Alfred Gessow Rotorcraft Center
Department of Aerospace Engineering
University of Maryland
College Park, MD 20742

To the 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 40th Annual Student Design Competition as they see fit.

Thank you,

The UMD Design Team

Alfred Gessow Rotorcraft Center
Department of Aerospace Engineering
University of Maryland
College Park, MD 20742

Nathan O'Brien
Graduate Student (Team Lead)
nobrien2@umd.edu

Brendan Egan
Graduate Student/(V-22 Pilot)
began91@umd.edu

Noam Kaplan
Graduate Student
nkaplan1@umd.edu

Nicholas Paternostro
Graduate Student
napatern@umd.edu

Xavier Delgado
Graduate Student
delgadx2@umd.edu

Ray-Shimry Garatsa
Graduate Student
rgaratsa@umd.edu

Dr. Inderjit Chopra
Faculty Advisor
chopra@umd.edu

Dr. Vengalatore Nagaraj
Faculty Advisor
vnagaraj@umd.edu

Dr. Anubhav Datta
Faculty Advisor
datta@umd.edu

Academic Course:
ENAE634: Helicopter Design (3 credits)

40th Annual VFS Student Design Competition

High-Speed Vertical Takeoff and Landing (HSVTOL) Aircraft

Sponsored by Sikorsky

UNIVERSITY OF MARYLAND

Alfred Gessow Rotorcraft Center
Department of Aerospace Engineering
University of Maryland
College Park, MD 20742

Arion: Swift to the Scene

Divinely-bred and endowed with extraordinary speed, Arion was an immortal horse. He was given to Heracles (or Hercules) who gave him to King Adrastus. A champion of the Nemean games, Arion used his extraordinary speed to save King Adrastus in the disastrous War of the Seven against Thebes. In addition to speed and bravery, legends have it he could also speak and prophesize.


The AGRC-developed Arion is also endowed with unprecedented speed and embodies the immortal dream of VTOL – helicopter like hover and jet like cruise. Arion is a 48,000 lb **mixed power tiltrotor**, capable of delivering 5000 lb of cargo, or 20 fully loaded troops in a pressurized cargo bay. Like the mythological horse, Arion can deliver the warfighter in and out of battle with **unprecedented speed and versatility** The Arion utilizes a special rotor system with **13.4% t/c transonic airfoils, a 54% rpm reduction drive, and a flutter free** transonic wing. Arion is capable of operating at a **propulsive efficiency of 0.68** at a 450 knots (231.5 m/s) 27,000 ft (8230 m) aided by **2 high-bypass turbofans** providing shared thrust. It can deliver troops and cargo onto rugged and unprepared surfaces as it operates at a **maximum disk loading of 23 lbf/ft^2** (112.3 kg/m^2),

