

# The Razor Rescue

## Executive Summary

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## **SMART – COPTER** Minimizing Energy Consumption

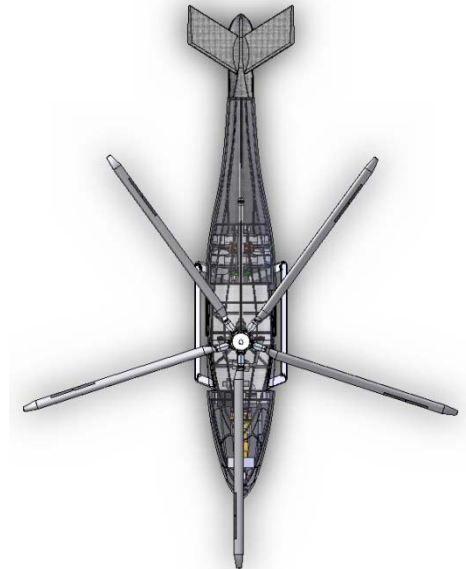
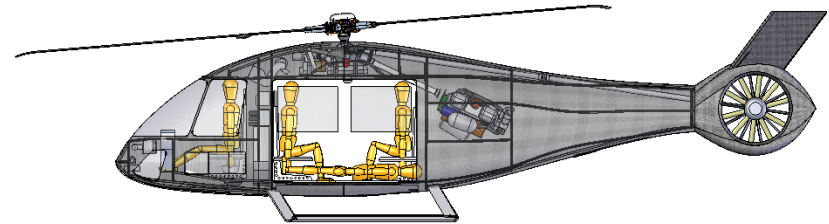
In response to the 2008 Annual AHS Student Design Competition -  
Undergraduate Category  
June 1, 2008



# RFP Requirements



- Mission Profile
  - Rescue and relief missions in disaster/congested environments
- Requirements
  - Size: 1 pilot + 4 passengers
  - Payload: 500 kg maximum
  - $V_{\max}$ : 120 kts
  - Range: 300 nm
  - **Design Mission: 1 hour flight at 120 kts**
  -
- Primary Design Objectives
  - Minimize environmental impact
    - Energy consumption (cradle – grave)
    - Pollution control
  - IOC 2020
  - 3 Variants: Military, Para-Military, Civil
  - Operation by non-professional pilots

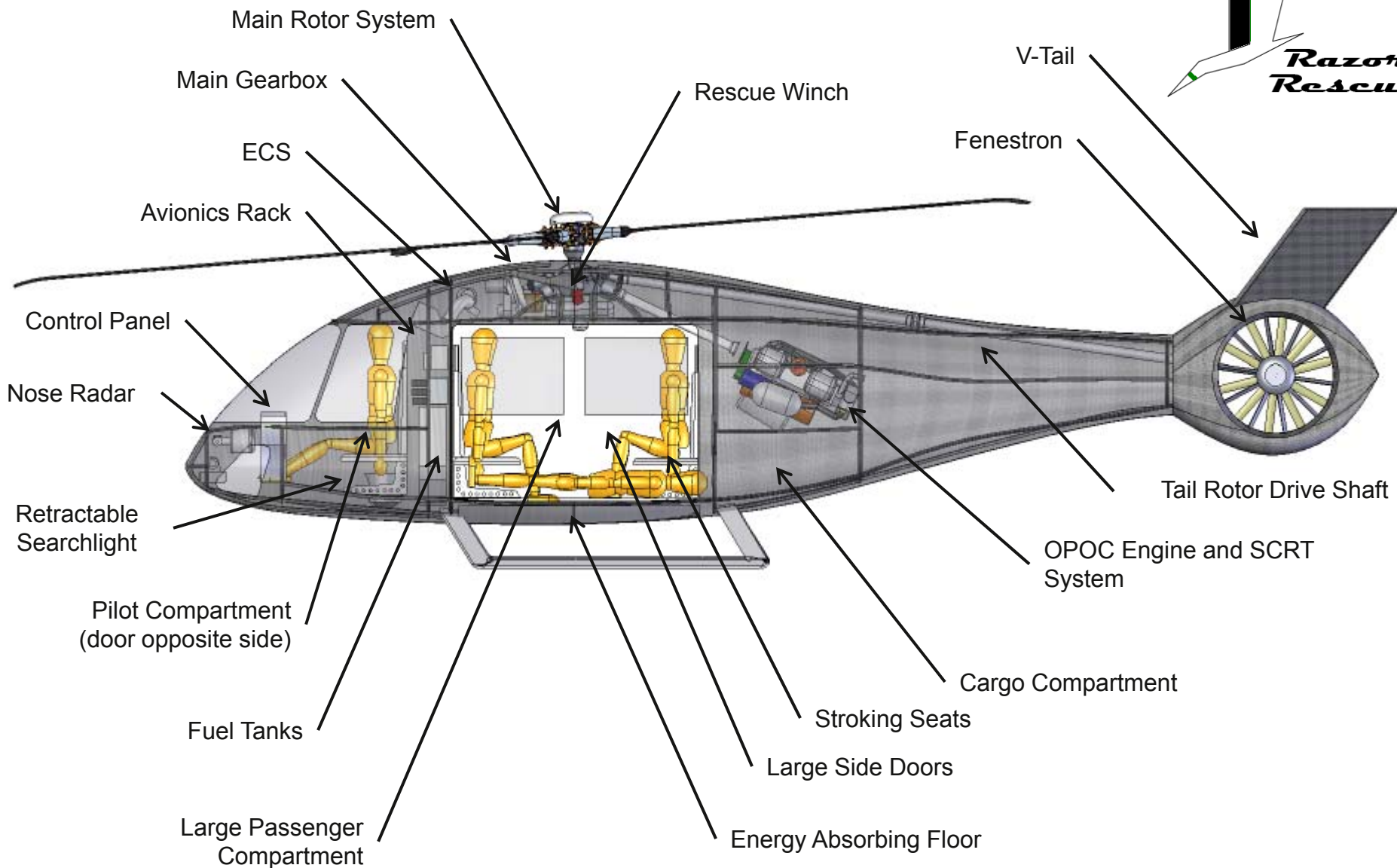


# Configuration Overview



Feature	Justification
A160 Inspired Fuselage	<ul style="list-style-type: none"><li>•Reduces total vehicle drag to minimize energy consumption</li><li>•Improved rotorcraft utility</li></ul>
OPOC Turbocompounded Diesel Engine	<ul style="list-style-type: none"><li>•Better SFC than turbines, increasing range and endurance.</li><li>•Wide RPM/HP range</li><li>•Large future advancements of proven technology</li></ul>
Servo Flap Rotor Control	<ul style="list-style-type: none"><li>•Weight/complexity savings over current swashplate standard</li><li>•Meets RFP directive of morphing rotor</li></ul>
Fenestron	<ul style="list-style-type: none"><li>•Better safety/performance than conventional tail rotor</li><li>•Improved weight over NOTAR</li></ul>

