



**36<sup>th</sup> Annual VFS Student Design Competition**

# **Extreme Altitude Mountain Rescue Vehicle**

*Sponsored by Airbus Helicopters*



*Alfred Gessow Rotorcraft Center  
Department of Aerospace Engineering  
University of Maryland  
College Park, MD 20742 U.S.A.*



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The students listed above will receive credit for the course ENAE634: Helicopter Design.



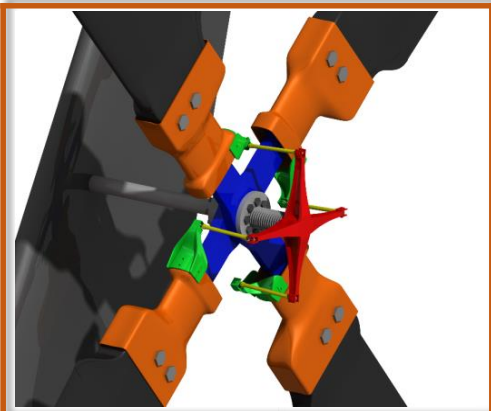
**Alfred Gessow Rotorcraft Center**  
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To Vertical Flight Society:

The members of the University of Maryland Graduate Student Design Team hereby grant VFS full permission to distribute the enclosed Executive Summary and Final Proposal for the 36<sup>th</sup> Annual Design Competition as they see fit.

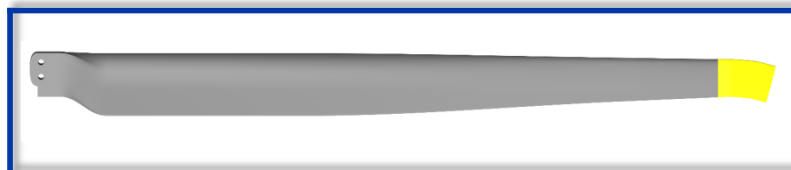
The UMD Graduate Design Team

# Caladrius: Designed for Extreme Altitude Mountain Rescue



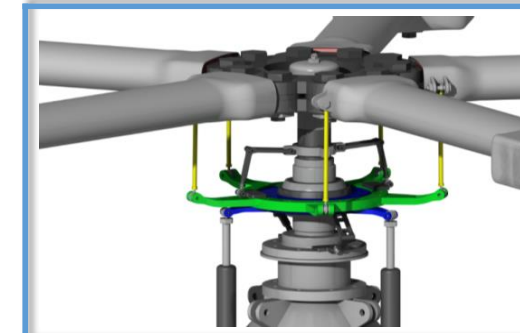
## Tail Rotor

Large tail rotor designed for low power consumption and high wind speeds from any azimuth at extreme altitude



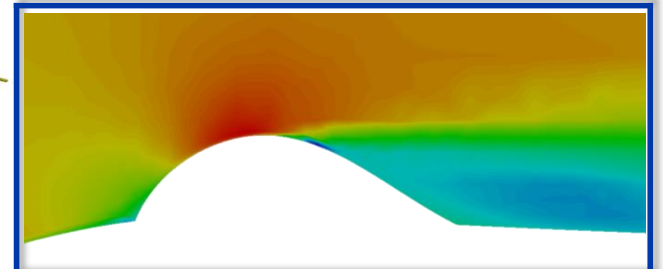
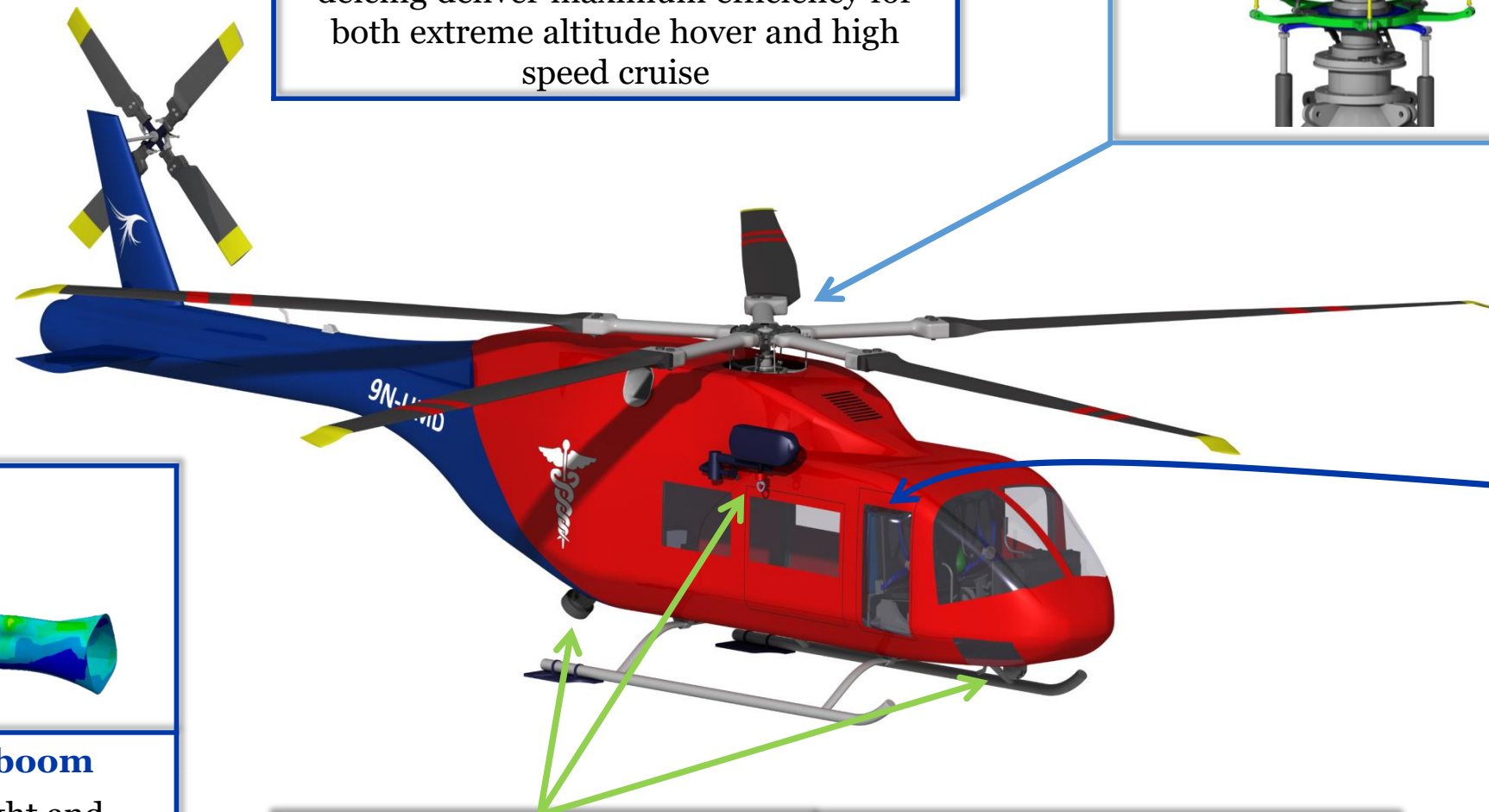
## Efficient Blades

Aerodynamically optimized blades with deicing deliver maximum efficiency for both extreme altitude hover and high speed cruise



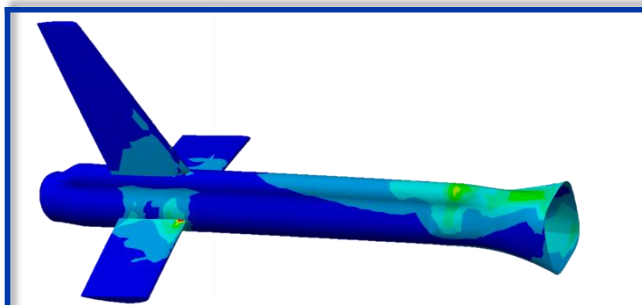
## Bearingless Hub

Low drag bearingless hub with a flap frequency of 1.06/rev provides agility during mountain rescue



## Wide Field of View

Wide, bird strike resistant front windshield, bubble side window, and floor windows designed for maximum pilot field of view



## Monocoque Tailboom

Sized to reduce weight and withstand extreme conditions

## Search and Rescue Equipment

Equipment selected for effective operation for harsh weather conditions at Mount Everest



<b>GTOW</b>	3500 kg
<b>Rotor Radius</b>	6.88 m
<b>Installed Power</b>	2894 kW
<b>Disk Loading</b>	24 kg/m <sup>2</sup>

# Caladrius: A Pilot's Helicopter



Only one bird has conquered the iconic Mount Everest: the Himalayan bar-headed goose. It is no ordinary bird, as *Caladrius*, designed by the University of Maryland Graduate Design Team, is no ordinary helicopter. Like the bar-headed goose that has special hemoglobin to withstand hypoxia far beyond any human athlete, *Caladrius* has specially designed rotors, a capable flight control system, and powerful engines for extreme altitudes. The goose only has to cross the mountains, but *Caladrius* must battle the winds and the snow to pluck the bold and the brave from the jaws of

inevitable death. It must also be swift, for every minute is precious for those fighting against the unforgiving elements on the Mount Everest.



*Caladrius*, named after a snow-white bird from Roman mythology with healing abilities, is a single main rotor helicopter designed for mountain rescue missions at unprecedented altitudes that no other rotorcraft can perform. *Caladrius* is not only a highly capable mountain rescue helicopter, it can also perform several other missions.

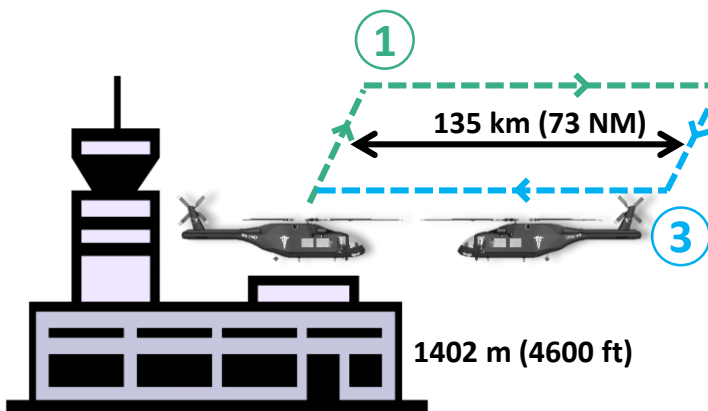
The design team interviewed a number of highly experienced pilots including Didier Delsalle from Airbus Helicopters, the only pilot to have ever landed a helicopter on the summit of Mount Everest, and Samuel Summermatter from Air Zermatt. The insights and sage recommendations provided by them helped focus the engineering efforts on designing a true “**Pilot's Helicopter**”. **Concept of operations, rotor hub and flight control system designs, avionics suite and search & rescue equipment selection, tail rotor, front windshield, side bubble window, and floor window designs** were all influenced by the valuable inputs obtained from these pilots. **High safety** and **low pilot workload** emerged as the main design objectives.