Arion: For the Army of the Future

Terp Two Speed Transmission
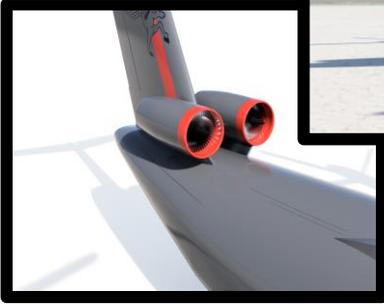
**Rear cargo entrance
Two turbofans for
power sharing**
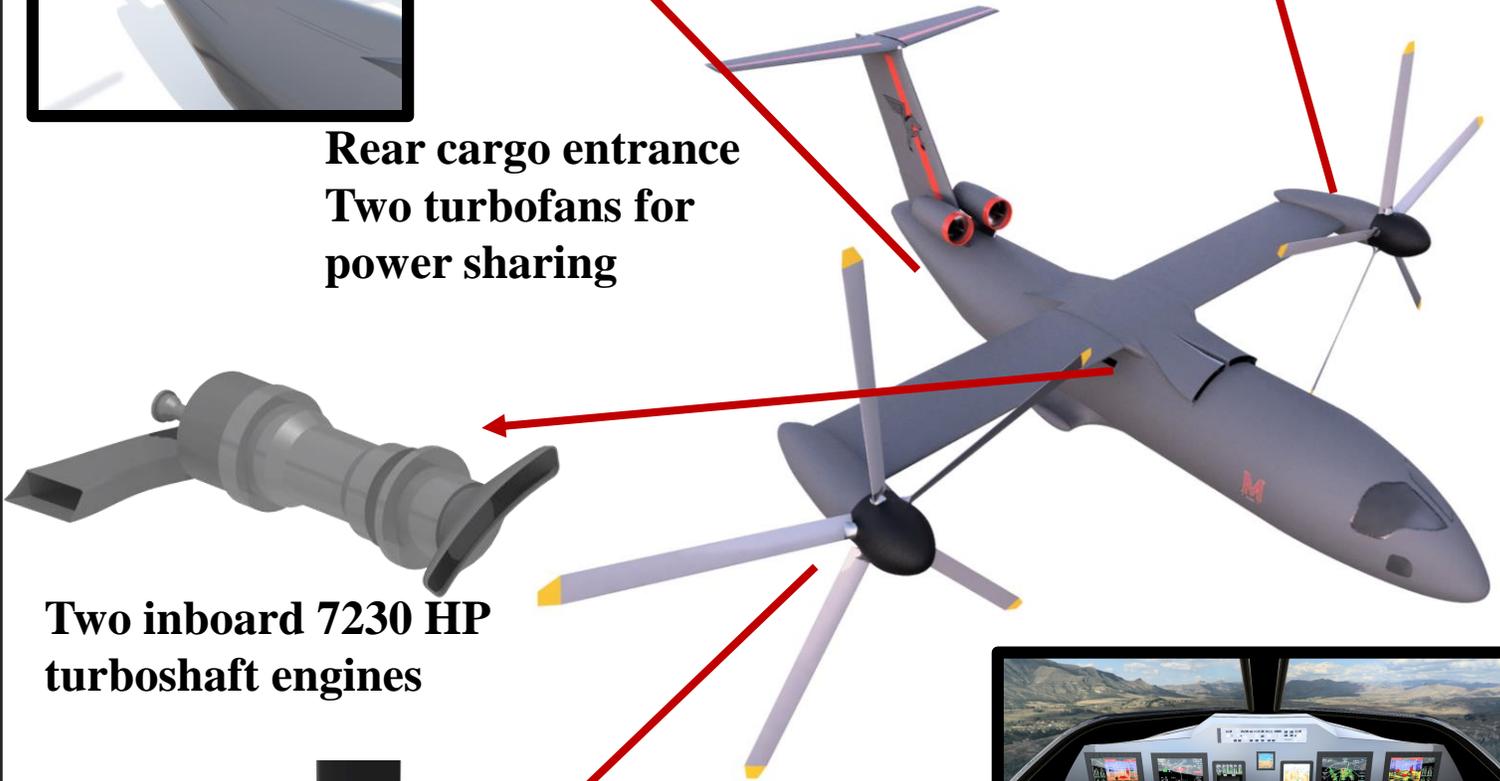
**Two inboard 7230 HP
turboshaft engines**

Ergonomic Cockpit
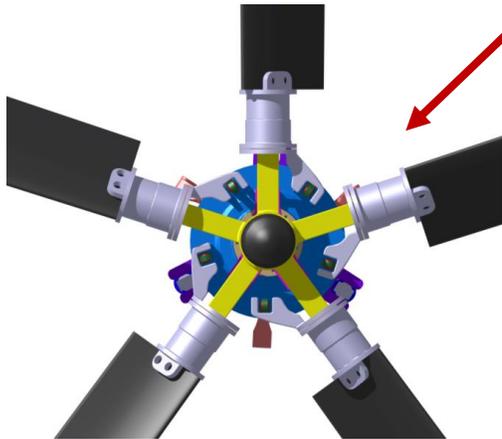
Hingeless Hub with Uniquely Thin Blades