# Major Components



# Diesel Engine Design



## Weight Advantages

- 2 Stroke allows higher power density
- Two Pistons, One Cylinder = Less space
- Shared Crankshaft
- Total 25% less weight than standard diesel

## Original Specifications

- 365 HP @ 1800 RPM
- 325 lbs
- 0.38 SFC

## Turbocompounding

- Recovers energy of wasted exhaust
- Efficiency improvement with relatively minor weight penalty

## New Specifications

- 376.6 HP @ 2080 RPM
- 240 lbs
- 0.33 SFC

## OPOC Diesel Engine

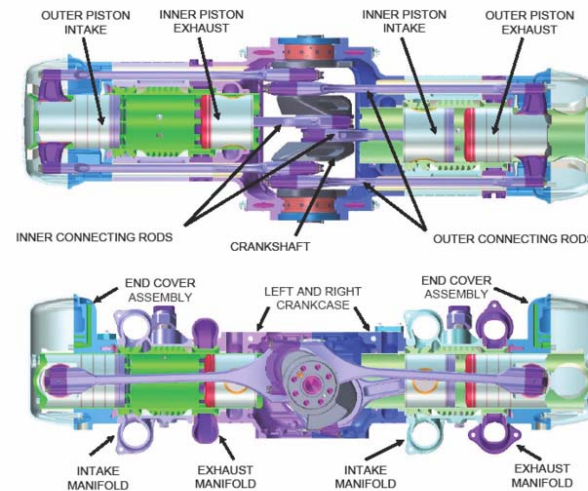
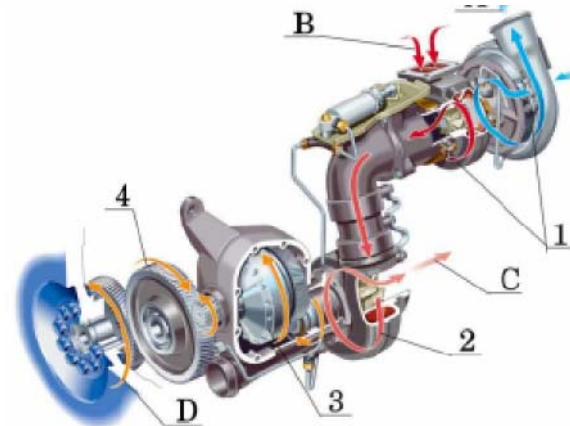


Figure 3: Principal Components of the opoc Engine Module



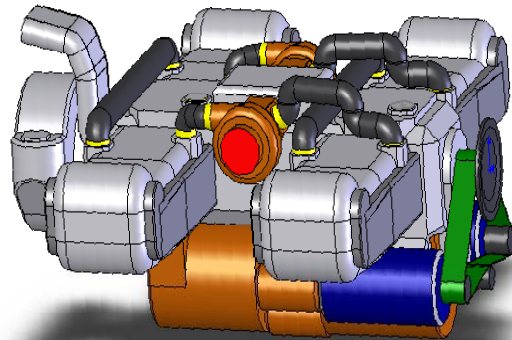
# EC-120 Propulsion Comparison



## Turbocompounded OPOC Diesel

- SFC  $\approx$  .33 lb/hp/hr
- Specific Power = 1.57 Hp/lb
- V Cruise = 120 knots
- R = 300 nm
- Fuel Tank = 44.41 gals

\* 10% reserves  
 $\approx$  48.86 gals



## Turbomeca Arrius 2F

- SFC  $\approx$  .543 lb/hp/hr
- Specific Power = 2.2 Hp/lb
- V Cruise = 122 knots
- Range = 393 nm
- Fuel Tank = 96.52 gals

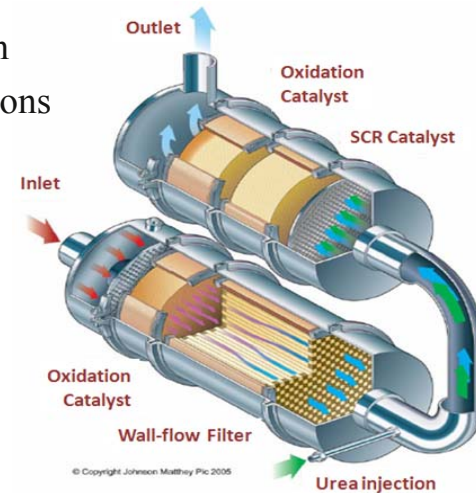


# Local Pollution

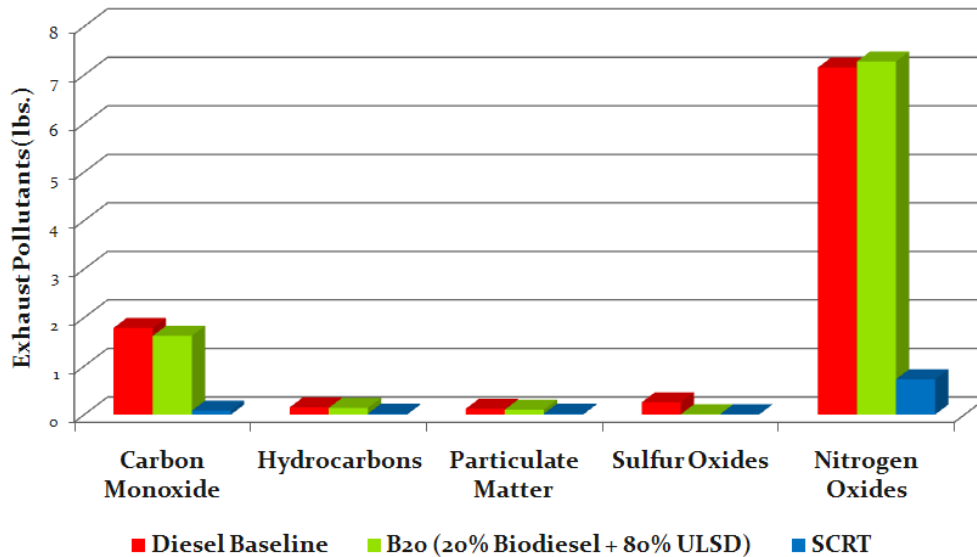


## SCRT

- Catalysts filters NO<sub>x</sub>, HC, CO, & PM through means of oxidation
- Popular in Large Diesel Engines due to stricter emissions regulations
- Even Improves Fuel Consumption