# Extreme Altitude Rescue Mission Profile



## Leg 1

- Take-off from 1402 m (4600 ft) with 3 crew + 150 kg EMS equipment
- Climb to 3780 m (12400 ft)
- Level cruise for 135 km (73 NM)
- Land, refuel



8870 m (29100 ft)

2

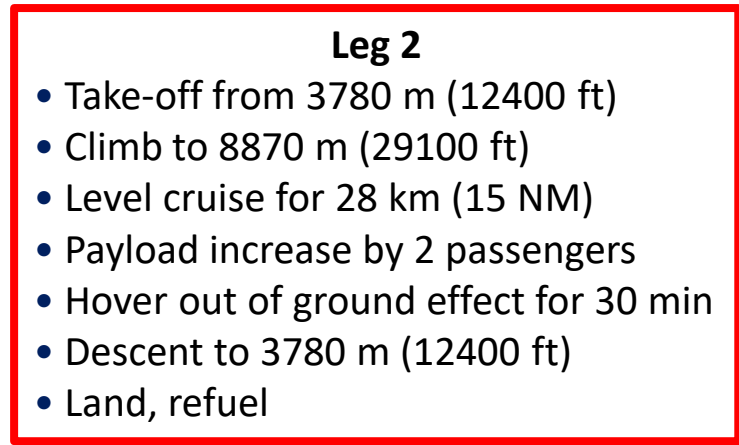
3780 m (12400 ft)

## Leg 2

- Take-off from 3780 m (12400 ft)
- Climb to 8870 m (29100 ft)
- Level cruise for 28 km (15 NM)
- Payload increase by 2 passengers
- Hover out of ground effect for 30 min
- Descent to 3780 m (12400 ft)
- Land, refuel

## Leg 3

- Take-off from 3780 m (12400 ft)
- Descent to 1402 m (4600 ft)
- Level cruise for 135 km (73 NM)
- Land



	RFP Requirement	Caladrius Mission Capability
Mission Time	3 hrs	<b>2 hrs 55 min</b>
Max. Wind to Maintain Hover Heading at 8870 m (29100 ft)	40 knots	<b>44 knots</b>
Single Pilot Day/Night IFR Capability	-	✓

# Concept of Operations Driven by the Pilots



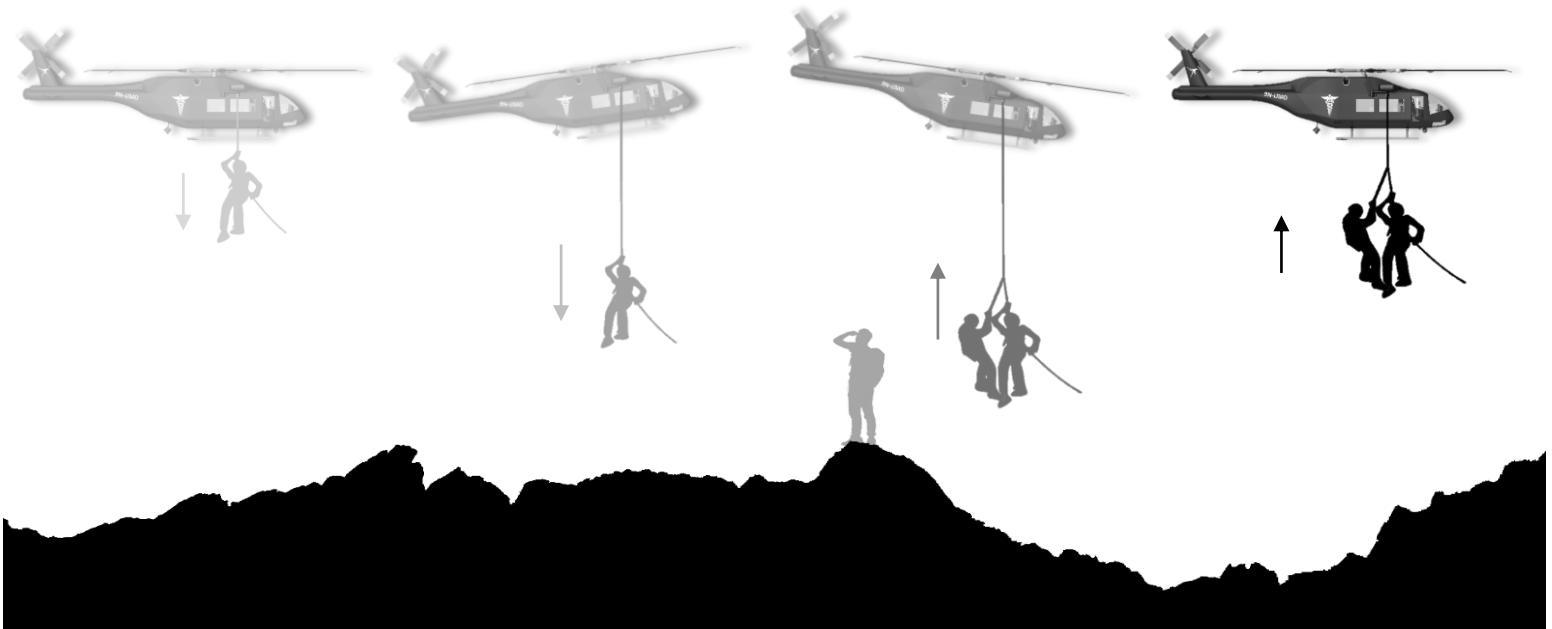
Understanding the details of rescue operations such as the crew composition and different hoisting methods was an important feature of *Caladrius's* design. Having interviewed,

- Baltimore County Police Aviation Unit
- Maryland State Police Aviation Command
- John Tritschler (Director of Research at U.S. Naval Test Pilot School)
- Christian Polyka (USCG Pilot)
- Samuel Summermatter (Search and Rescue Pilot at Air Zermatt, Switzerland)
- Didier Delsalle (Experimental Test Pilot at Airbus Helicopters, Marignane, France)

the requirements for this mission were fully analyzed and insights and recommendations provided by these experienced sources were applied to the design. *Caladrius's* crew composition is:

- Pilot
- Co-Pilot/Hoist Operator (Crew Chief)
- EMS Specialist

For safety on the ground and stability of the slung load, dynamic hoist operation (illustrated below) will be performed.



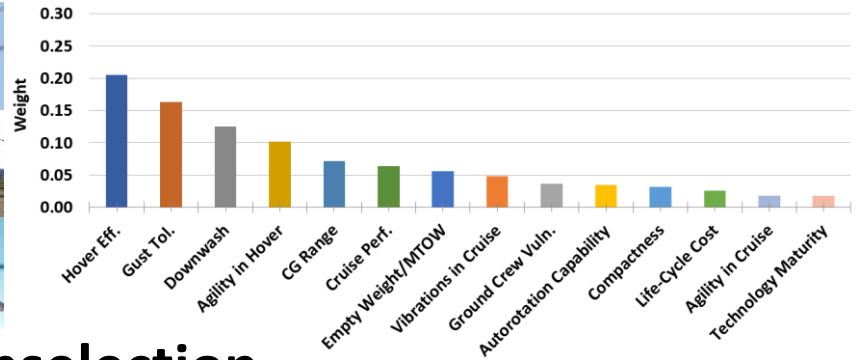
# Vehicle Configuration



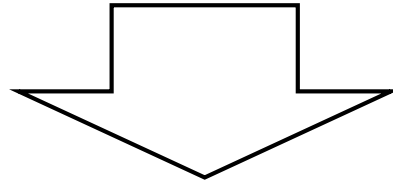
## Configuration Space



## Design Drivers



## Downselection



### Side by Side



### Single Main Rotor



### Tandem



## Further Down Selection



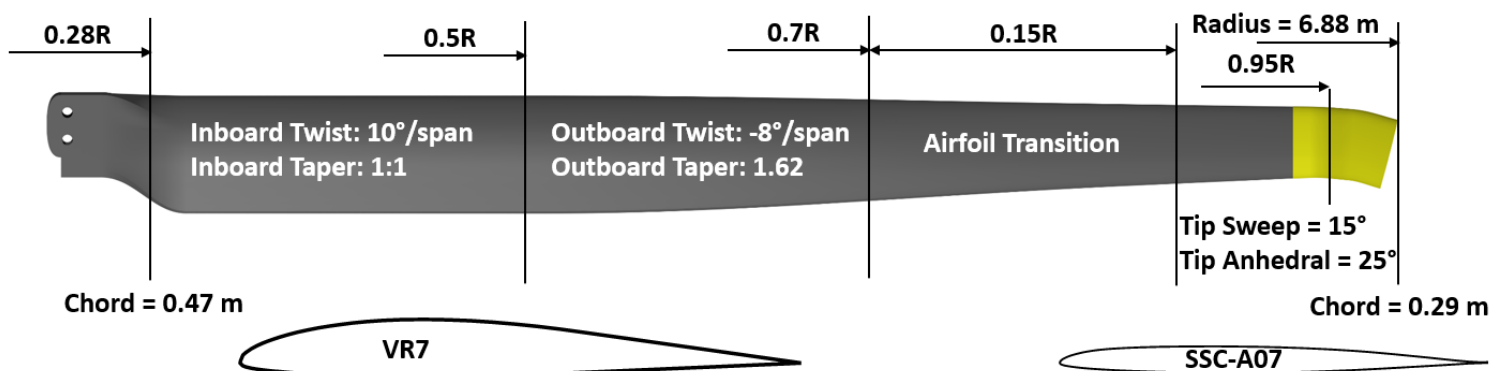
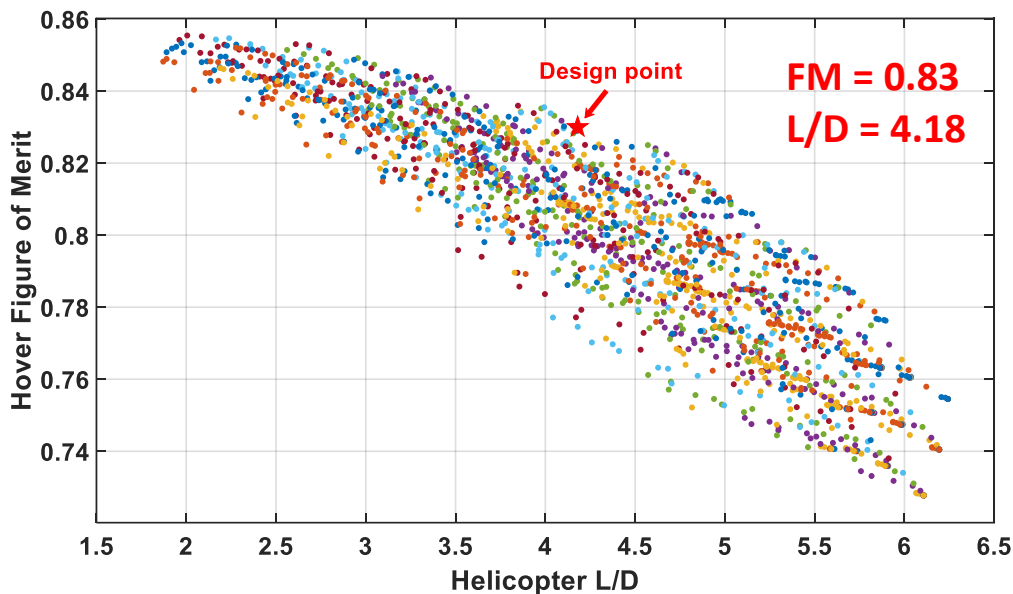
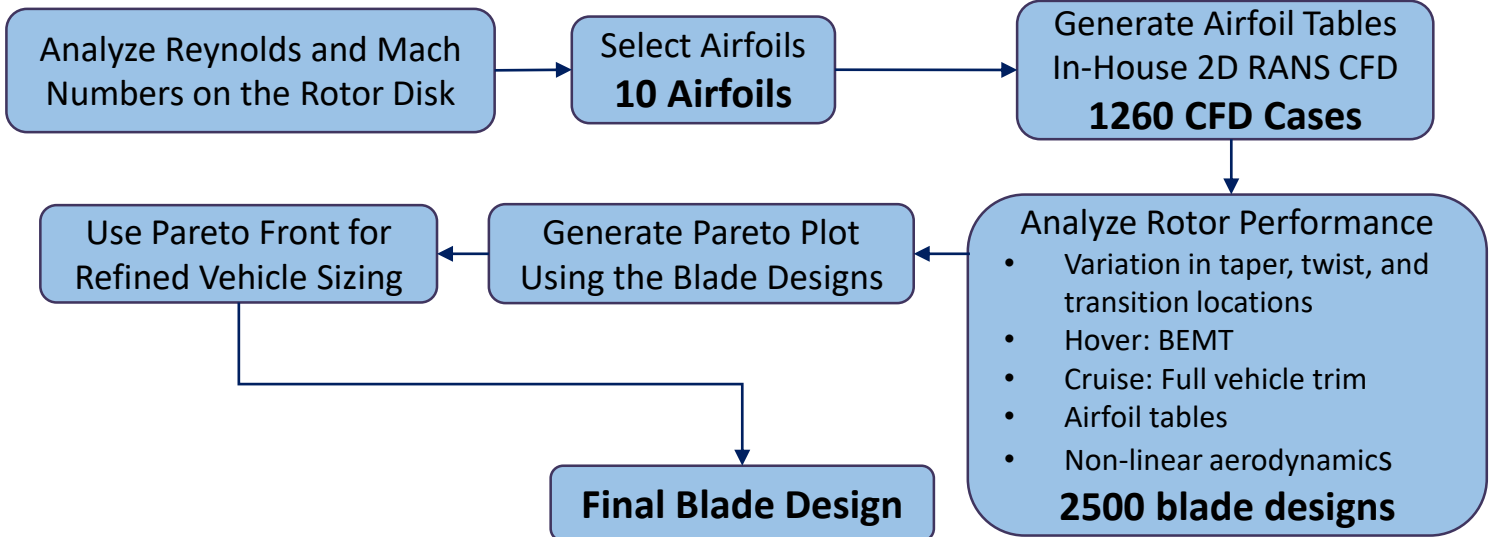
### Single Main Rotor Configuration

