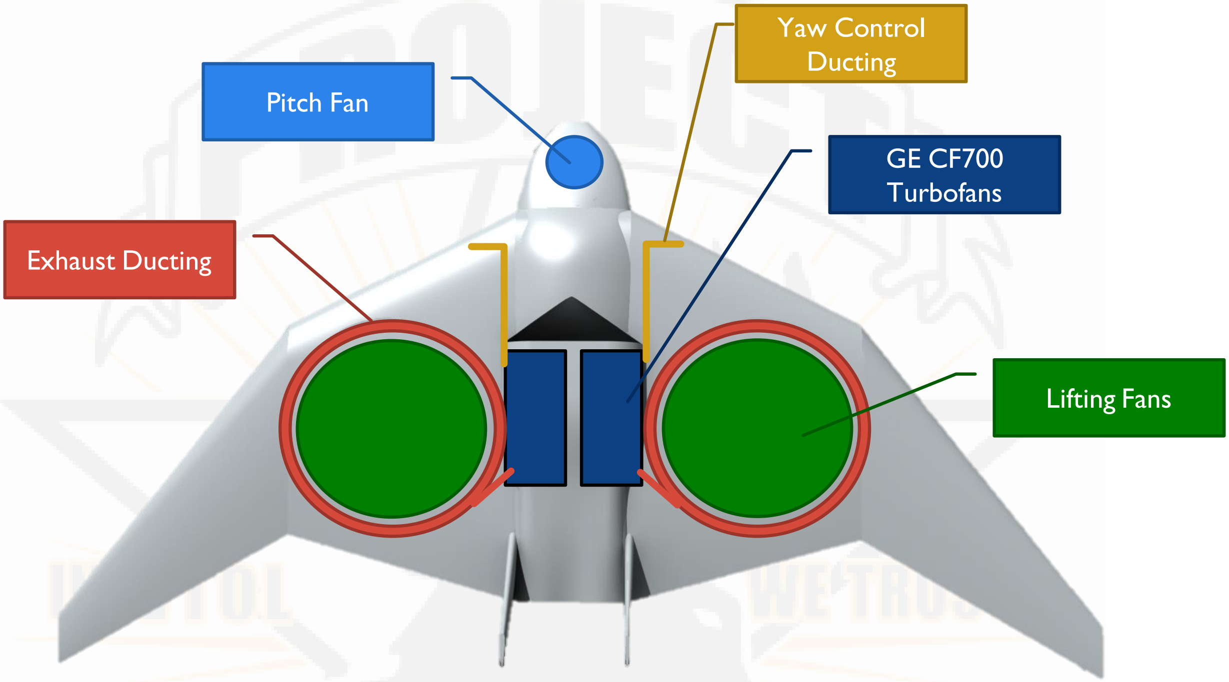
CATIA







Internal Arrangement and Armament



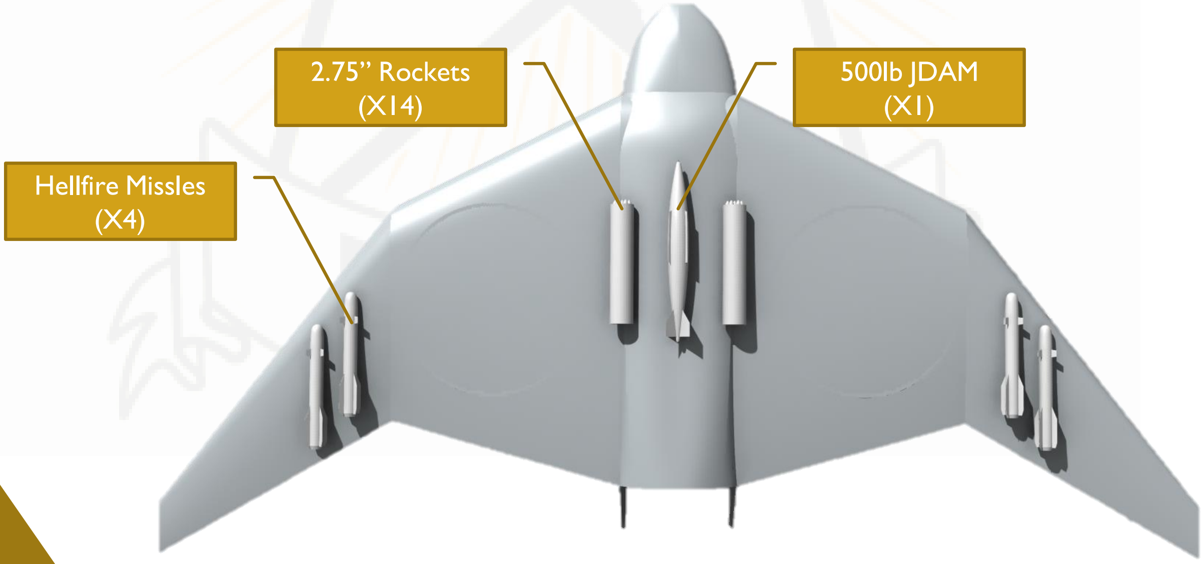
Pitch Fan

Yaw Control Ducting

GE CF700 Turbofans

Exhaust Ducting

Lifting Fans

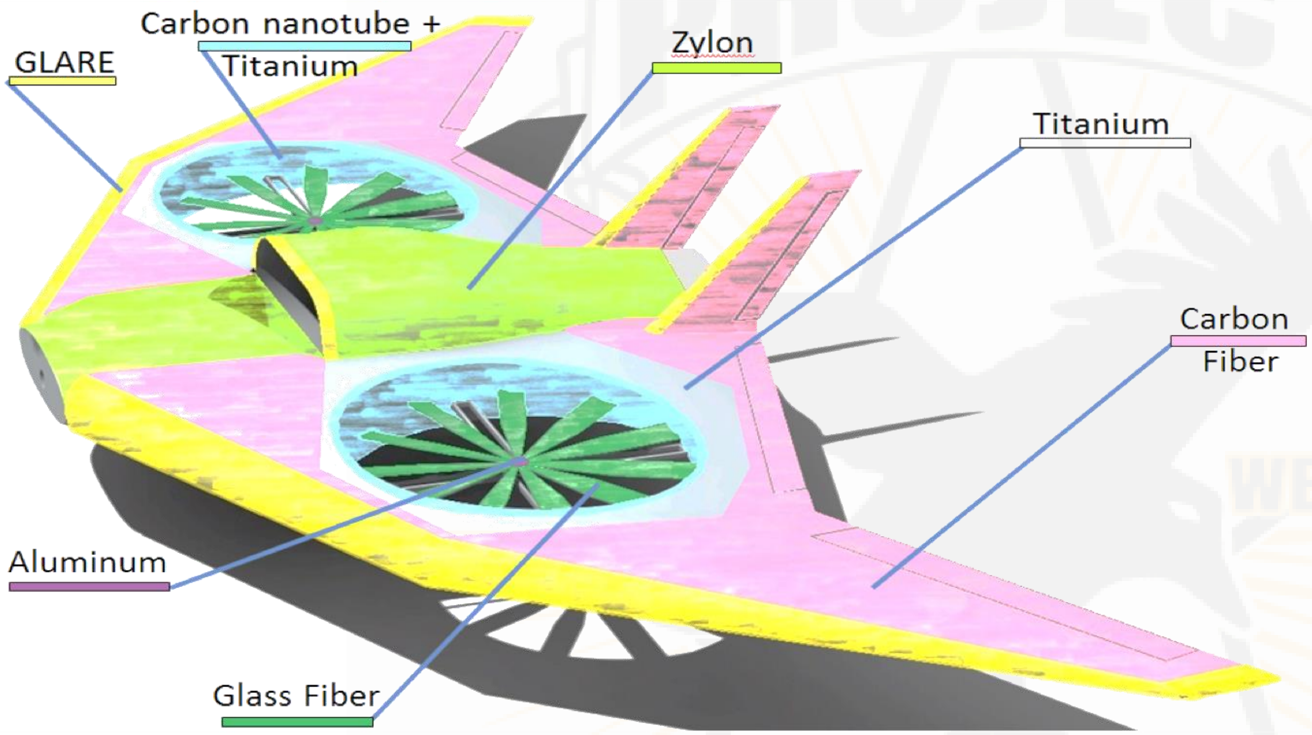


2.75” Rockets (X14)

500lb JDAM (X1)

Hellfire Missles (X4)

Advanced Materials



Selection

Rotorcraft operating conditions drove material selection requirements

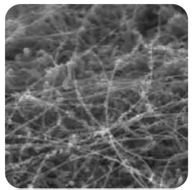
Many advanced alloys and composite materials considered for each component