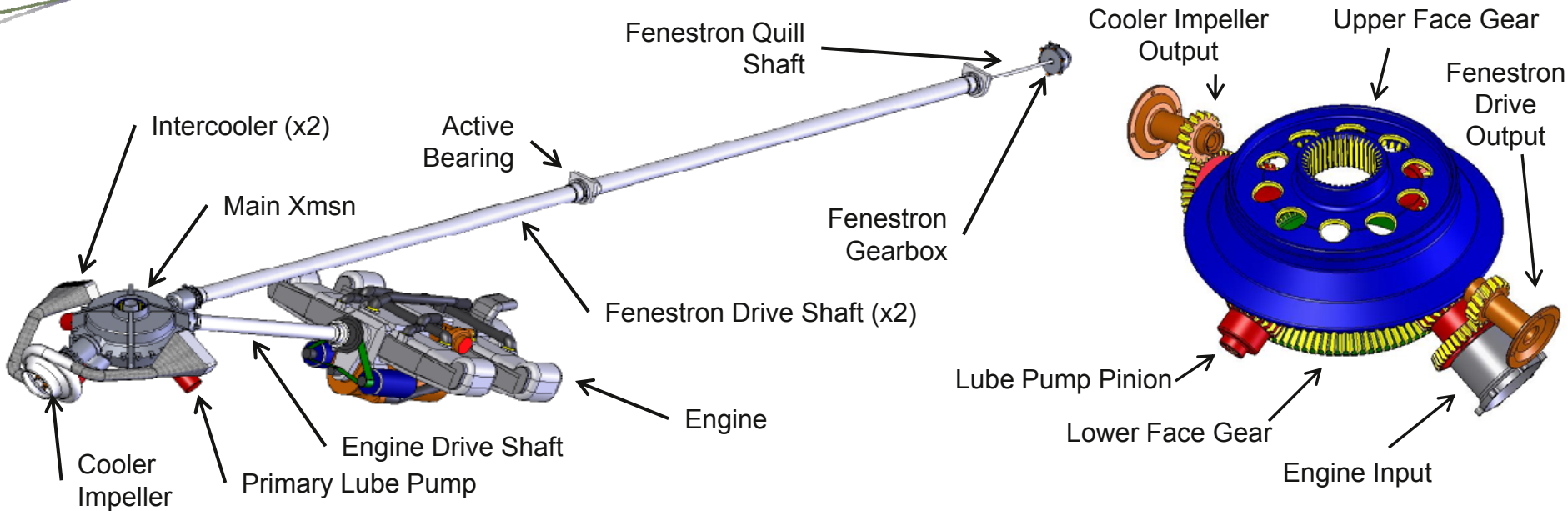


Local Pollution for RFP Mission (300nm)



Emission	Overall Percent Reduction
Carbon Monoxide	95.46%
Hydrocarbons	86.10%
Particulate Matter	82.72%
Sulfur Oxides	97.53%
Nitrogen Oxides	89.82%

# Drive System Design



- Face Gear Main Transmission

- ~50-50 torque split
- ~7000 hour life

- Integrated Cooling System

- Redundant Lube Pumps, Scavenge Pump
- Dual Intercoolers

- Spiral Bevel Fenestron Gearbox

- Composite Housings

- Shafting

- Supercritical flexible matrix drive shafts
- Active magnetic bearings

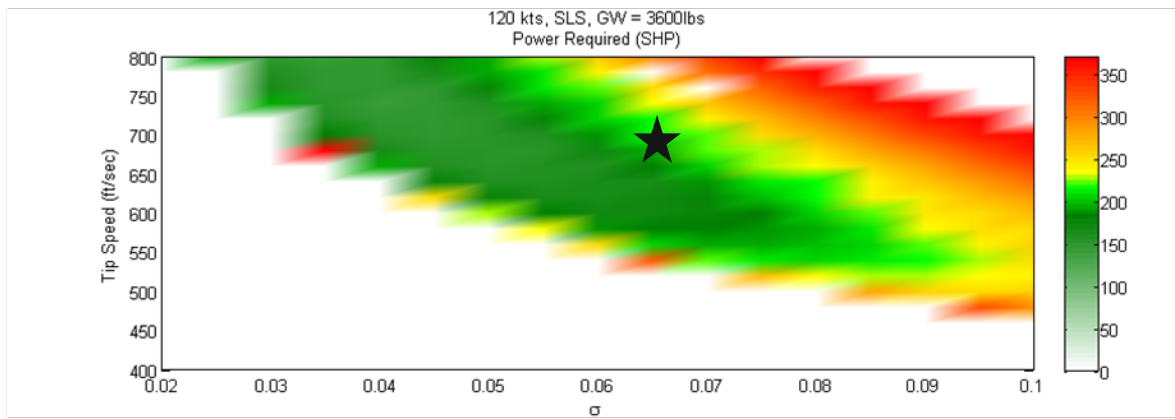
- Maintenance

- Reduction in operation and support costs due to high reliability
- Hunting Ratios and Isotropic Superfinishing: Increases MTBO
- Auxiliaries are mounted one component deep

# Rotor Design

- Variable Speed Rotor
  - High Efficiency in hover & 120 kts
  - Low tip speeds reduce noise
- Advanced Tip Design
  - Noise and loads reduction
- Control
  - Trailing Edge Flaps for Individual Blade Control (IBC)
    - Piezoelectric Buckling Beam Actuators
  - Variable Blade Indexing (VBI) for increased efficiency