- Compact for access
- Superior cruise performance
- Low empty weight fraction
- Low vibrations in cruise
- High autorotation capability
- Low cost

# High Efficiency Blades



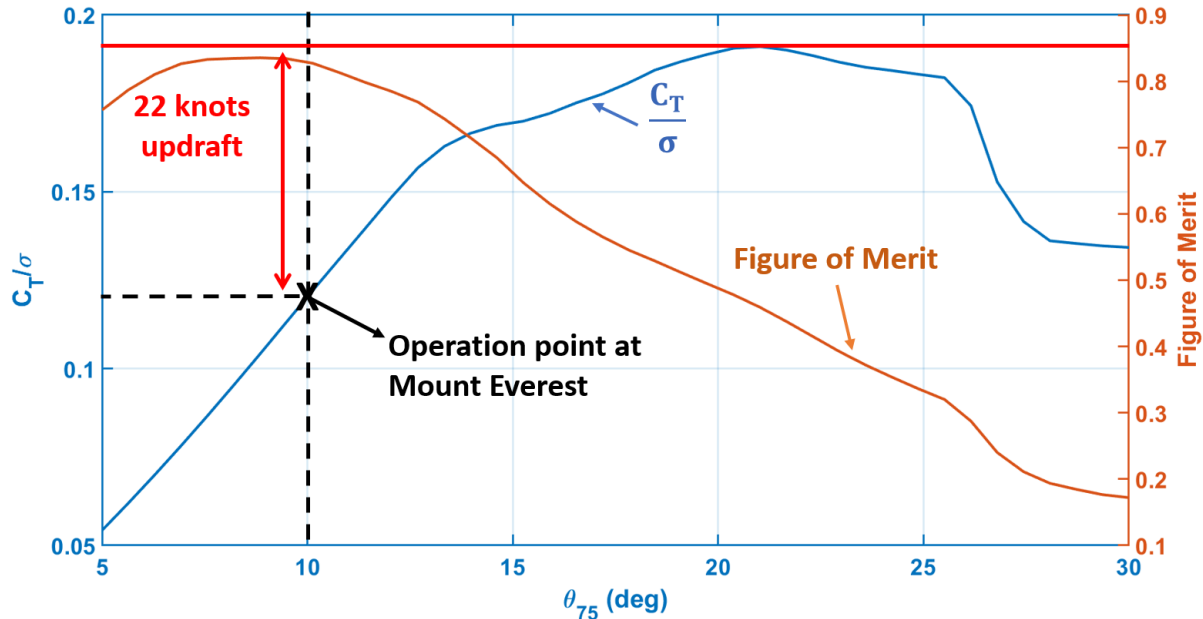
*Caladrius's* blades are aerodynamically optimized for both **extreme altitude hover** and **high speed cruise**.



# High Stall Margin and Low Vibrations



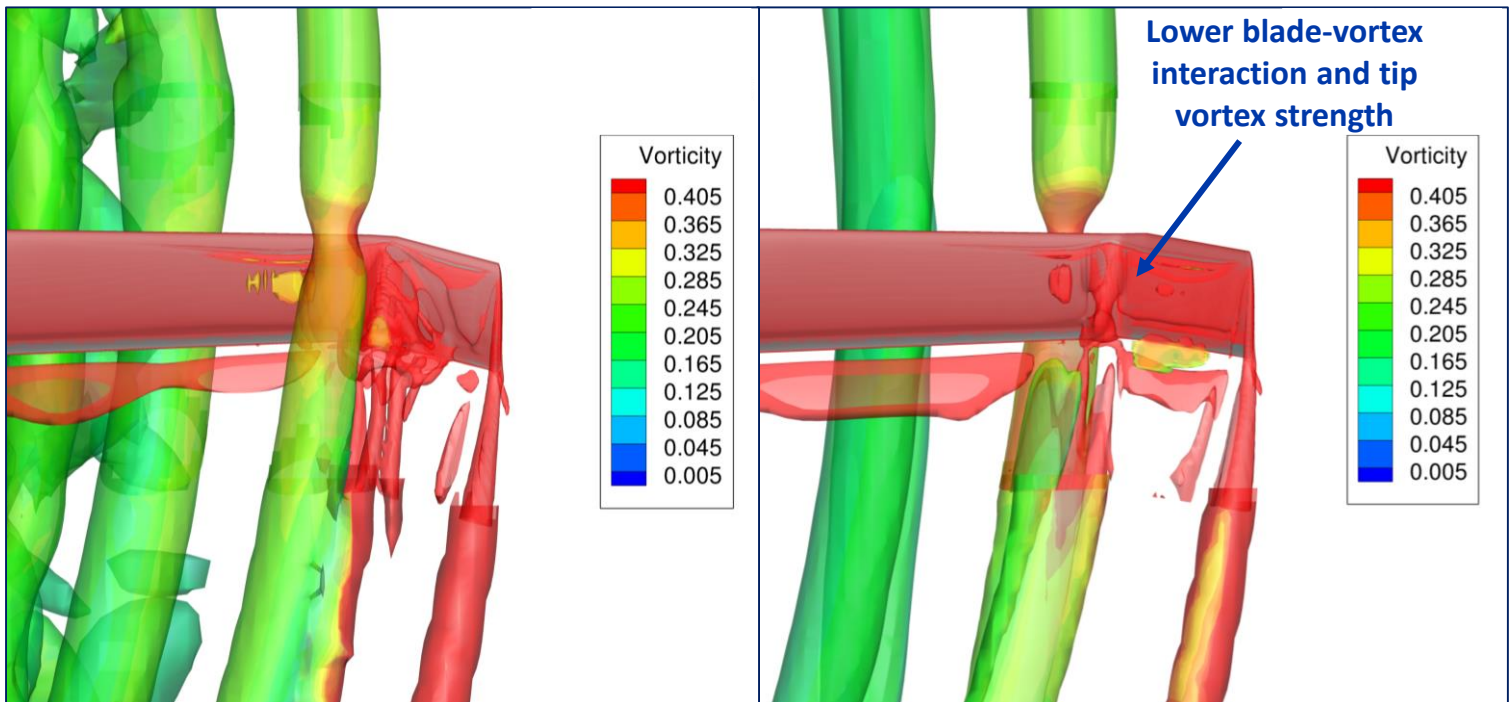
The rotor is **free of stall** while hovering in up to **22 knots updraft** at Mount Everest altitude.



Blade tip was designed with high-fidelity RANS for **high hover and cruise performance** and **low vibrations** to ensure EMS personnel can easily stabilize the condition of the rescuees.

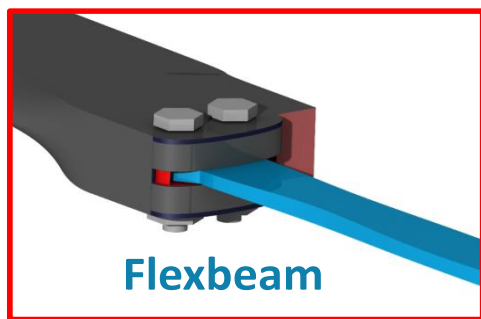
**No anhedral**

**Anhedral angle = 25°**

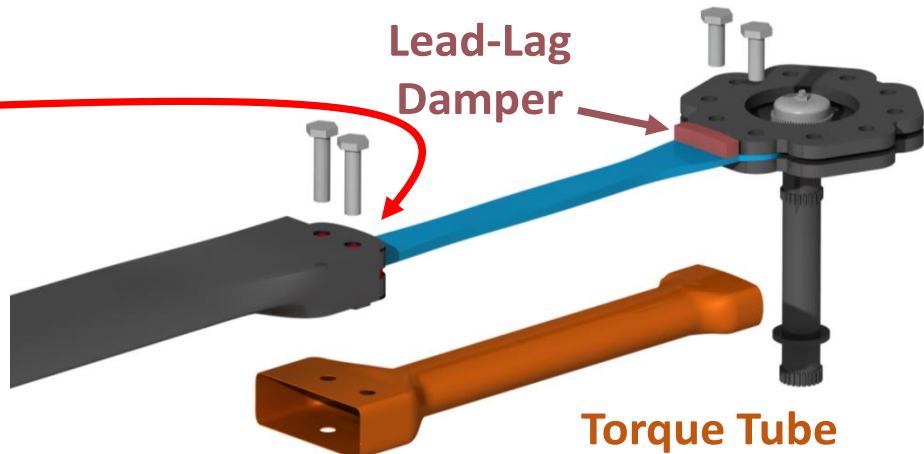




# Hub Design: Bearingless Hub for Low Drag and Robustness



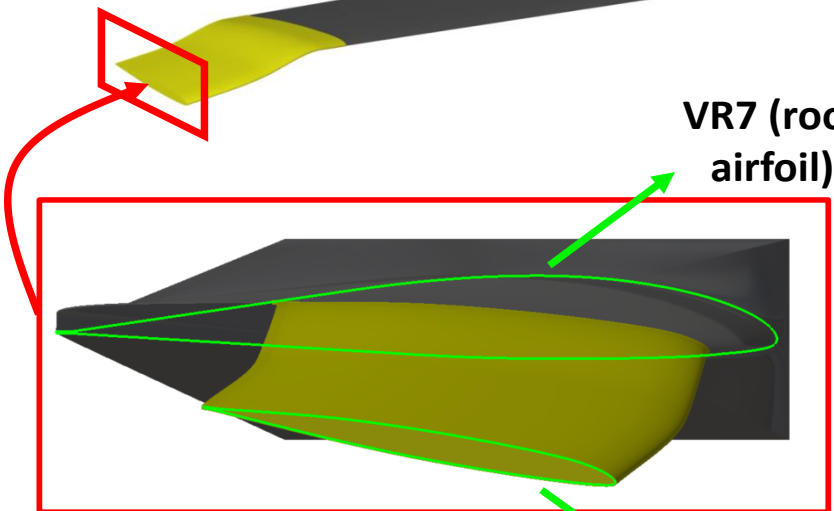
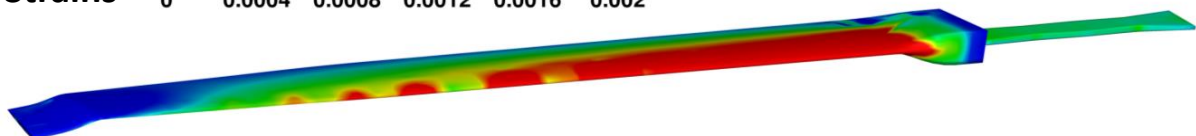
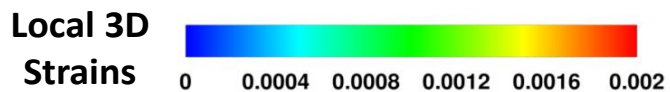
Flexbeam