Properties such as density, tensile strength, and fatigue resistance were compared and optimal materials selected

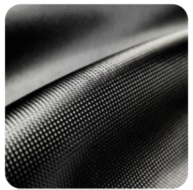
Material	Rationale
Titanium	Handles vibrations, fatigue
Aluminum 6061-T6	High strength, relatively lightweight
GLARE	Very common for aircraft leading edges
Glass Fiber (PAG)	Very strong, stiff, lightweight
Carbon Fiber	Extremely lightweight, strong
Zylon	Lightweight, strong, heat resistant
Titanium Carbon Nanotubes	Stiffest, strongest fiber material

Composite Materials

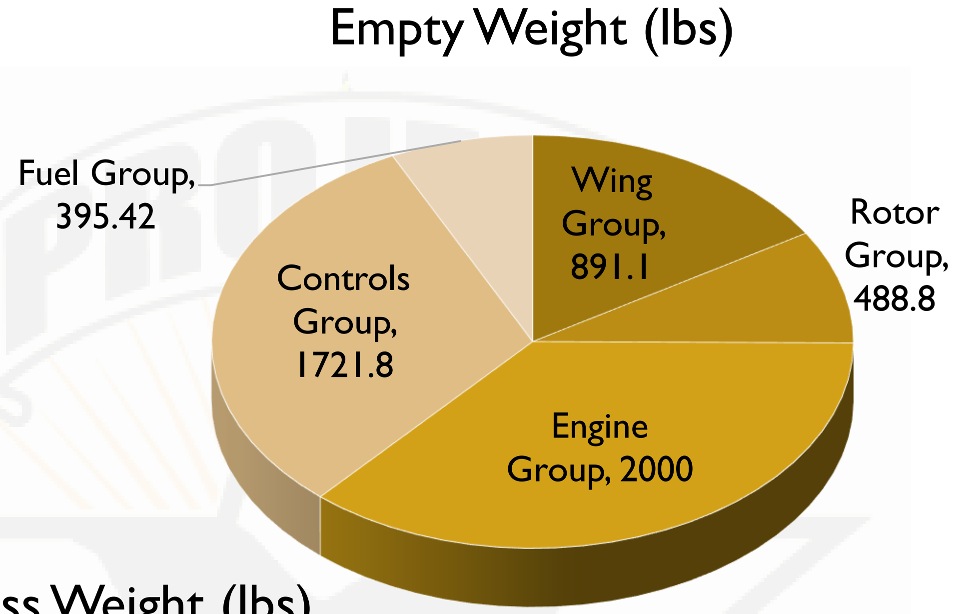

Glass Fiber (PAG)