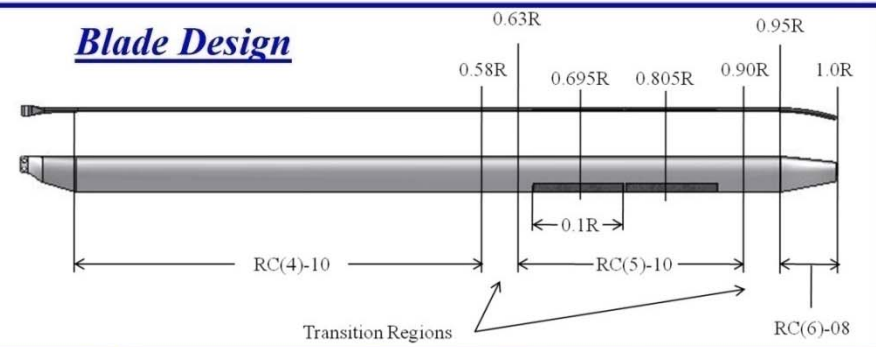
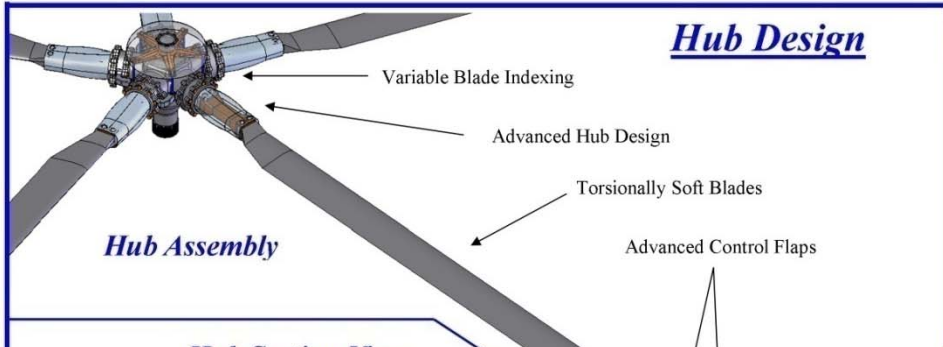
	Units	EC-120	Razor Rescue
R	ft	16.45	13.5
$\sigma$	-	0.0465	0.068
Twist	deg	-12	Variable
Vtip Hover	ft/sec	670.4	600
Hover FM	-	0.73	0.79
$(C_T/\sigma)_{\text{hover}}$	-	0.109	0.104
Hover Pwr Req'd	SHP	350.2	307.8
Vtip 120 kts	ft/sec	713.4	700
$(C_T/\sigma)_{120 \text{ kts}}$	-	0.0747	0.083
Pwr Req'd 120 kts	SHP	317.62	287.2