Streamlined Fuselage

UNIVERSITY OF
MARYLAND
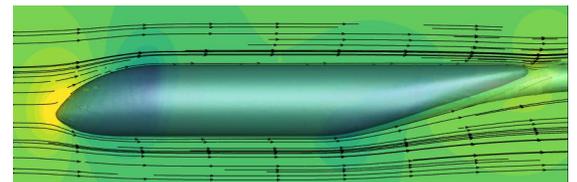
Arion: Vehicle Characteristics

53.72 ft
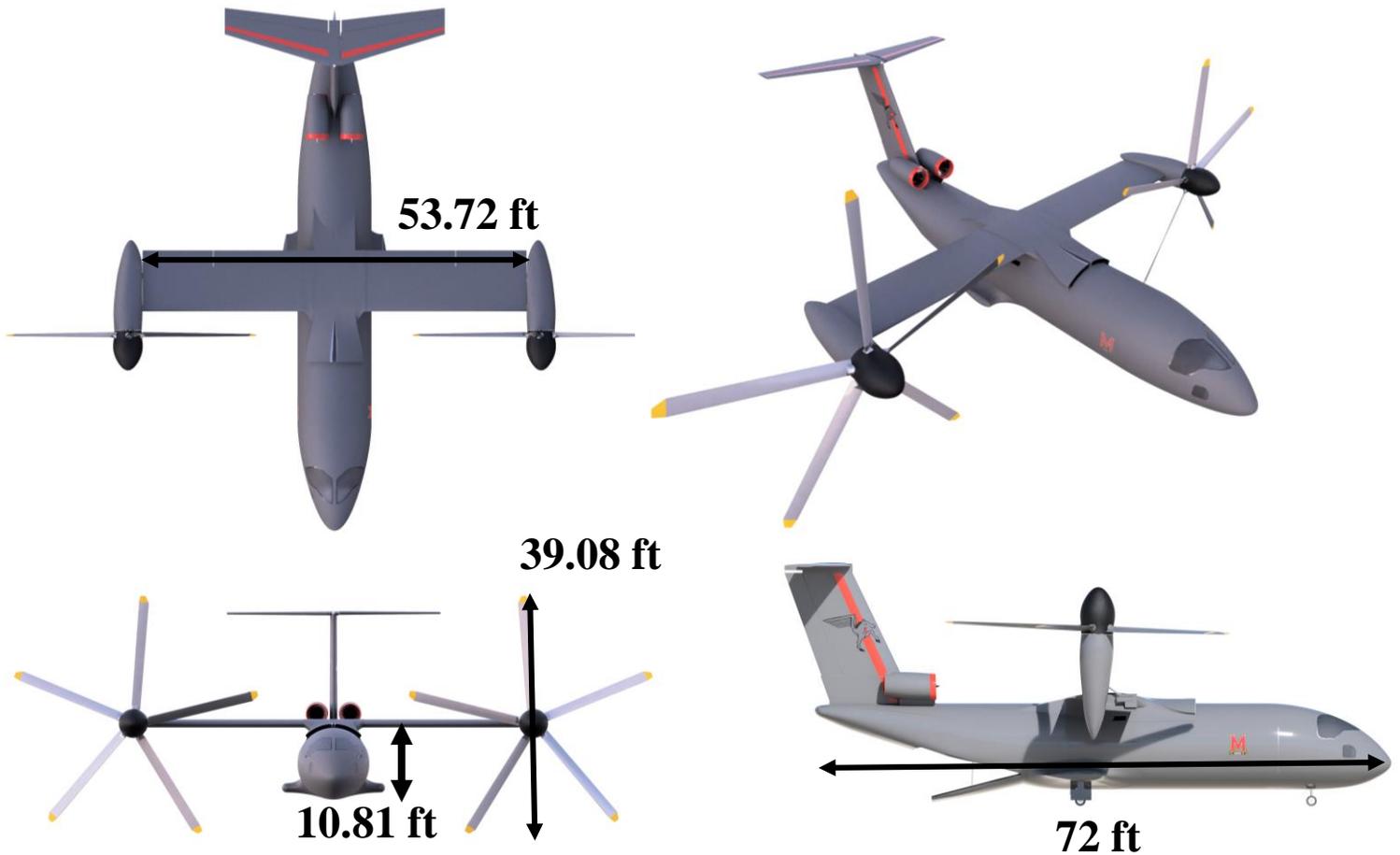
39.08 ft

10.81 ft

72 ft

	Arion
Wing Span	53.72 ft (16.37 m)
Fuselage Length	72 ft (21.94 m)
Fuselage Height	10.81 ft (3.30 m)
Rotor Diameter	39.08 ft (11.91 m)
Wing Sweep	0°
Wing Aspect Ratio	6
Wing Planform Area	480.9 ft² (44.65 m²)
Turboshaft Installed HP	7230 HP x 2 (5391.41 kW x 2)