Lead-Lag Damper

Torque Tube

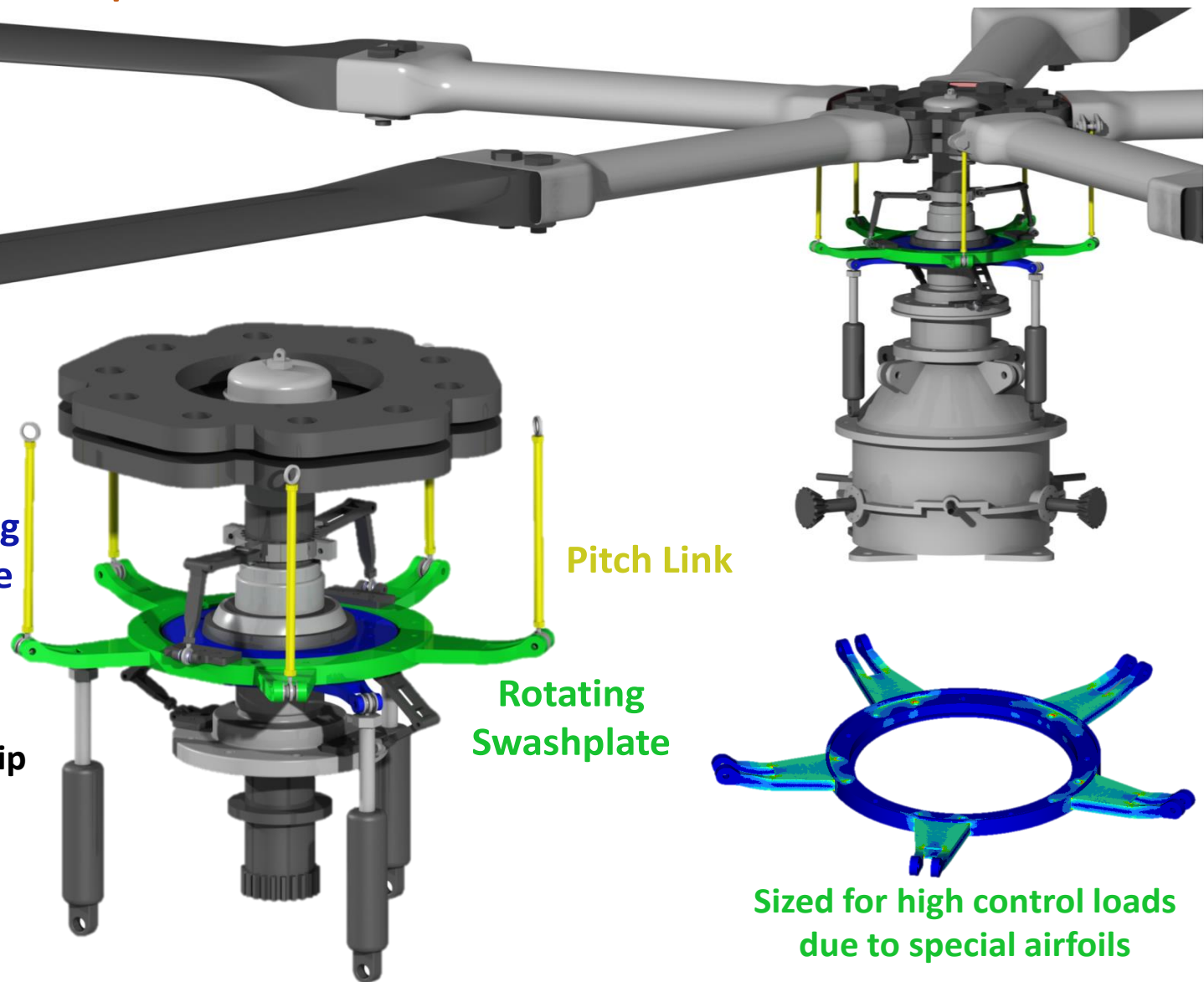
- Flap frequency: 1.06/rev to find the balance between high control power and high gust tolerance
- Soft in-plane
- Clean, robust, low drag profile hub
- Low part count
- Protected from snow and debris



VR7 (root airfoil)

SSC-A07 (tip airfoil)

- -6° bilinear twist
- Bilinear taper
- Swept, anhedral, thin tip



Nonrotating Swashplate

Pitch Link

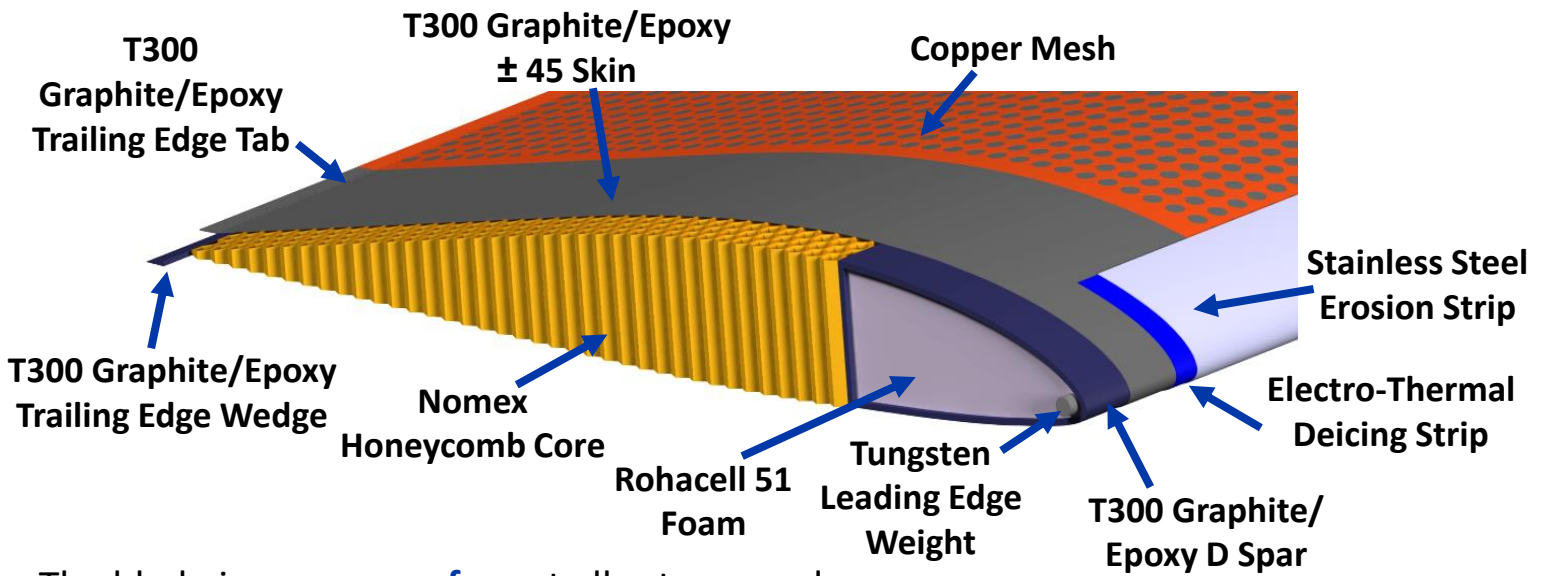
Rotating Swashplate

Sized for high control loads due to special airfoils

# Extreme Altitude Blade Design



Blade and flexbeam were designed to achieve the balance between **control authority** and **gust tolerance** both of which are crucial for extreme altitude mountain rescue operations. **Electro-thermal deicing system** ensures **cold weather operation safety** and **performance**.

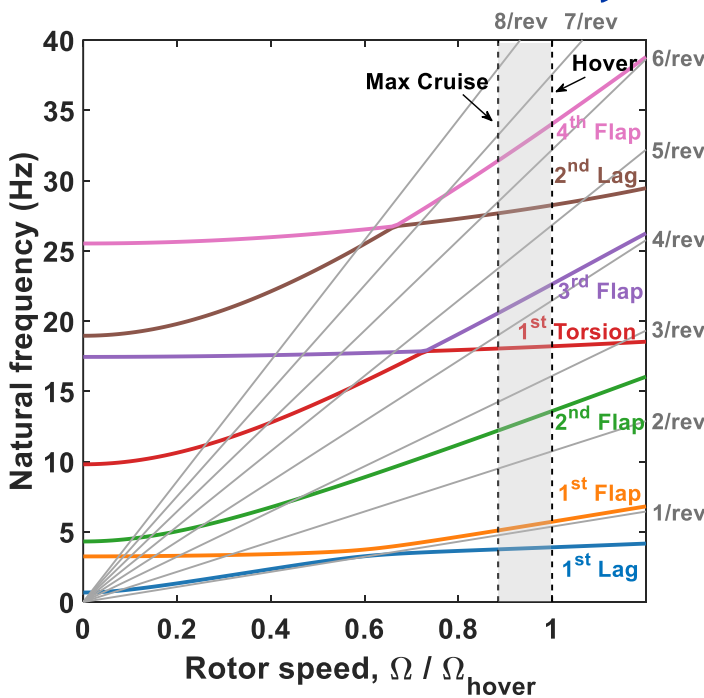


The blade is **resonance free** at all rotor speeds.

**Rotor speeds:**

- Leg 1  $\rightarrow$  282.0 rpm
- Leg 2  $\rightarrow$  320.5 rpm
- Leg 3  $\rightarrow$  297.7 rpm

Chosen for maximum efficiency



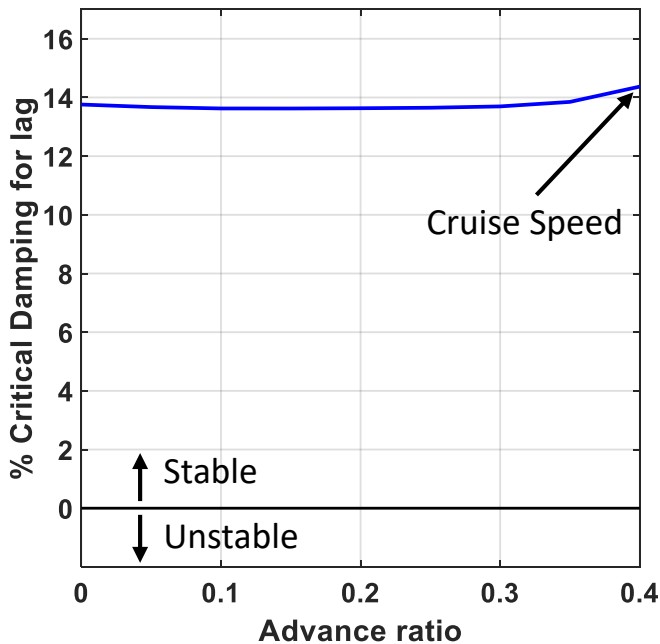
Mode	Hover (/rev)	Cruise (/rev)
1 <sup>st</sup> Lag	0.72	0.79
1 <sup>st</sup> Flap	1.06	1.07
2 <sup>nd</sup> Flap	2.53	2.57
1 <sup>st</sup> Torsion	3.4	3.8
3 <sup>rd</sup> Flap	4.21	4.33
2 <sup>nd</sup> Lag	5.27	5.82

# Rotors Free from Air and Ground Resonance

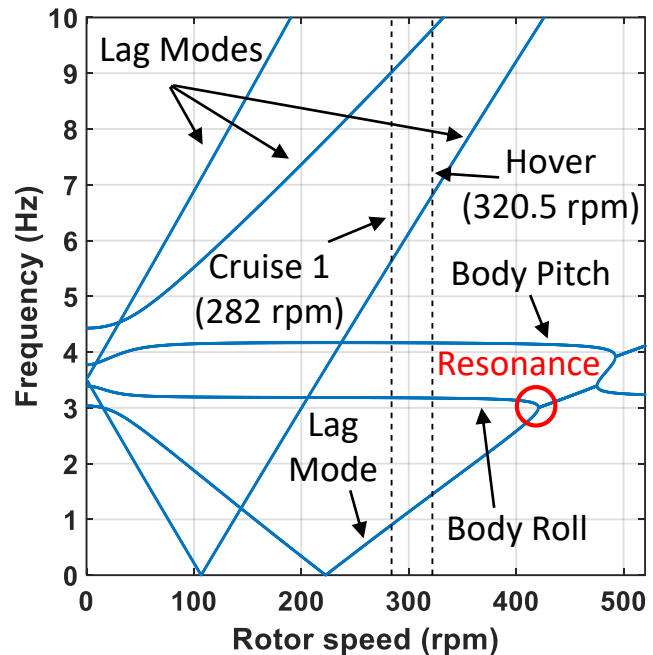


High thrust coefficient ( $C_T$ ) at extreme altitude and possible snow landing presented challenges for aeroelastic stability and ground resonance. *Caladrius's* blades are designed to be free from any such instabilities.