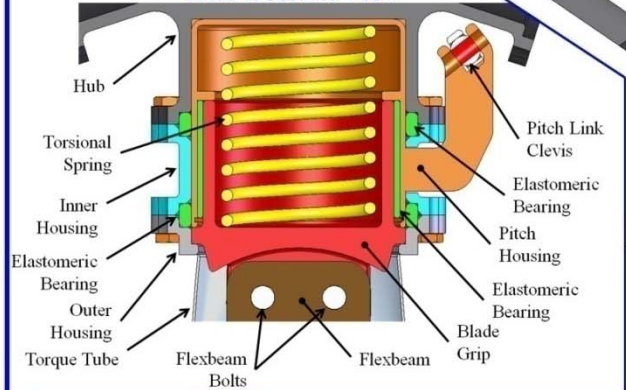
# Rotor Design

## Hub Design

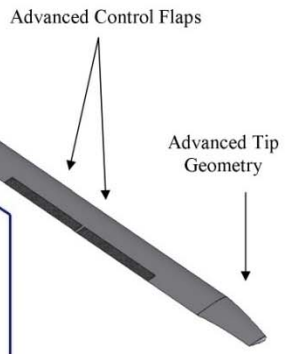
## Blade Design



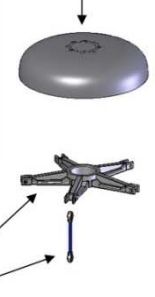
## Hub Section View



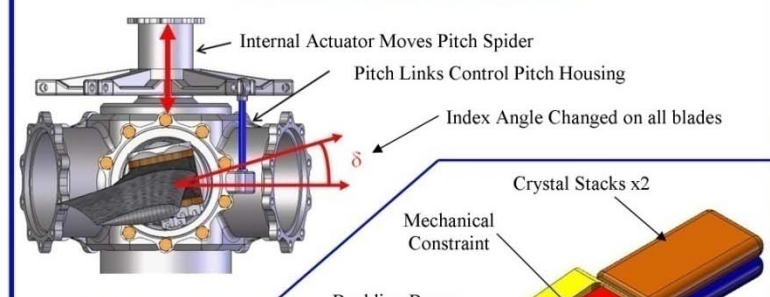
## Advanced Tip Geometry



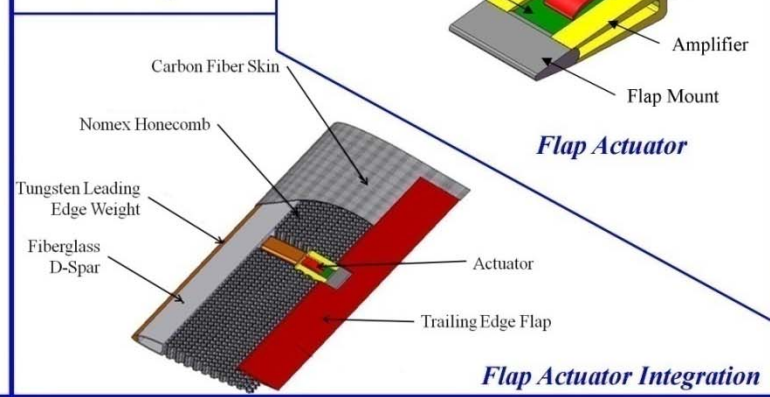
## Beanie Fairing



## Controls Integration



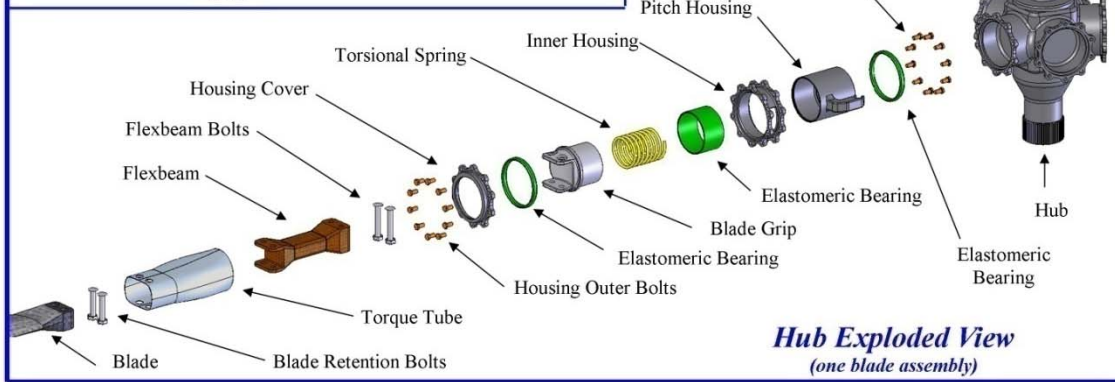
## VBI Integration



## Flap Actuator

## Flap Actuator Integration

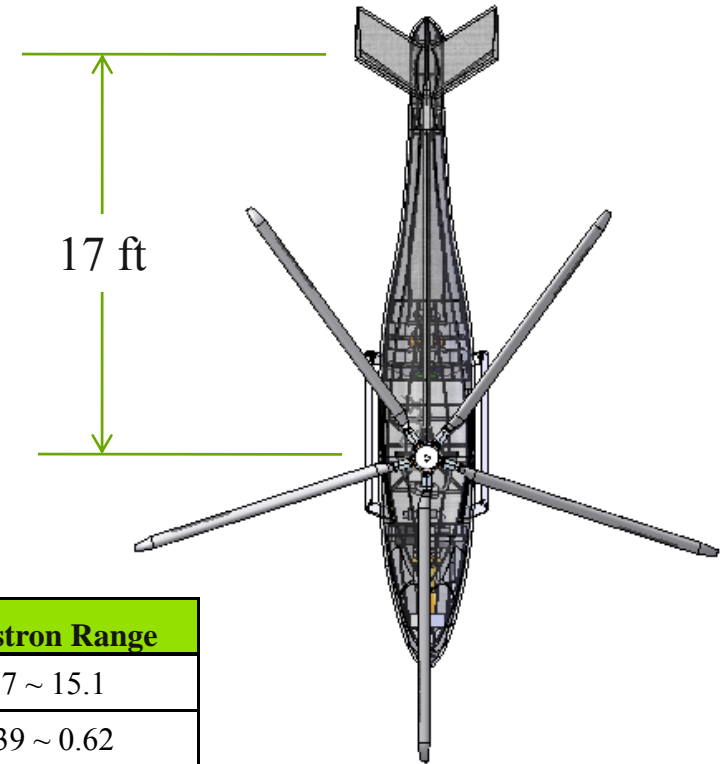
## Hub Exploded View (one blade assembly)



# Fenestron Design



- Anti-Torque needed: 3700 ft lbs
  - Includes main rotor torque and control forces
- Moment arm = 17ft
  - Allows for less power required for the fan
- Tip speed = 590ft/s for hover
  - 768ft/s in forward flight

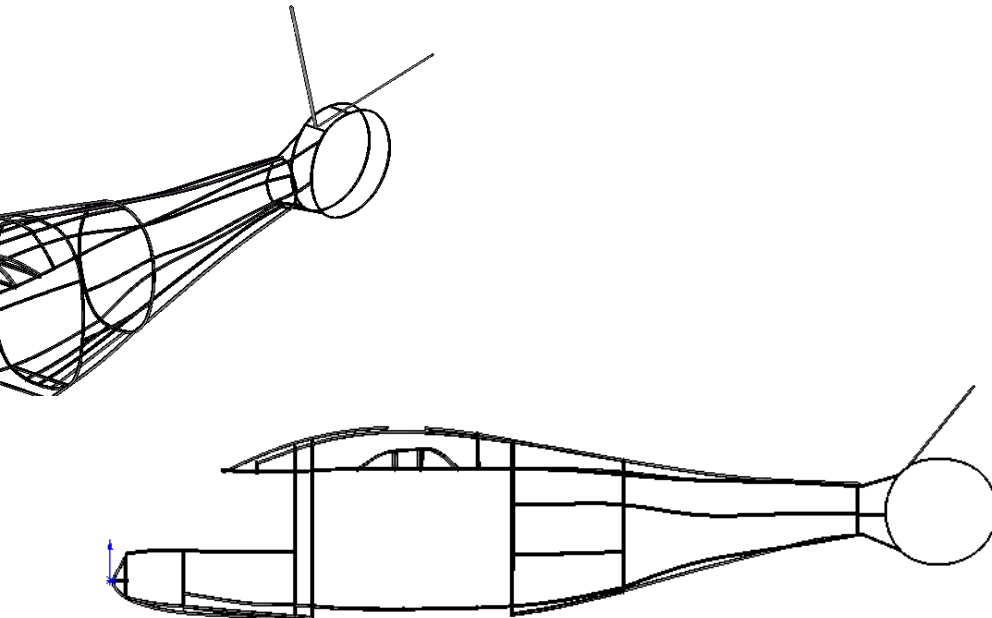
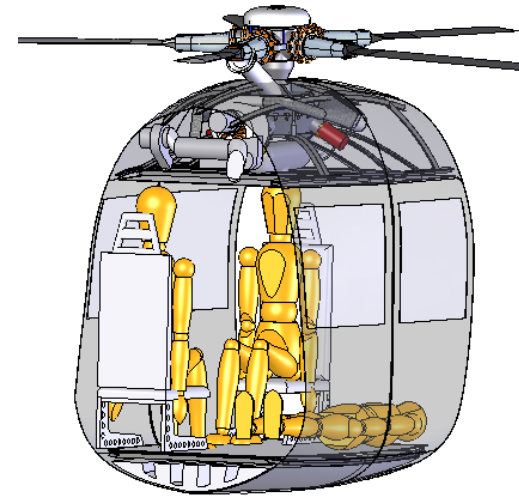