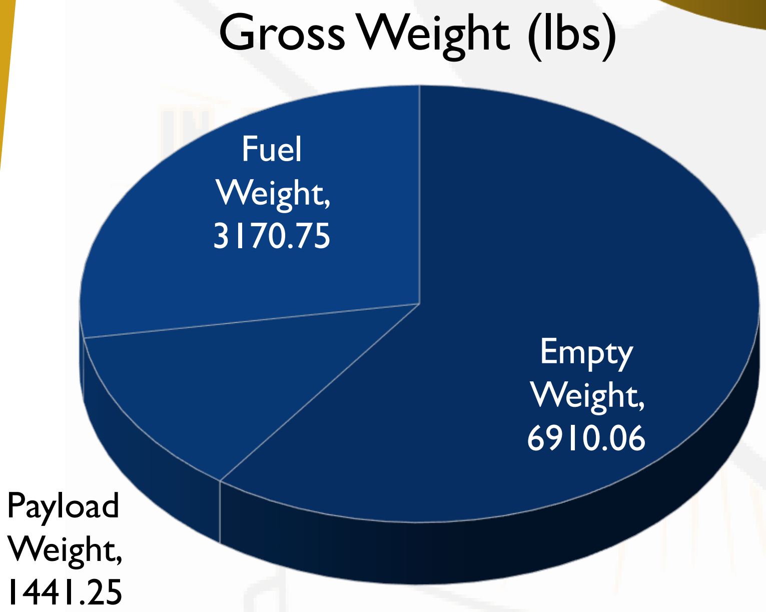

Titanium Carbon Nanotubes


Zylon


Carbon Fiber

Weight Breakdown





Lightweight Aircraft Materials

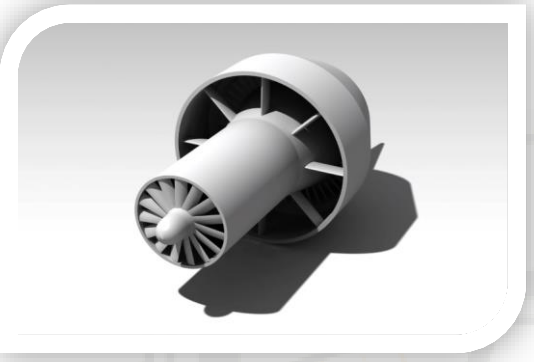
- Composites and alloys enable a strong structure while maintaining high payload and useful load fractions

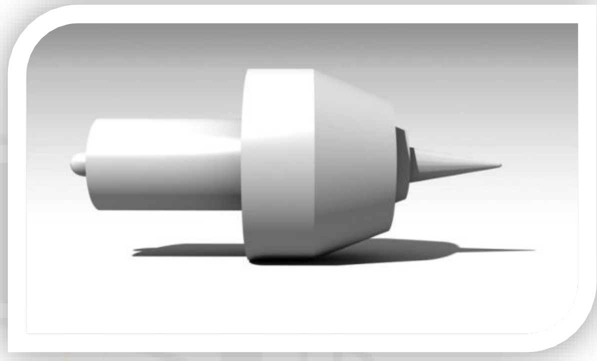
Turbine Drive Propulsion System

- Enables hover and forward flight to be powered by same power plant
- Removal of transmission allows for large weight savings

Design Gross Weight = 11,522lbs

Engine Selection





Make	Model	Weight(lbs)	TO Thrust(lbs)	T/W Ratio
Pratt & Whitney Canada	PW617F	400	2050	5.13
Pratt & Whitney Canada	PW530	540	2887	5.35
Pratt & Whitney Canada	PW535	630	3400	5.4
Pratt & Whitney Canada	PW545	730	3995	5.47
GE	CJ610	400	3100	7.75
GE	CF700	680	4500	6.62
GE	HF120	360	2100	5.83
Rolls-Royce	Mk951	1340	6500	4.85
Rolls-Royce	Mk811	1633	8400	5.14
Pratt & Whitney Canada	PW300	1240	6295	5.08
SNECMA Turbomeca	Larzac 04	650	3147	4.84