## Air resonance damping

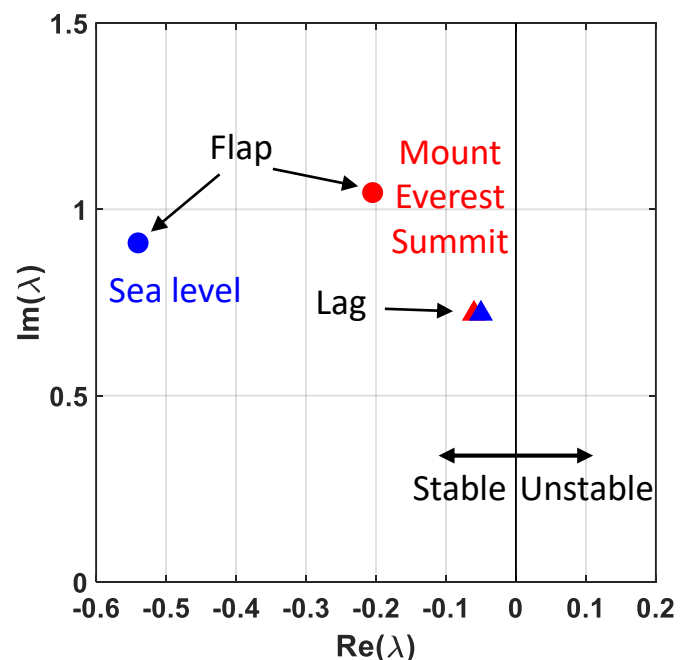


## Ground resonance frequencies



Terrain Type	Terrain Damping	Lead-Lag Damper
Concrete	0.05	0.02
Mud	0.03	0.04
Grass	0.03	0.04
Snow	0.01	0.1

## High altitude flap-lag flutter

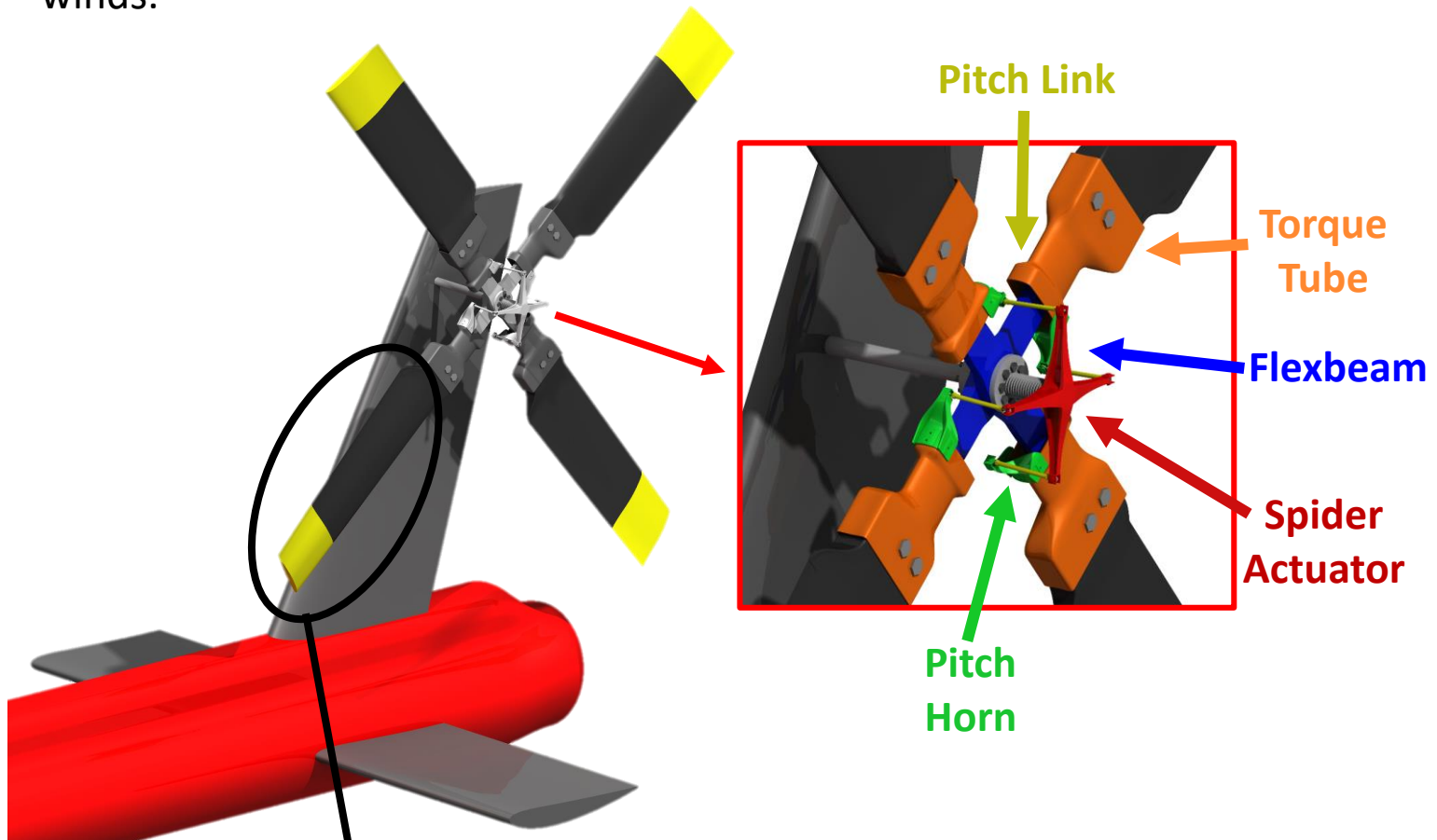


Elastomeric damper is selected for a possible **snow landing** which assures freedom from ground resonance for all terrain conditions.

# Special Bearingless Tail Rotor



*Caladrius's* 4-bladed tail rotor with twist prevents **loss of tail rotor effectiveness** and **vortex ring state** in winds up to **81 km/h (44 knots)** at 8870 m (29100 ft). The pedal control range was designed for high side winds.



**Highly twisted blades**

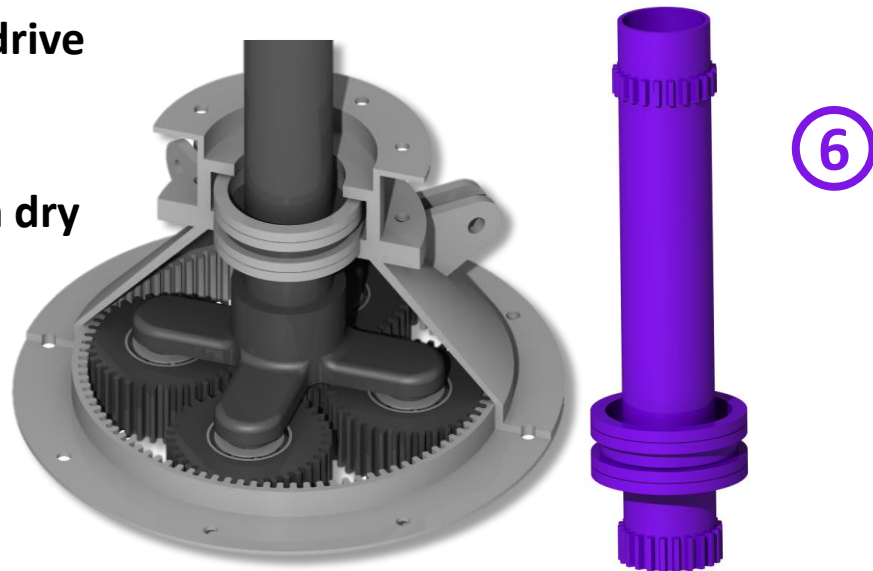
Parameter	Value
Diameter	2.80 m (9.19 ft)
Chord	0.27 m (0.89 ft)
Solidity	0.239
Rotor Speed (Hover)	139 rad/s (1328 rpm)
Twist	-20° linear
Airfoil	RC510

# Lightweight Gearbox Design with 50 minute Dry Running Capability

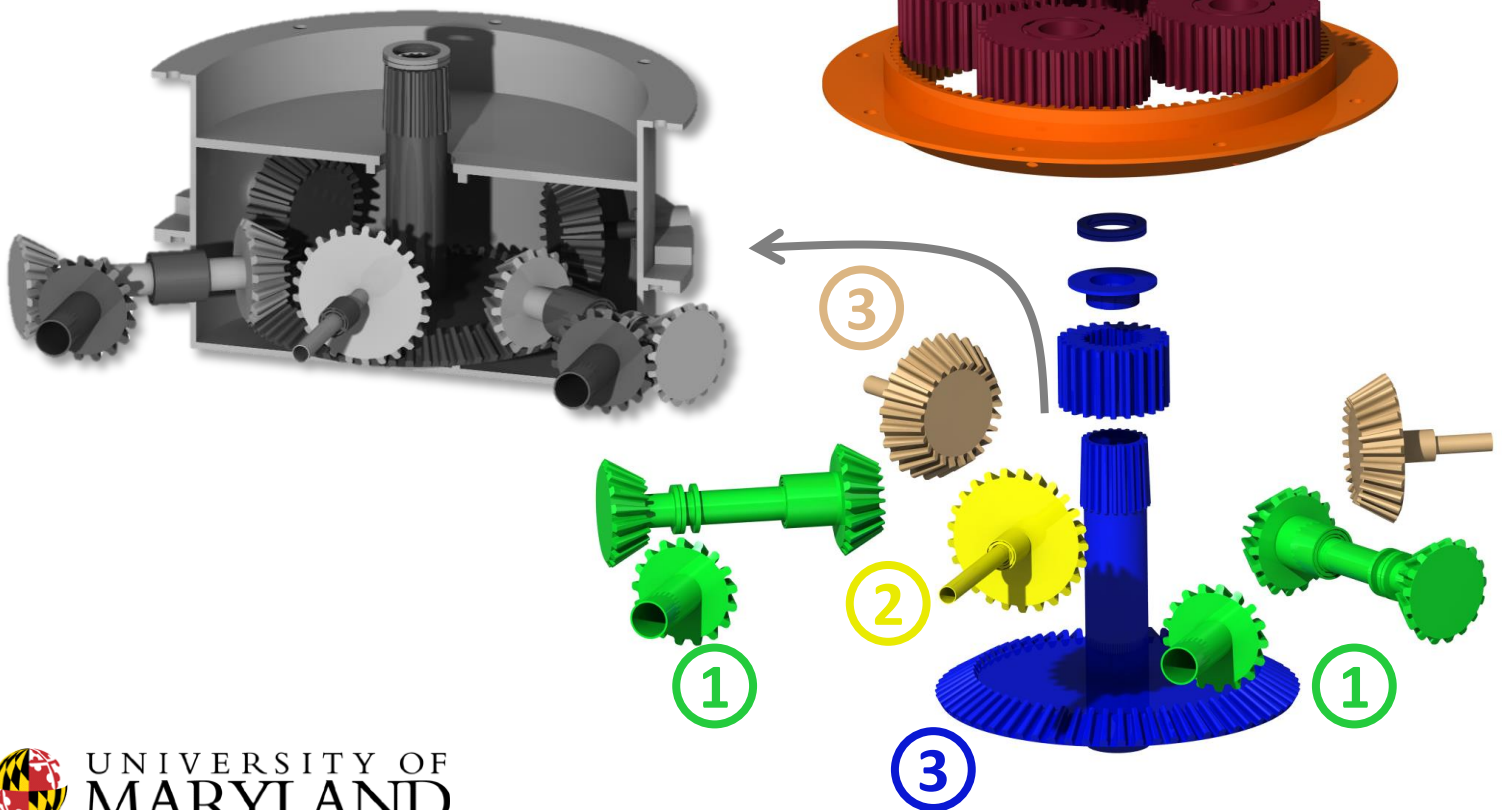


Weight minimized drive system

Reserved oil 50 min dry running



- 1: Engine Inputs
- 2: Tail Drive Shaft
- 3: 1st Stage Bevel Reduction
- 4: Accessory Outputs
- 5: 2nd Stage Planetary Reduction
- 6: Main Rotor Drive Shaft