Parameter	Razor Rescue	EC-120	Fenestron Range
$D_{MR} / D_{TR}$	9.6	13.3	8.7 ~ 15.1
$\sigma_{TR}$	0.43	0.39	0.39 ~ 0.62
$V_{tip TR}$ (ft/s)	590	591	564 ~ 725
$c$ (ft)	0.186	0.197	0.131 ~ 0.394
$N_b$	10	8	8 ~ 13

# Structural Layout



- 4 Passengers in the Cargo Area and 1 Pilot
  - Minimizes flow separation around aft fuselage
  - Maximizes usable internal space
  - Allows for multiple configurations for different circumstances



- Five primary Bulkheads support most of the weight of the helicopter
- A transmission deck is utilized to support the lift and torque generated by the rotor
- Eight Longitudinal stringers give necessary support for the anti-torque

# Passenger Comfort



## 1. Seats

- Martin Baker Passenger Seat

## 2. Internal Noise

- Passive (Work best at middle and high frequencies) : Sound proofing cabin interior
- Active (Work best at low frequencies) : Sound Cancellation Speakers

## 3. Vibration

- Active Damping Device : Introduces structural damping into any vibration mode that can be observed by the sensor.

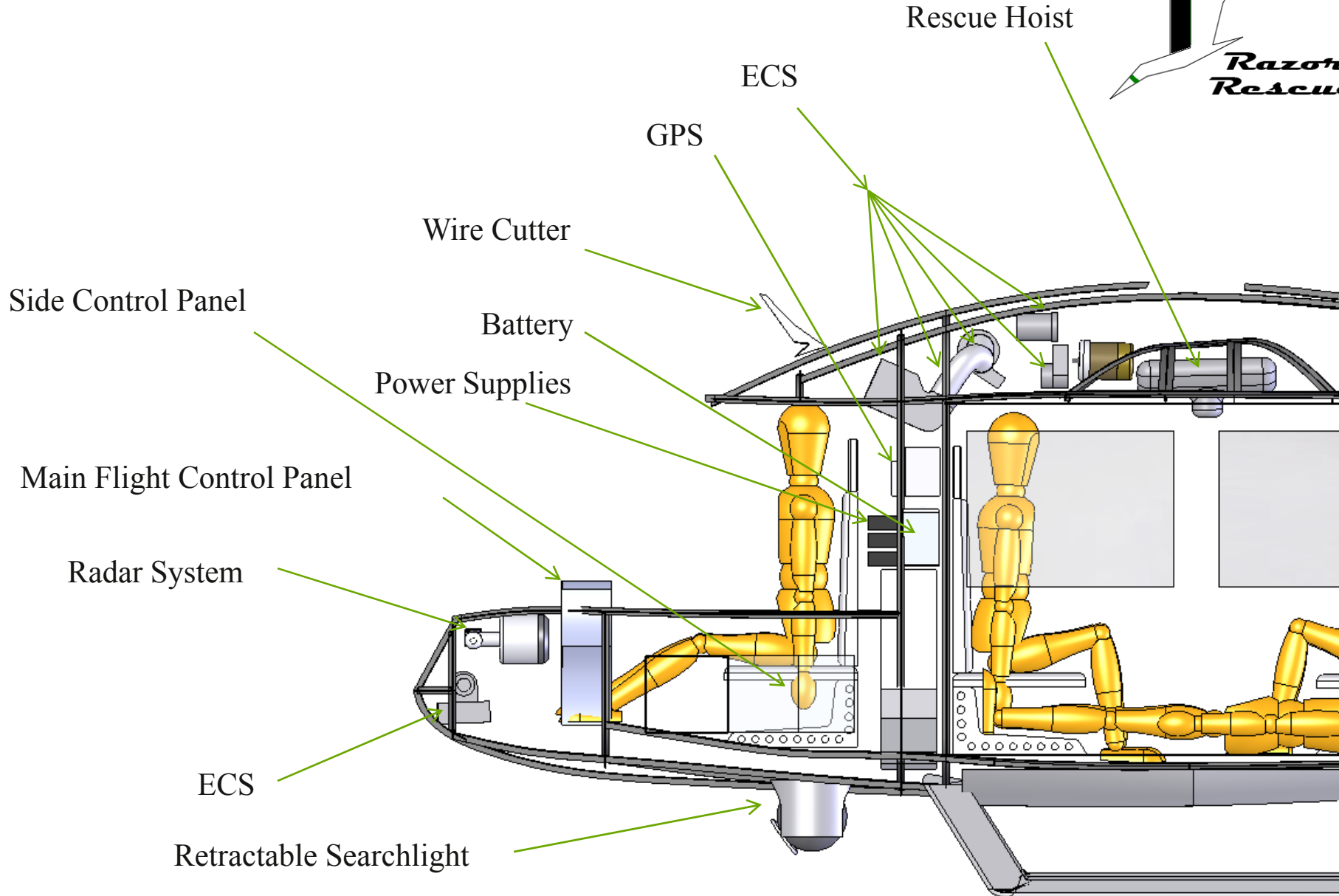
## 4. Sun Protection

- LC Smart Glass : Glass which changes light transmission properties when voltage is applied