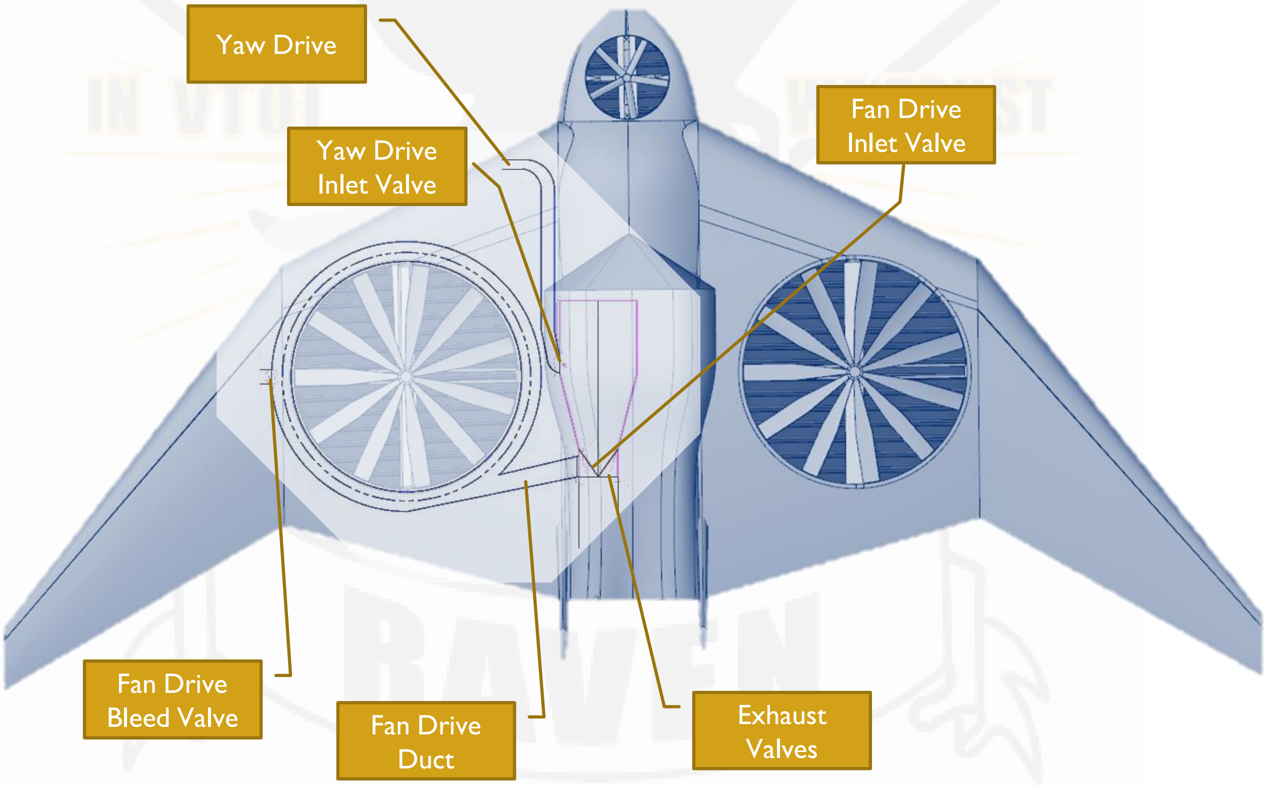
The size and overall weight were used as filters when building a list of potential engines, since these constraints had been dictated by aerodynamic, structural, and weight factors.The number of engines was allowed to vary from 1 to 4, with the 4-engine configuration being a turbojet only due to size constraints.After an initial list of over 30 engines was compiled, a decision was made to forego the single engine option to allow for the vehicle to operate with one engine out.The single engine configurations, while very powerful and efficient, simply did not justify the risk of loss of total power.

RAVEN will harness the power of two GE CF-700-2D2 engines for both vertical lift and forward propulsion.

Ducting Layout

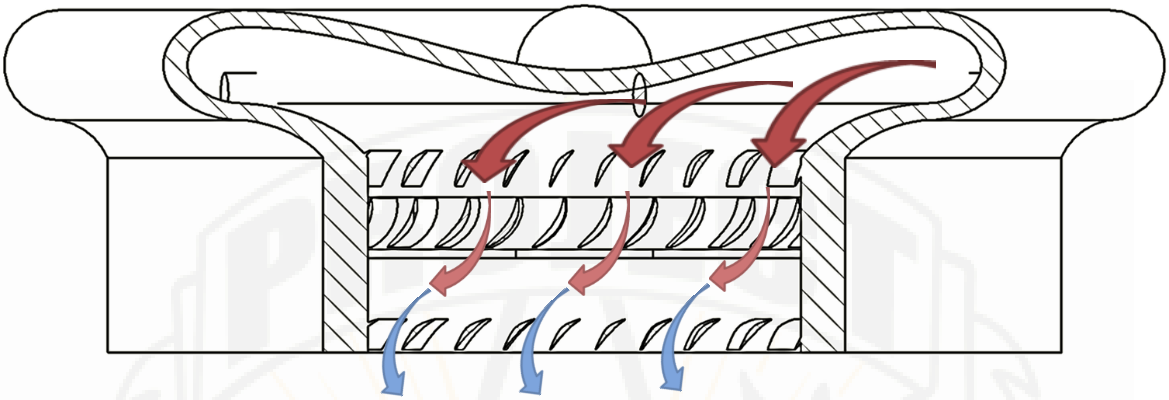
In the effort to maximize engine utility, exhaust from the two turbofan-engines will be diverted from the main exhaust track to a ducting system. The ducting will guide the engine exhaust into the wing and to a novel turbine drive system surrounding each lift fan. Additional ducting will stem from the leeward side of the compressor to drive another turbine drive system that powers a smaller pitch fan as well as two nozzles utilized for yaw control.

The exhaust gas from turbofan engines is diverted through a ducting system during vertical takeoff and landing. This ducting concept is very similar to the Ryan XV-5 model, which also took advantage of exhaust ducting to provide lift. The immediate advantage of achieving vertical lift by means of ducting is using one engine to accomplish two different tasks.

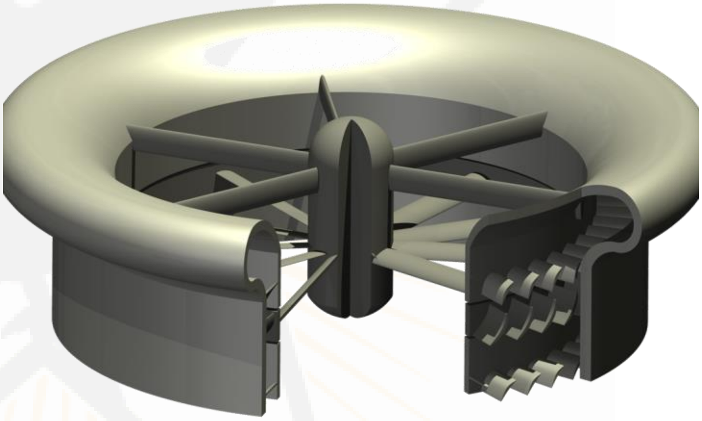


It is important to note that both the exhaust and compressor bleed flow are cross-ducted to allow for one engine to power all fans and thrust controls

Fan Drive Design



Lift is achieved by diverting jet exhausted through a ducting system, which then guides the gas into a turbine blade drive system. The air enters a radial duct, which contains a rotating valve that opens or closes the inlet to the turbine, thereby controlling the mass flow rate.