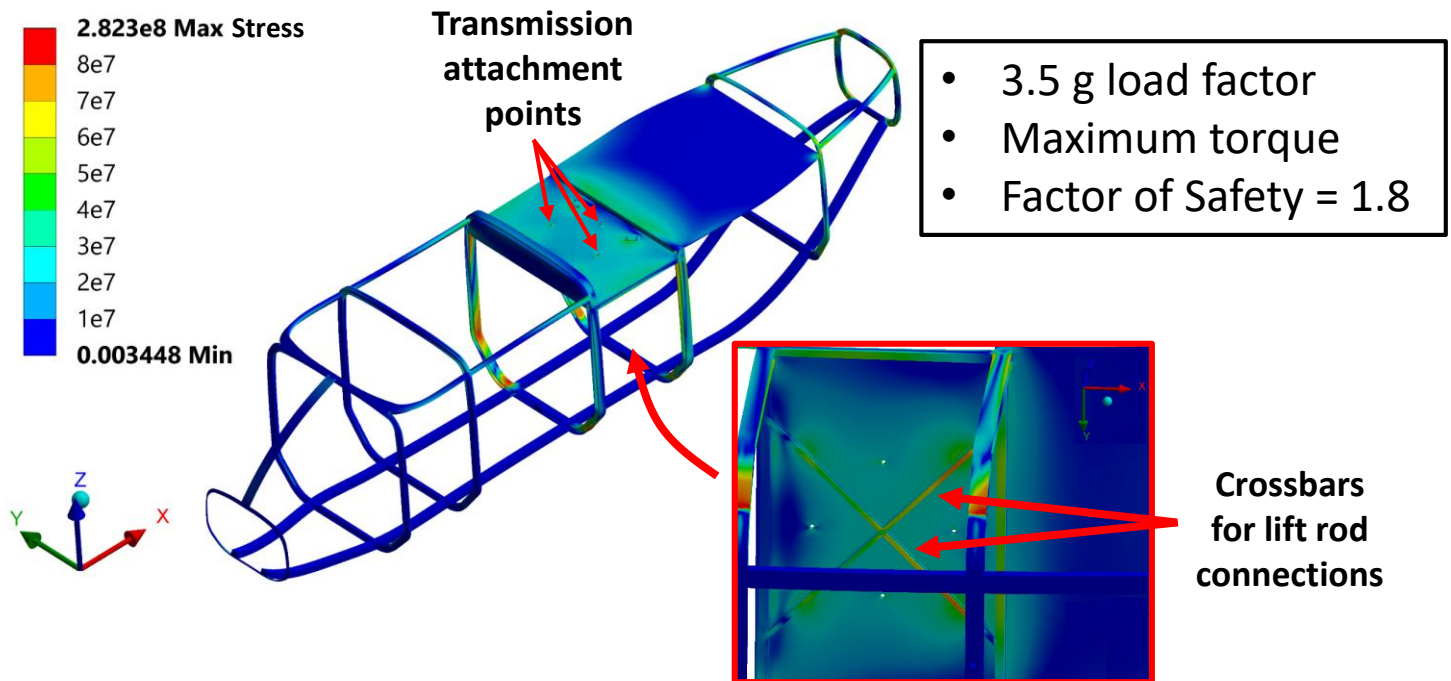


# Airframe Sized for Extreme Conditions

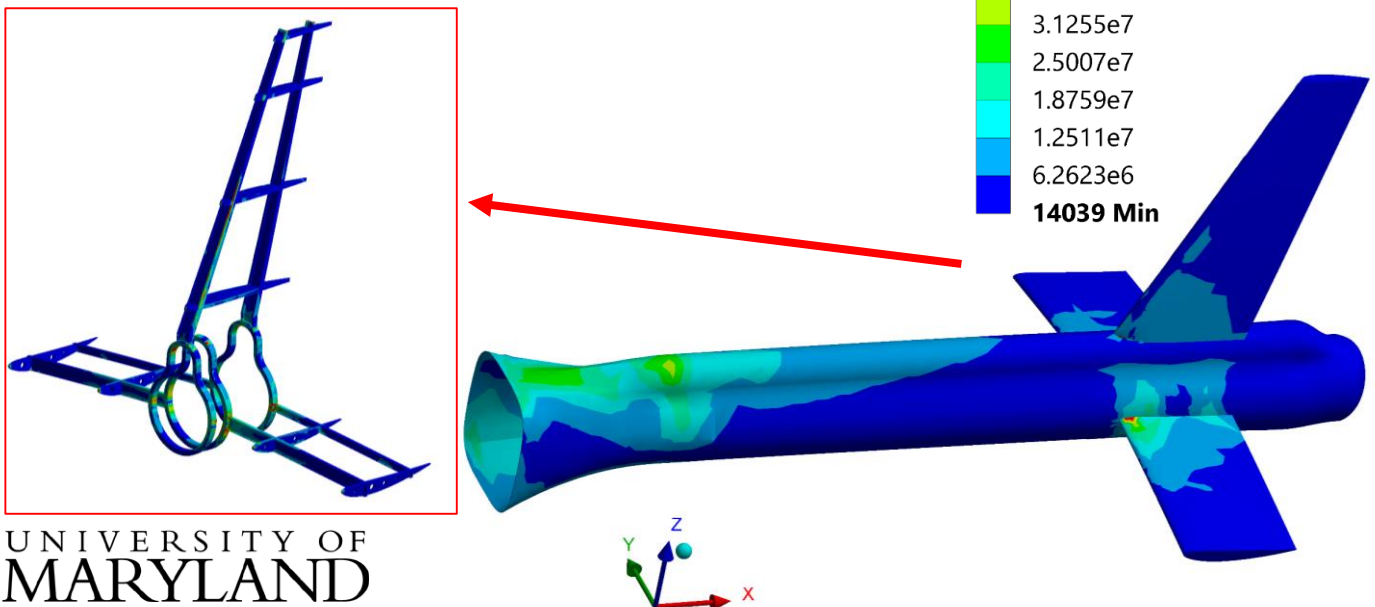


Airframe was sized with high fidelity finite element tools to satisfy CS 29 requirements.

Combinations of **high tail rotor thrust** and **extreme side winds, updrafts, and downdrafts** were considered for maximum load cases.



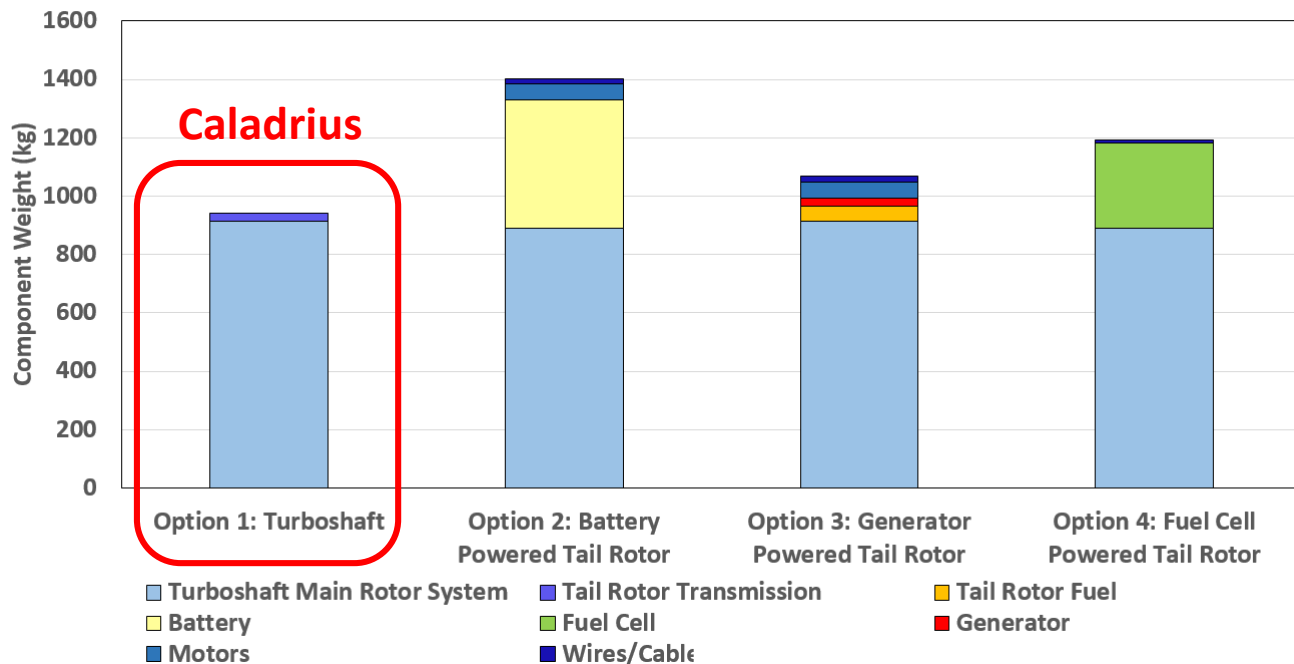
CS 29 requirements and high updrafts/downdrafts at Mount Everest were considered



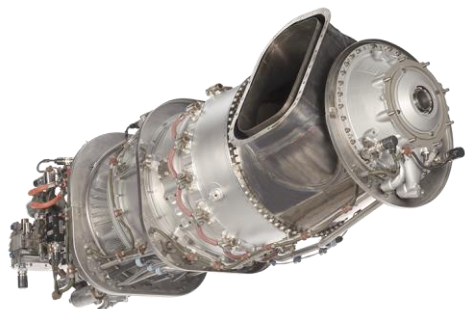
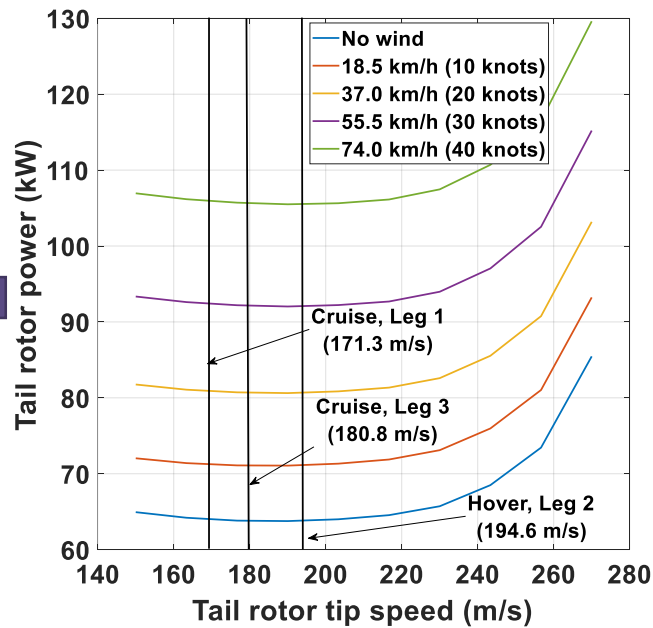
# Twin Turboshaft Engines for Safety



Minimizing power consumption during rescue is critical for the mission. Trade studies were performed among several configurations to examine the pros/cons of an electric tail rotor.