Turbofan Installed Thrust	19,000 lbf (84516.21 N)

Unprecedented Ultra Speed Mission
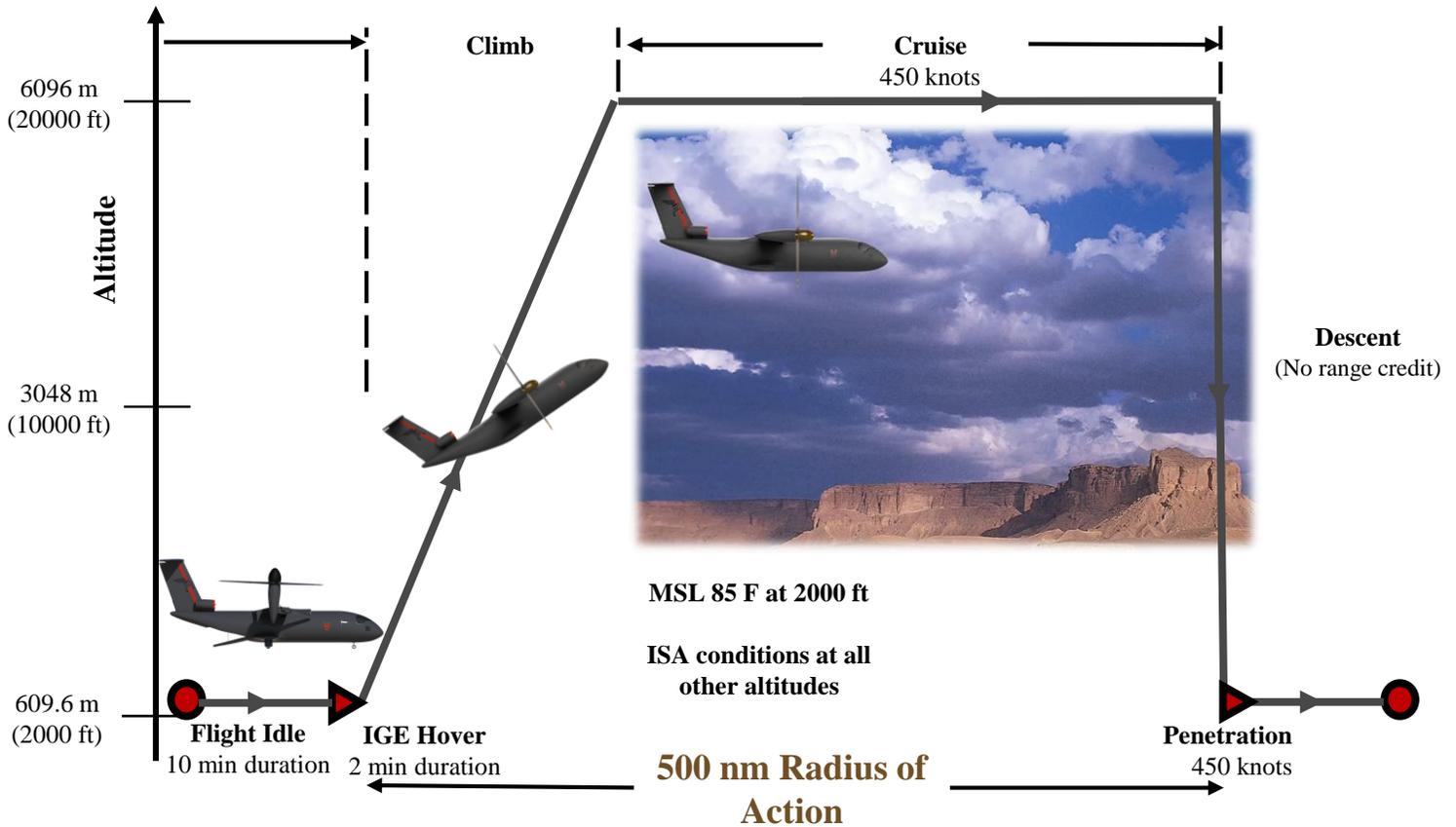
	RFP Requirement	Arion
Cruise Speed	450 knots	**460 knots**
Disk Loading	-	23 psf
Radius of Action	500 nm	**541 nm**
Hover Altitude (85°F)	2000 ft (609.6 m)	**3470 ft (1057.66 m)**
Cruise Altitude	20,000 ft (6096 m)	**25,000 ft (7620 m)**
FM	-	0.813
L/D	-	6.17
Payload	5000 lb (2267.96 kg)	5000 lb (2267.96 kg)
Empty Weight	-	28,745 lb (13038.5 kg)