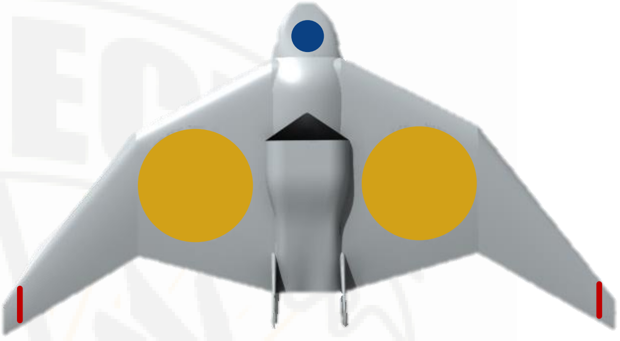
Once the air has entered the turbine system through the control valve, the air is guided to the turbine blades via inlet control guides, or stators. The flow then expends its energy on the turbine blades, which are attached to a rotating ring on which the fan blades are oppositely attached. Finally, the flow exits the radial duct via a second row of stators that guide the flow downward at ambient pressure.

RAVEN Controls

🔵 Pitch control provided by nose mounted fan

🟡 Roll control provided by differential rotor thrust

🔴 Yaw control provided by air ducted through wingtips



🔵 Pitch control provided elevons

🟡 Roll control provided by elevons

🔴 Yaw control provided by rudders

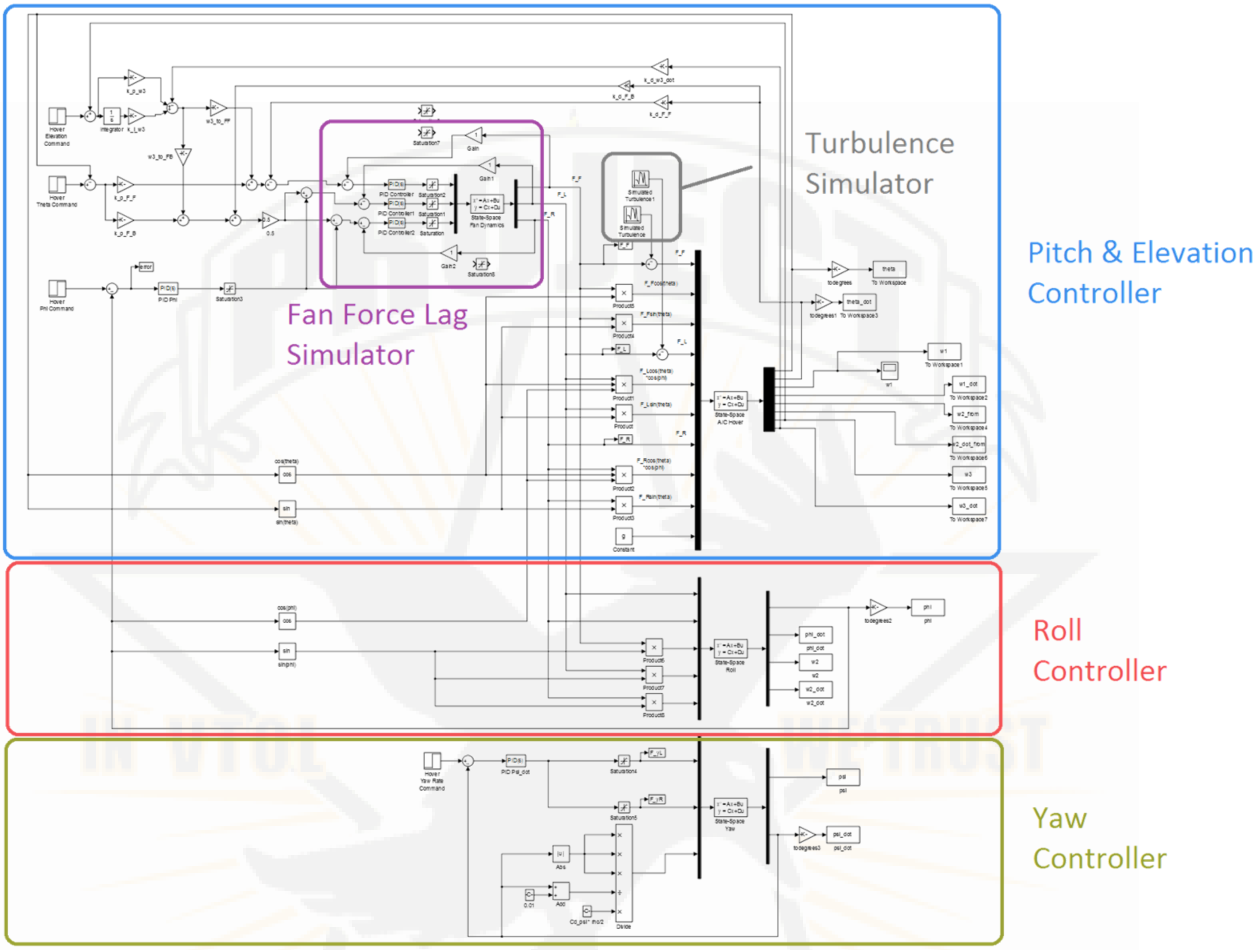
Fly-by-light:

- Replaces the conventional mechanical systems with electronic components
- Immune to electromagnetic interference
- Rapid data transfer results in a quicker response time for control inputs
- Computers perform tasks automatically to guarantee stability, according to predefined limits and control laws.
- Improves safety, reliablility, redundant control systems can easily be implemented

Power-by-wire

- Replaces hydraulic systems with electrical power circuits
- Saves weight
- Enhances safety, since it improves the integration of control systems and avionics

RAVEN Control System



Turbulence Simulator

Pitch & Elevation Controller

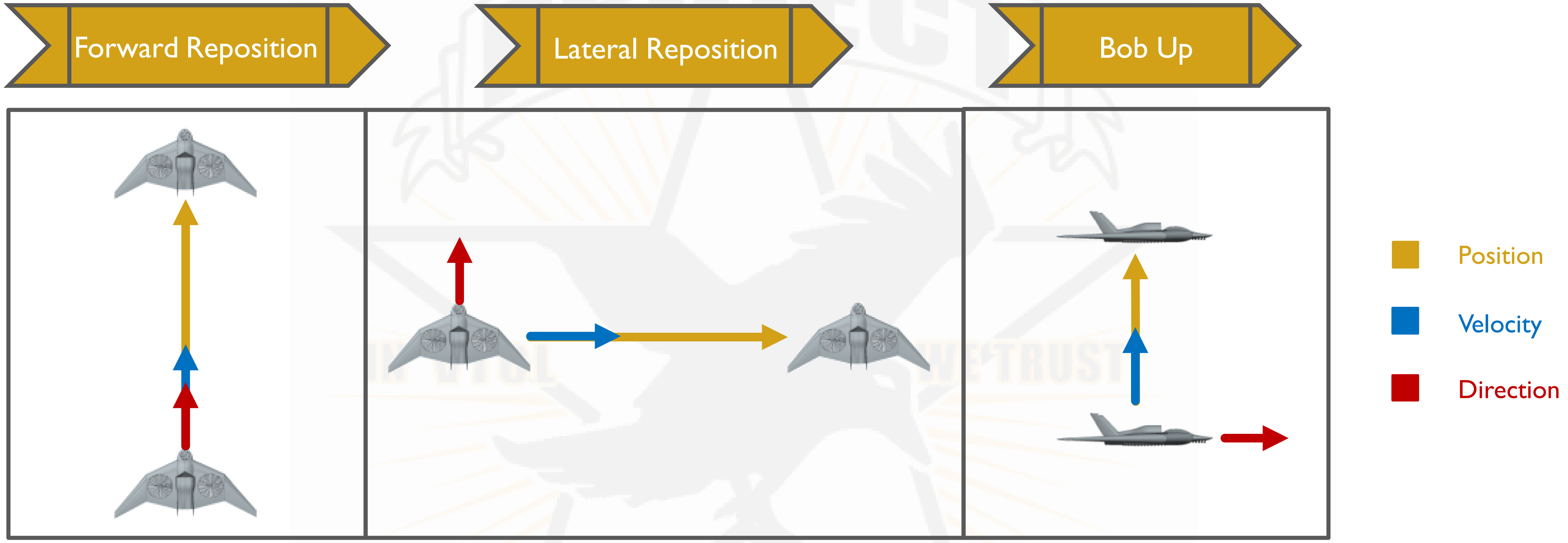
Fan Force Lag Simulator

Roll Controller

Yaw Controller

There is a small controller integrated into this block diagram that simulates the dynamics between the vectored thrust of the engine, applied torque on the lift fans, and the resulting lag in force delivered by the lift fans. The pitch, elevation, roll, and yaw feedback loops are coupled such that the power saturation of the engine is never exceeded.

Mission Task Elements



Forward Reposition

Lateral Reposition

Bob Up

🟨 Position

🟦 Velocity

🟥 Direction

Elevation Deviation: 0.538 meters

Pitch Command Rise Time: 0.840 s

Settling Time: 2.13 s

$q_{pk}/theta_{pk}$: 1.1646 s^{-1}

Elevation Deviation: 0.131 meters

Roll Command Rise Time: 0.548 s

Peak Roll Rate: 47.050 deg/s

Settling Time: 1.65 s

Max Heading Deviation: 0.201 deg

Rise Time: 2.54 s

Settling Time: 4.32 s

These hover maneuvers demonstrate the excellent controllability and maneuverability of Project Raven in its hover configuration. Whether supporting troops with agile combat maneuvers and precision strike capabilities or providing low altitude, low-observable surveillance in dangerous airspaces, Project Raven will remain stable and in control of the situation.

Cockpit Layout

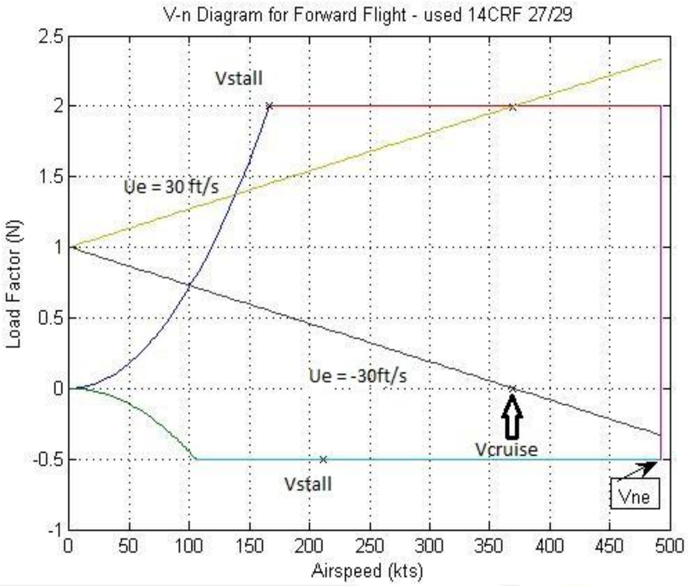
- Cockpit design based on that of the Joint Strike Fighter allows for modular display of critical information to the pilot.
- Displays easily adaptable from a ground-based control station to a cockpit in the nose of Project Raven
- Visual sensors mounted on the aircraft provide live video feeds to ground-based control station