- **Lowest weight:** Twin turboshaft engines with mechanically powered tail rotor
- Tail rotor operates in the drag bucket for each wind case
- No power benefit with electric tail rotor (variable rotor speed)
- **Twin engines** for high safety



2 X Pratt & Whitney Canada PT6C-67A

**Power:** 1447 kW (1940 hp) X 2

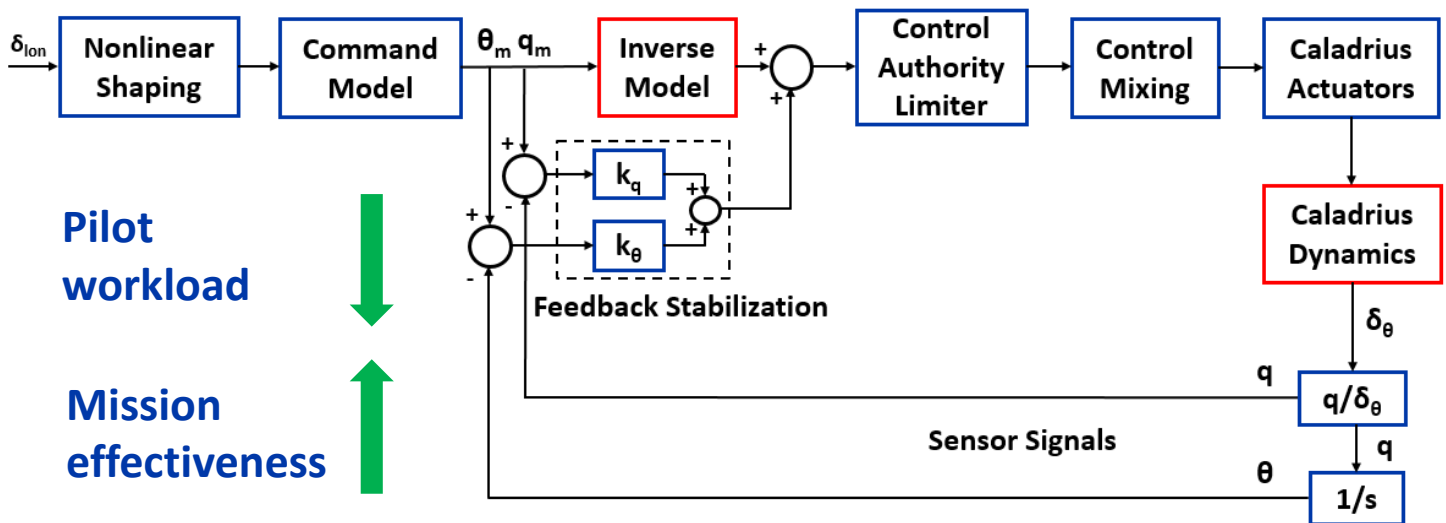
**Weight:** 190 kg (419 lb) X 2

**SFC:** 0.308 kg/kW/h (0.506 lb/hp-hr)

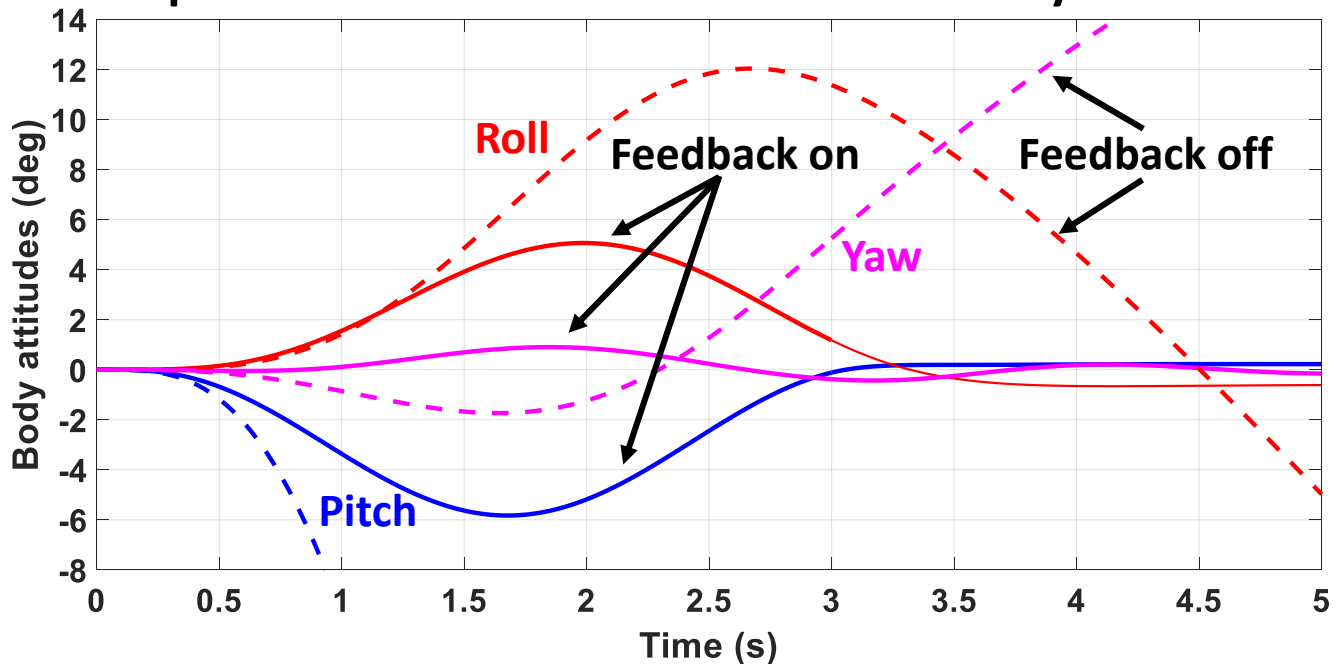
# Flight Control System Designed for Extreme Gusts



*Caladrius* is equipped with a **Model Following Control System** and a triple redundant **four-axis autopilot** to ensure both **high gust tolerance** and **control authority**.

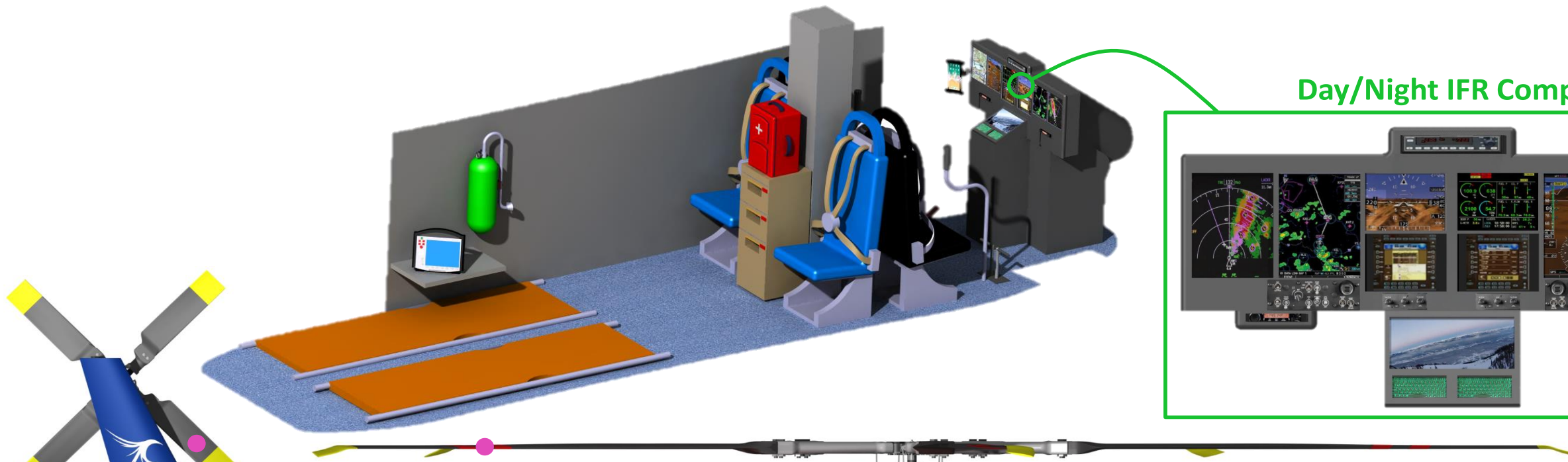


### Response to 40 knots Side Gust Stabilized by Feedback



The flight control system **satisfies IFR requirements**.

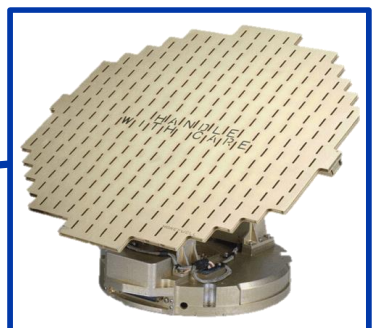
# Avionics: Selected for High Safety and Low Pilot Workload



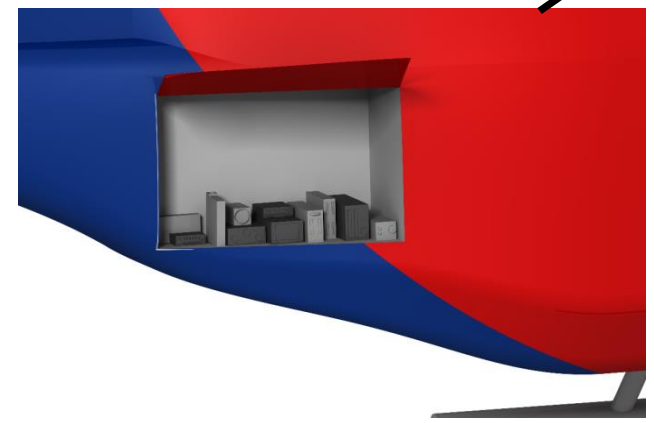
Day/Night IFR Compatibility



Weather Radar



Electro-Thermal Deicing System



Wireless Intercom System



Triple Redundant Radar Altimeter

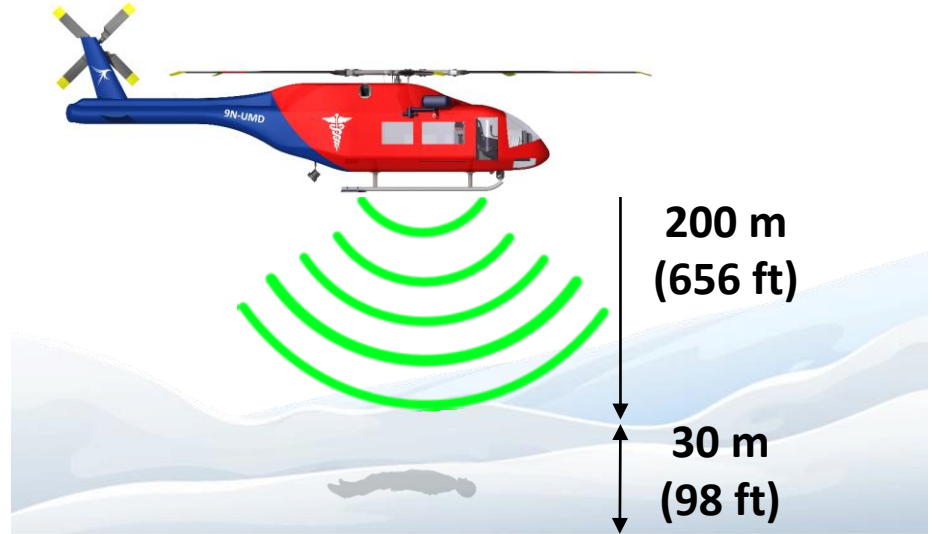


# Mountain Search and Rescue Equipment for Day and Night, All Weather Conditions

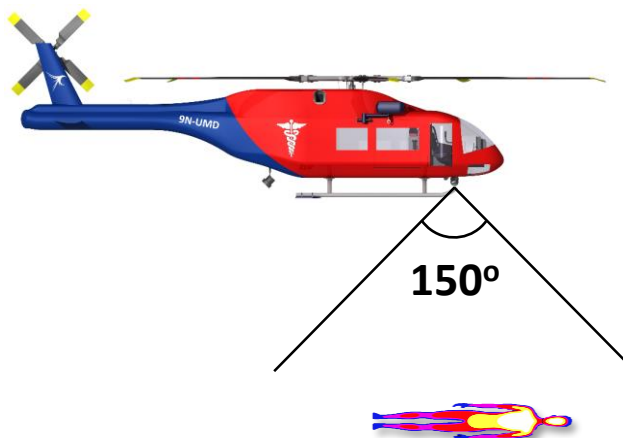


State-of-the-art search and rescue equipment in order to reduce the **pilot workload** and **increase mission effectiveness**.