## 5. ECS

- System based on Keith Products Bell 206 Model

# Avionics/Sub-System Placement

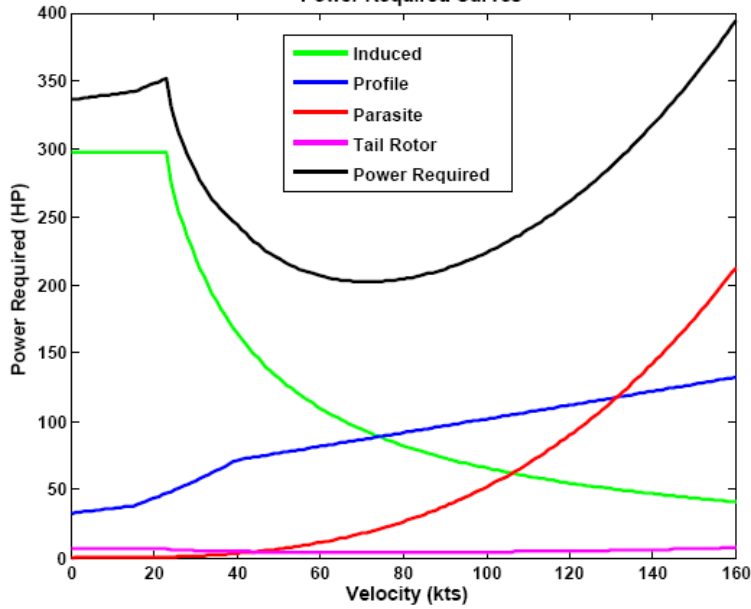


# Performance

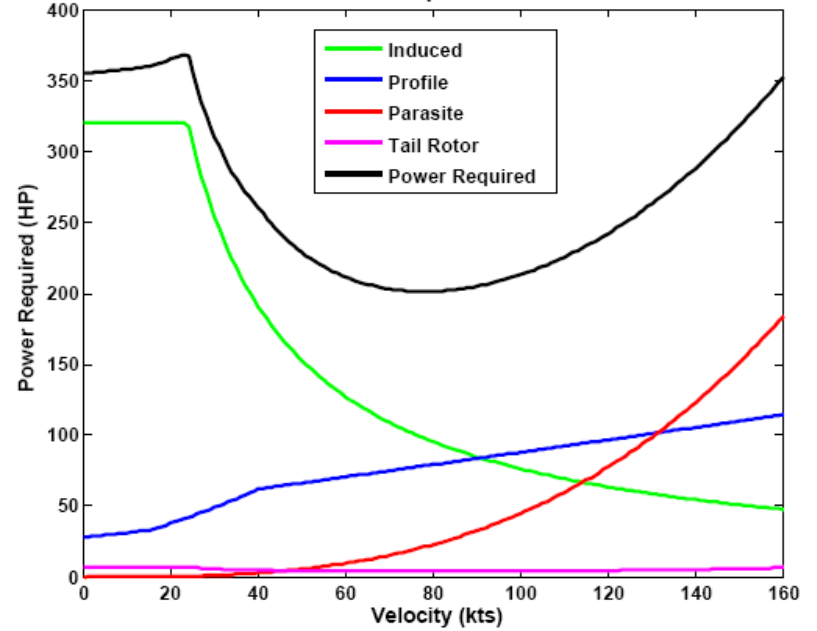
SSL

1500m

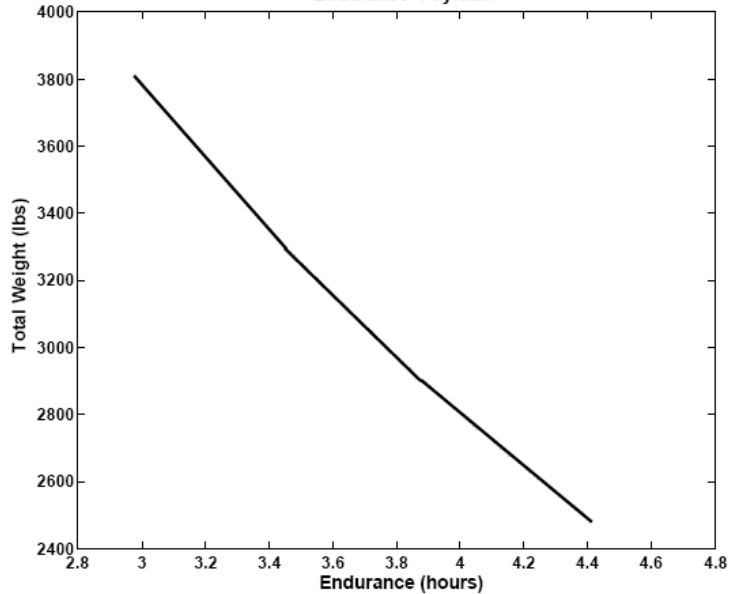
Power Required Curves



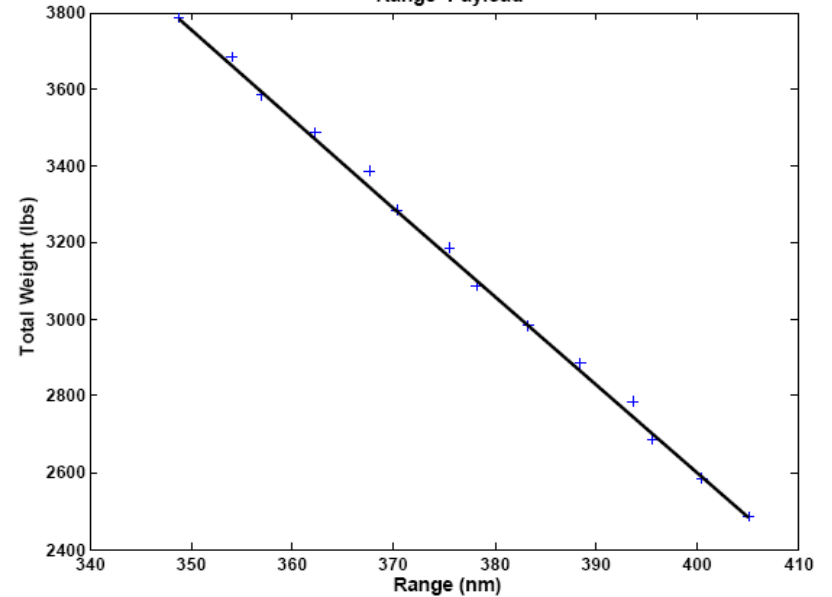
Power Required Curves



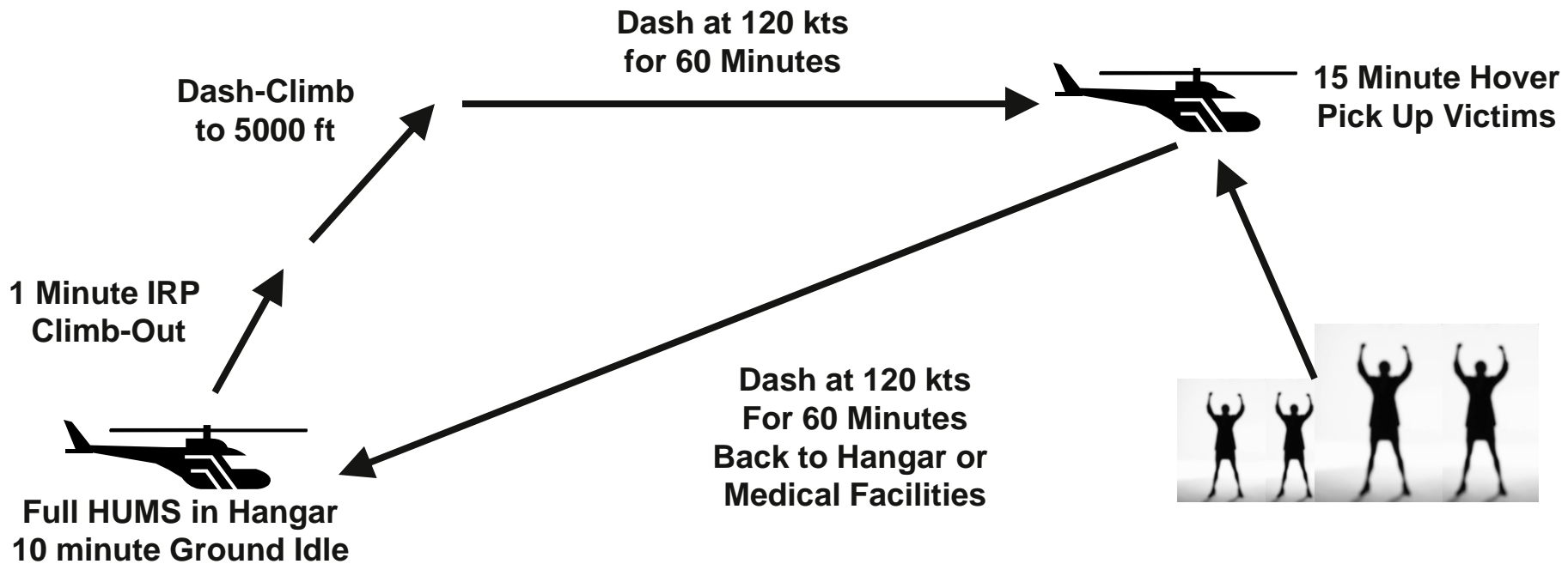
Endurance-Payload



Range-Payload



# Example Mission Paramilitary: Disaster Relief



# Disaster Relief Comparison



No passengers at take-off, max payload at landing

Razor Rescue

<b>Ground Idle</b>	<b>10 minutes</b>
<b>IRP Takeoff</b>	<b>1 minute</b>
<b>Dash-Climb (~ 5000 ft)</b>	<b>5.2 minutes</b>
<b>Dash (120 kts)</b>	<b>60 minutes</b>
<b>Hover</b>	<b>15 minutes</b>
<b>Dash (120 kts)</b>	<b>60 minutes</b>
<b>Total Mission Time</b>	<b>151 minutes (~ 2.5 hrs)</b>
<b>Total Fuel Required</b>	<b>239.6 lbs (~ 35 gallons)</b>

EC 120

<b>Ground Idle</b>	<b>10 minutes</b>
<b>IRP Takeoff</b>	<b>1 minute</b>
<b>Dash-Climb (~ 5000 ft)</b>	<b>14.2 minutes</b>
<b>Dash (120 kts)</b>	<b>60 minutes</b>
<b>Hover</b>	<b>15 minutes</b>
<b>Dash (120 kts)</b>	<b>60 minutes</b>
<b>Total Mission Time</b>	<b>160 minutes (~ 2.6 hrs)</b>
<b>Total Fuel Required</b>	<b>450 lbs (~ 70 gallons)</b>

## Weight Breakdown

Component	Weight (lbs)
Main Rotor Blades	165.00
Main Rotor Hub and Hinge	100.00
Tail Rotor	60.00
Body (Fuselage / Empenage)	357.00
Landing Gear	60.00
Engine Installation	240.00
Propulsion Subsystem	35.01
Drive System	174.16
Cockpit Controls	7.85
System Controls (non-boosted)	4.67
Urea Tank	80.00
Instruments / Avionics	90.64
SCRT Tanks	20.00
Electrical / Lighting	150.25
Furnishings and Equipment	568.00
Manufacturing Variation	15.22
<b>WE</b>	<b>2127.80</b>
Pilot	220.00
Passengers/Payload	1100.00
Fuel	250.00
Contingency	106.39