- Hands on Throttle and Stick (HOTAS) control layout with addition of twist grip to throttle unit allows for cyclic and collective control in hover,. Traditional antitorque pedals provide yaw control.
- Controls systems, governed by flight computers, allow Project Raven to seamlessly transition to forward flight mode with the addition of forward thrust from turbofan engines.
- The HOTAS layout easily handles traditional pitch, roll, and yaw inputs in forward flight.

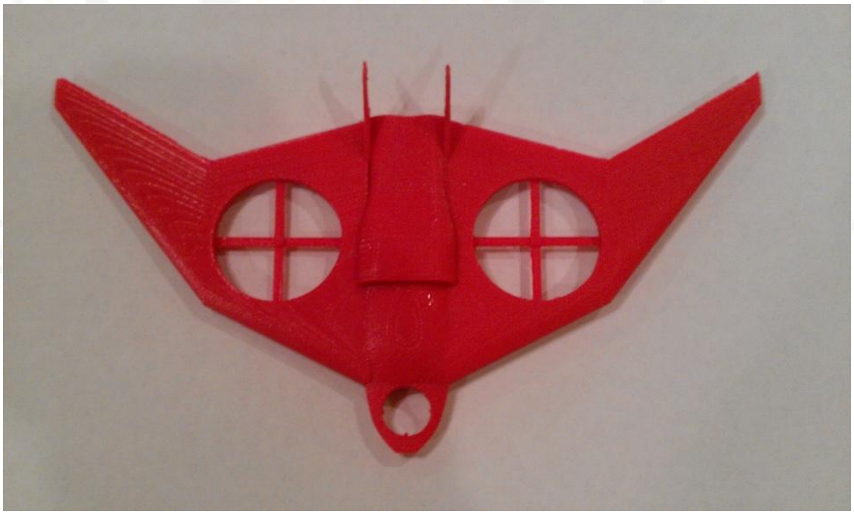
- Helmet mounted display provides vital information about the aircraft's orientation.
- Allows easy interaction with the aircraft's weapons and targeting systems.

Structural Analysis

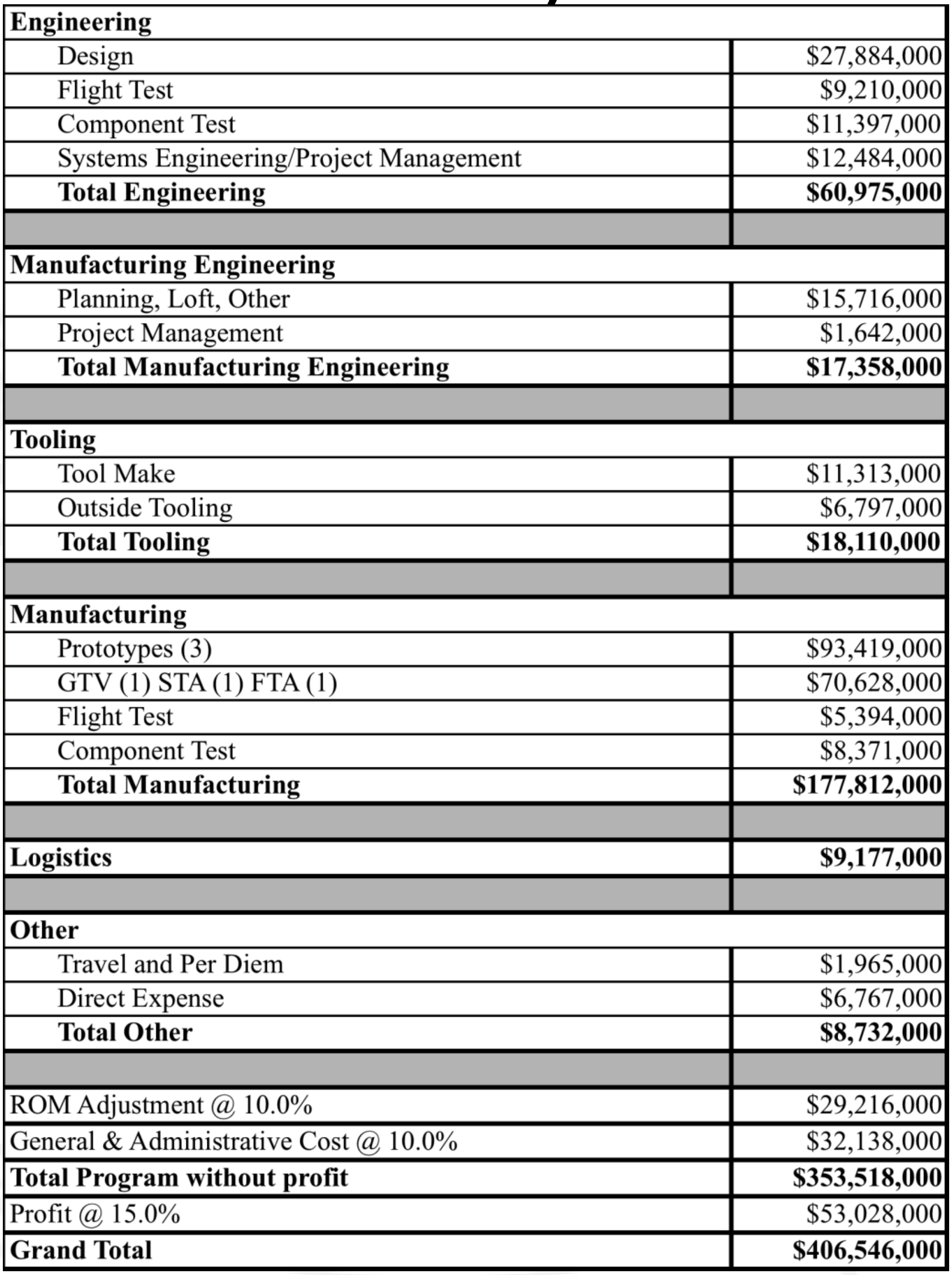
- The velocity-load (V-n) diagram, shown below for this aircraft was created using specifications from 14CFR Part 27/29.