Recco avalanche detector to find the rescues trapped **under snow**



External searchlight with **25 million candlepower**



Electro-optical system with **thermal imaging** capabilities with coverage of

- 150° elevation
- 360° azimuth

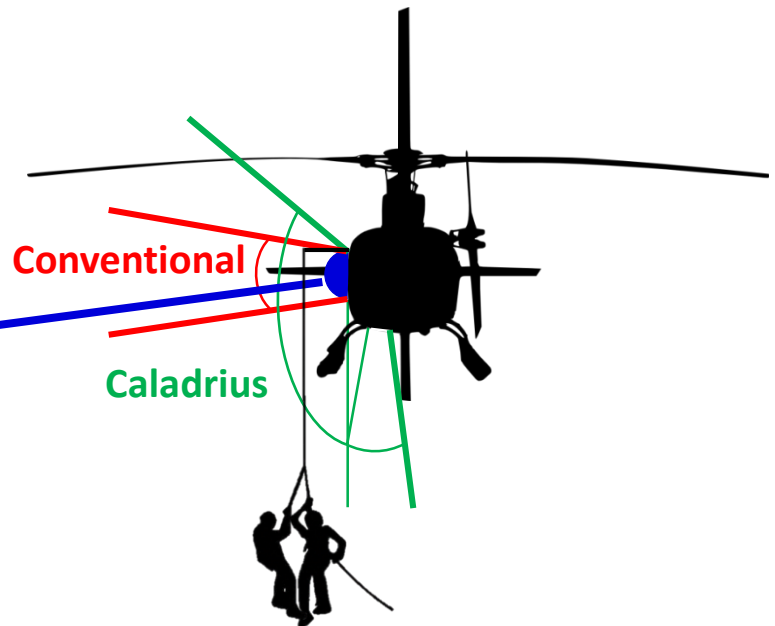
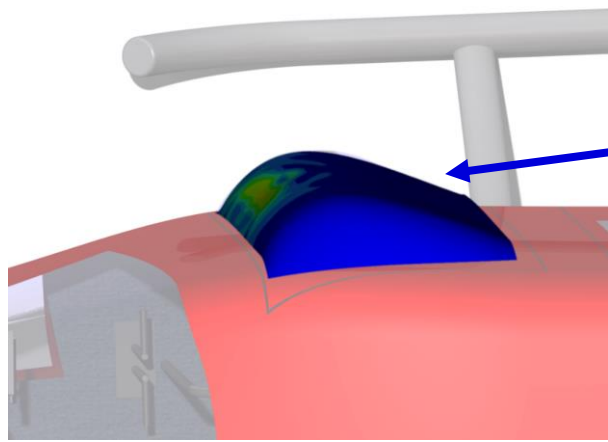
to expeditiously locate the rescues

# Wide Field of View for High Mission Effectiveness

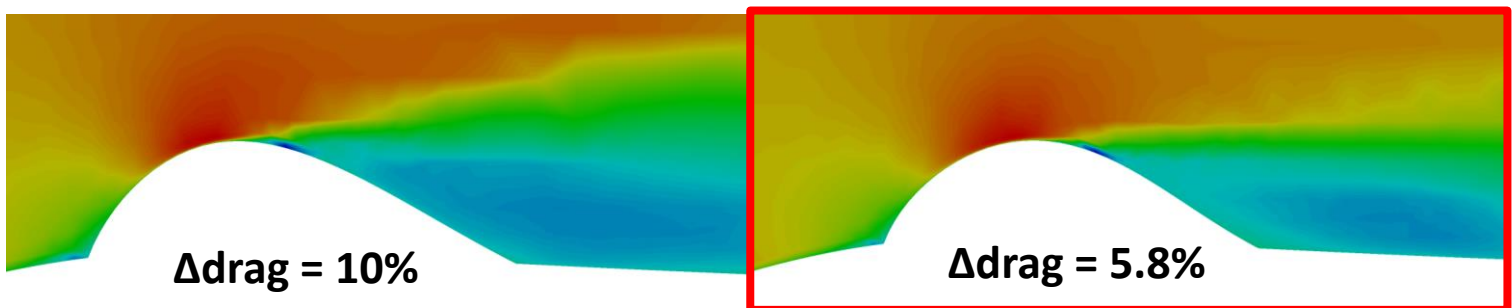
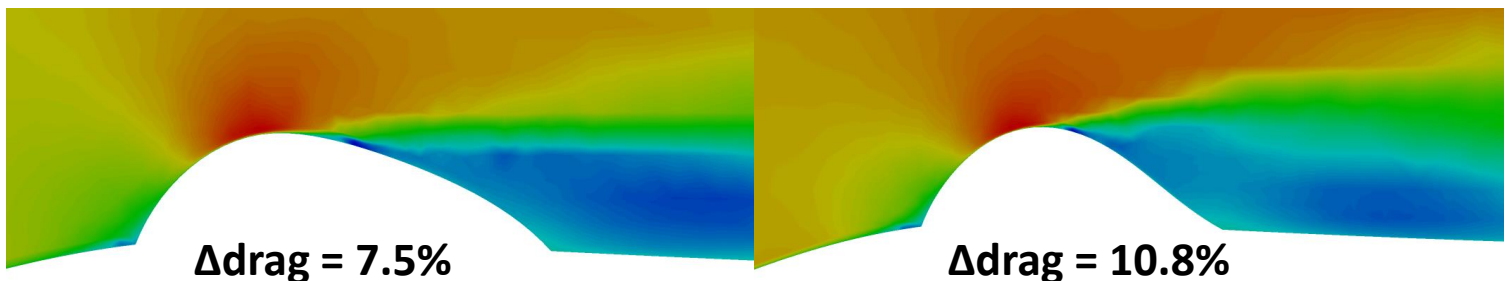


Bird strike resistant **windshield, side bubble window, and bottom windows** provide **excellent field of view**, which is especially important for the mountain rescue missions.

**Bird strike analysis carried out using Altair**



**Bubble window geometry was designed after extensive aerodynamic studies for minimal impact in aircraft drag and increased lateral field of view**

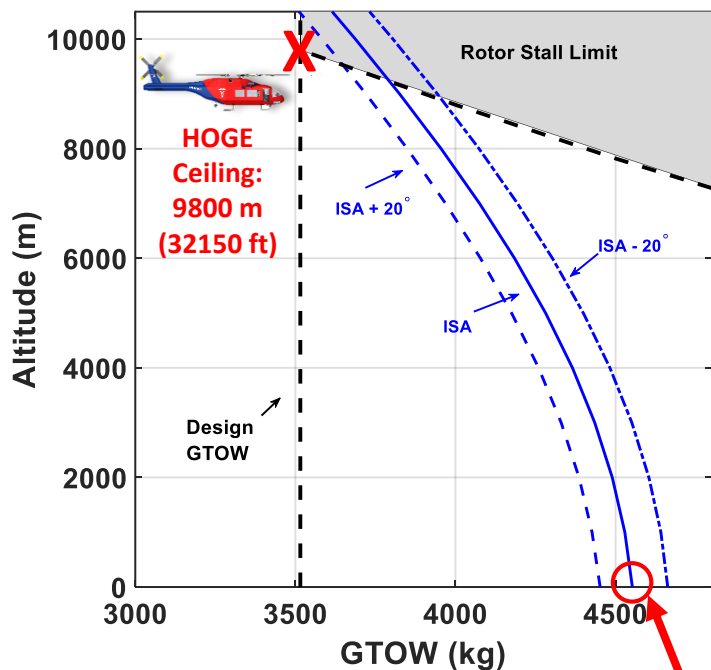


**Design point for lowest airframe drag**

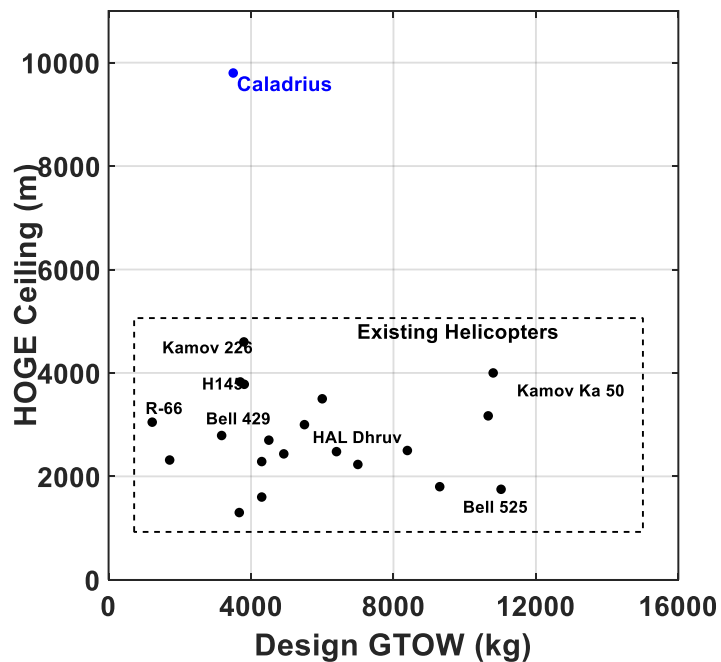
# Unprecedented HOGE Ceiling and Efficient Cruise



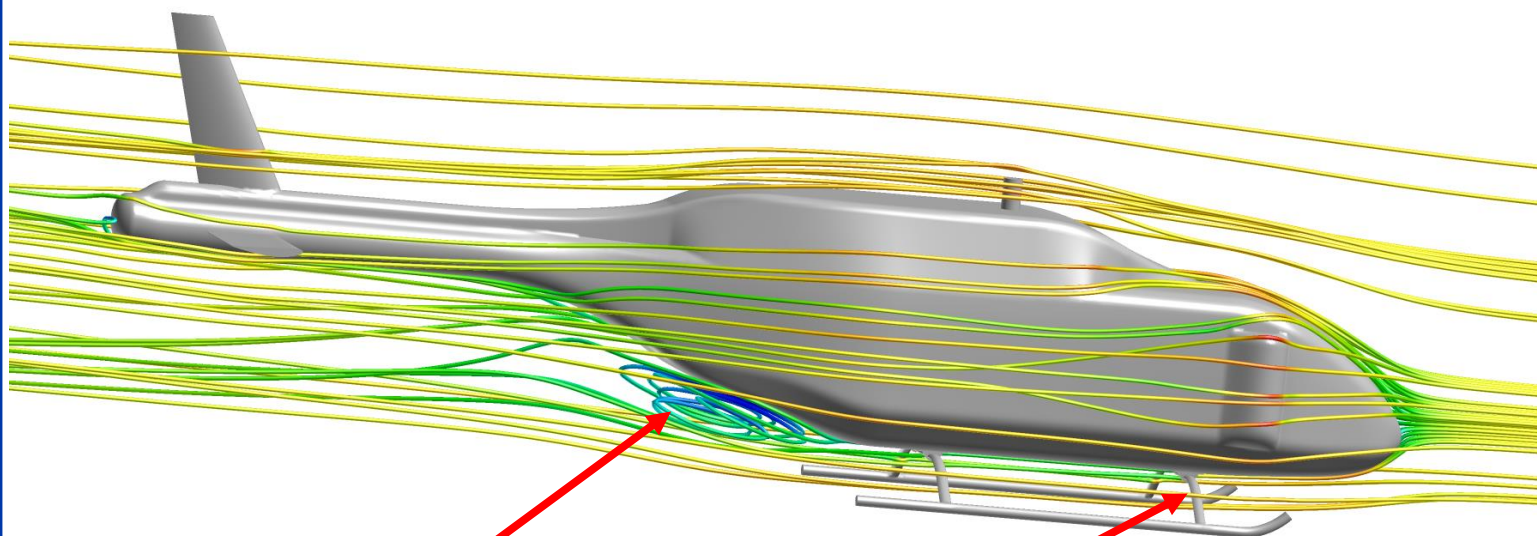
Only limited by transmission at low altitudes



Higher HOGE ceiling than any other helicopter by trading range and endurance



Greater than 1600 kg payload at sea level



Flow separation at upswEEP was minimized

Elliptical cross-section crossbars

Flat plate area 1.2 m<sup>2</sup> (13 ft<sup>2</sup>)

# Many Other Daring Missions



**Firefighting**

**External Payload: 1200 kg**  
**3 – 4 missions**

**Payload: 575 kg**  
**Mission Radius: 120 km**  
**Speed: 259 km/h**



**Arctic Monitoring  
and Rescue**

**Mission Radius: 150 km**  
**Endurance: 2.5 hrs**



**Severe Weather  
Disaster Relief**

**Payload: 600 kg**  
**Mission Radius: 120 km**

**Payload: 680 kg**  
**Range: 230 km**



**High Altitude EMS**

**Endurance: 2.5 hrs**



**High Altitude Surveillance**



**Offshore Transport**