<b>GW ESTIMATION</b>	<b>3804.19</b>

## Cost Breakdown

Component	2006 USD
Main Rotor	\$521,000
Final Assembly	\$110,000
Furnishing / Equip	\$81,200
Tail Rotor	\$79,800
Engine	\$68,500
Instruments	\$65,500
Drive System	\$56,700
Airframe	\$44,000
Electronics	\$31,500
Avionics	\$22,200
Propulsion Subsystems	\$15,100
Landing Gear	\$12,700
Flight Controls	\$3,660
Air Induction	\$1,660
Air Conditioning	\$138
<b>Total Cost</b>	<b>\$1,110,000</b>
<b>+ 35% Profit</b>	<b>\$1,500,000</b>



# Overall Energy Consumption



## Carbon Composite

- 30 to 40% weight savings versus aluminum
- Fatigue life is practically infinite versus metals
- 70% of Carbon Composite will have ability to be reused

## Makrolon Plastic

- High caloric value making it a source of energy if incinerated
- As long clean, Makrolon can be melted and reused

## Biodiesel (B20)

- Total fossil energy efficiency of biodiesel is 4 times greater than petroleum diesel

## Liquid Hydrogen Option

- Large amount of energy required for process of electrolysis to create liquid hydrogen
- Optimally to be produced by natural power such as wind turbine farms

# Conclusions



- Razor Rescue Meets all RPF Performance Requirements
  - Performance exceeds EC-120
  - Capable of military, paramilitary and civilian missions
- Design Attributes
  - Environmentally Friendly: low operational energy consumption, high recyclability
  - Usability: large, reconfigurable cabin improves disaster relief performance
  - Pilotability: advanced avionics systems aid non-professional pilot
  - Quiet: low rotor tip speeds and fenestron minimizes acoustic impact on population
  - Safe: advanced avionics systems and rotor systems improve flight safety
  - Low Maintenance: HUMS system and reliable propulsion systems reduce maintenance requirements