- ANSYS 14.5 was used to determine the stress and strain on the aircraft for the particular materials chosen. A picture of a 3-D model can be seen to the below.



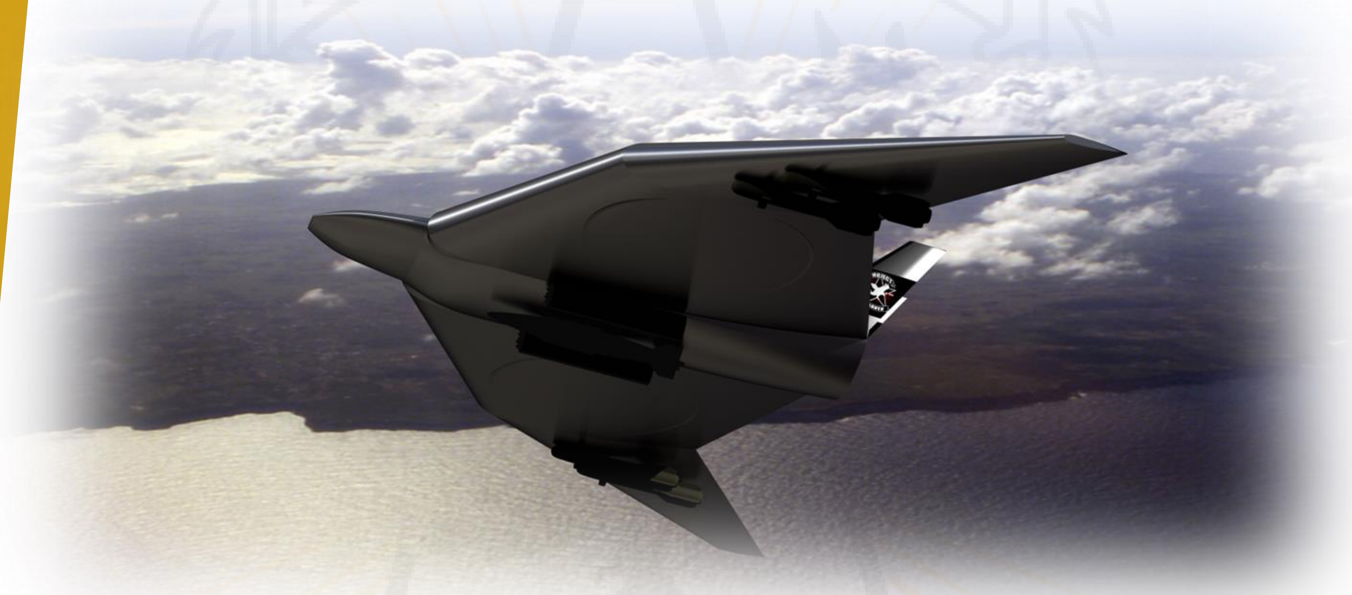
Cost Analysis



Engineering	
Design	$27,884,000
Flight Test	$9,210,000
Component Test	$11,397,000
Systems Engineering/Project Management	$12,484,000
Total Engineering	**$60,975,000**
Manufacturing Engineering	
Planning, Loft, Other	$15,716,000
Project Management	$1,642,000
Total Manufacturing Engineering	**$17,358,000**
Tooling	
Tool Make	$11,313,000
Outside Tooling	$6,797,000
Total Tooling	**$18,110,000**
Manufacturing	
Prototypes (3)	$93,419,000
GTV (1) STA (1) FTA (1)	$70,628,000
Flight Test	$5,394,000
Component Test	$8,371,000
Total Manufacturing	**$177,812,000**
Logistics	**$9,177,000**
Other	
Travel and Per Diem	$1,965,000
Direct Expense	$6,767,000
Total Other	**$8,732,000**
ROM Adjustment @ 10.0%	$29,216,000
General & Administrative Cost @ 10.0%	$32,138,000
Total Program without profit	**$353,518,000**
Profit @ 15.0%	$53,028,000
Grand Total	**$406,546,000**

The cost analysis for this aircraft was done using a Bell PC based model. Cost is for the development and manufacturing of a demonstrator aircraft.

The RAVEN stands ready to deploy, engage, and destroy the enemies of the United States of America in a Close Combat Attack role.



> *"Let every nation know, whether it wishes us well or ill, that we shall pay any price, bear any burden, meet any hardship, support any friend, oppose any foe, in order to assure the survival and the success of liberty."*
>
> \- John F. Kennedy, Inaugural Address, 20 January 1961