Clean Sheet Configuration Selection

12 Configurations/Variants Considered

Preliminary analysis

450 kt possible?

NO → **Configurations Dropped: Edgewise Flight Vehicles**

YES ↓

Minimal Outwash?

NO → **Configurations Dropped: Jet fan, Fan in wing, ducted fan**

↓

Qualitative Analysis

Downselect for Qualitative Analysis

Downselect for Detailed Analysis

Tiltrotor

Folding Tiltrotor

Jet Assisted Tiltrotor

Design Drivers

- Hover Efficiency 5%
- Pilot Workload 3%
- Autorotation/ Crashworthiness 6%
- GTOW 19%
- Cost Complexity 4%
- Ground Crew Safety 3%
- Survivability 6%
- Acoustics 2%
- Maneuverability 4%
- Stability/ CG range 6%
- TRL 5%
- Additional Top Speed 2%
- Cruise Efficiency 24%
- Downwash 10%
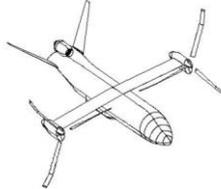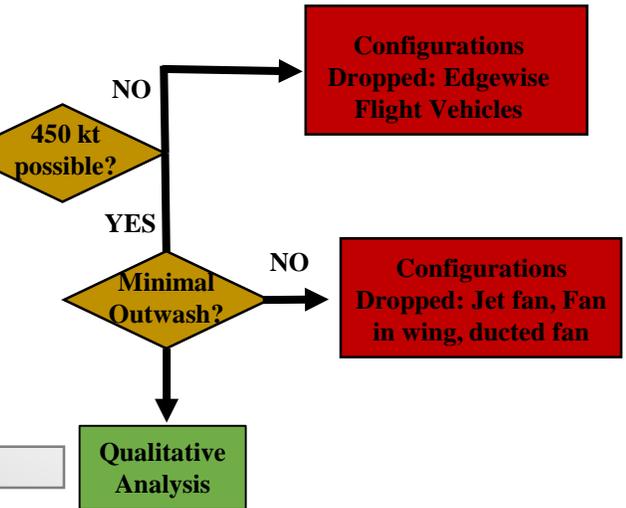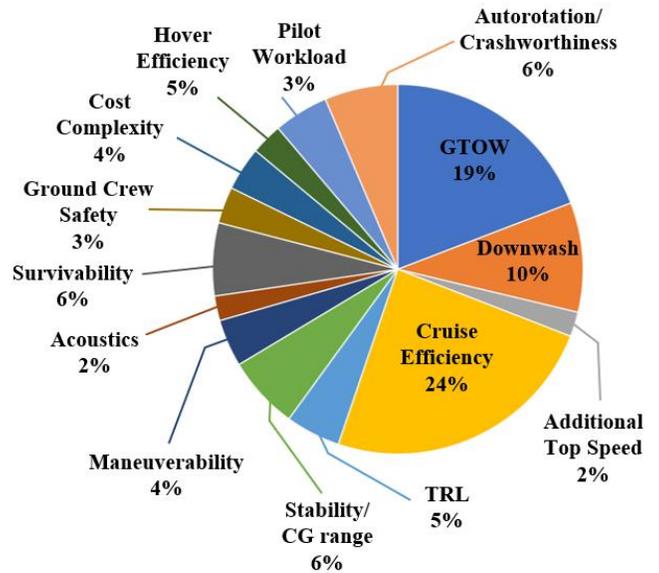
Comprehensive Trade Study Result:

Jet Assist Tilt-Rotor

- **Turboshafts assisted in cruise**
- **High efficiency rotor airfoils**
- **5-bladed hingeless hub**
- **Two speed transmission**
- **Minimal downwash**
- **Multipurpose cargo bay**

Jet Assist Tilt-Rotor

Optimized Transonic Tiltrotor

- Arion's blades are optimized for a **Figure of Merit of 0.78** in 2k/85 F hover and a **propulsive efficiency of 0.68** in 450 knot (231.5 m/s) cruise
- New airfoil design and distribution unlocks high speed potential
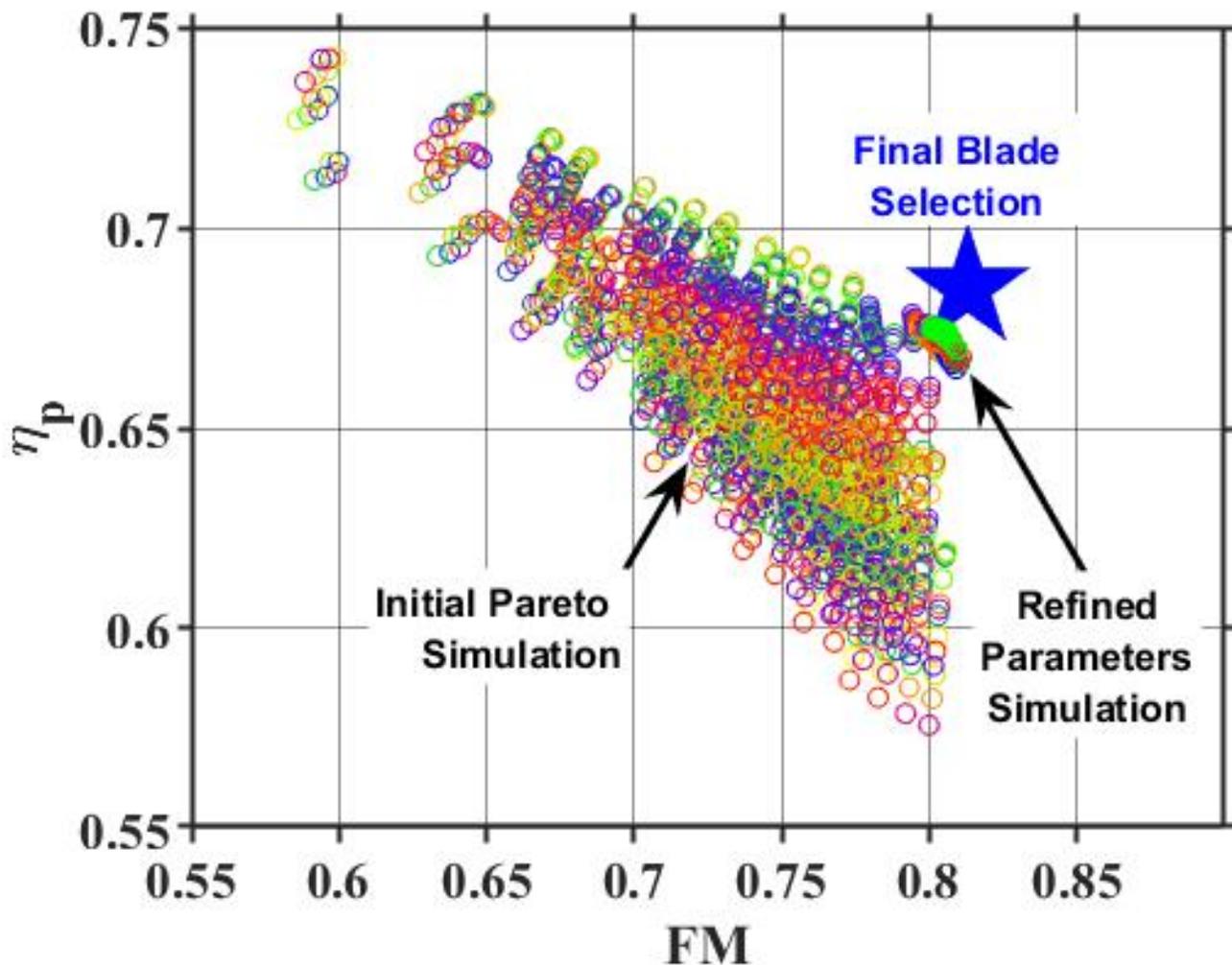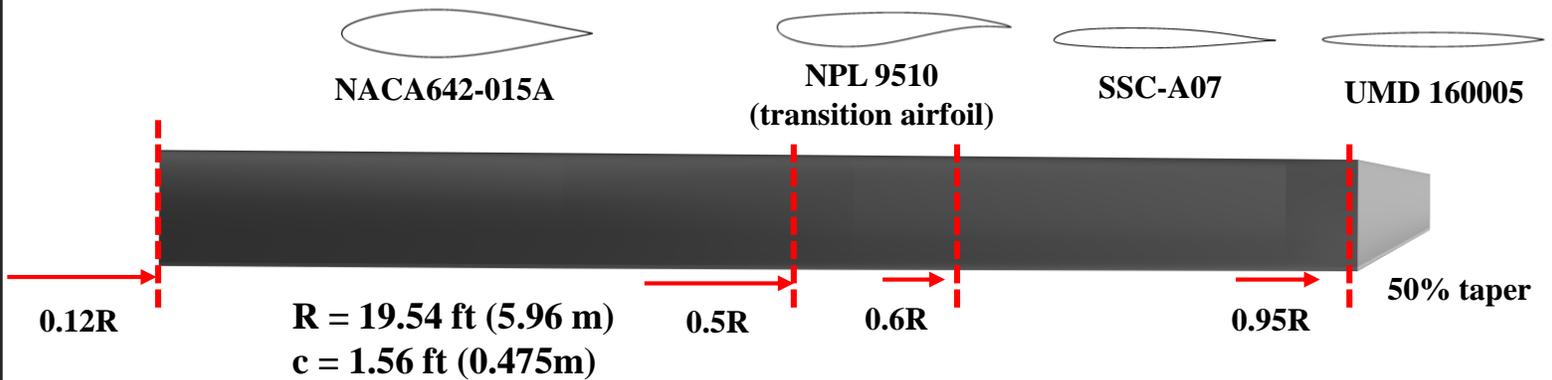
Novel Two Speed Transmission

- **54% reduction in shaft RPM removes twist compromise**
- **Slow speed cylindrical drum around drive shaft for lower RPM**
- **Automatically controlled dog clutch for shaft clutching/declutching**

1) **Slow Speed Outer Drum**
2) **Dog Clutch (Rotor Side)**
3) **Dog Clutch (Drive Side)**
4) **Hydraulic Bearings**
5) **Drum Gear**
6) **Spring Loaded Solenoid**
7) **Spring for Solenoid**
8) **Drive Shaft**
9) **Drum to Slow Speed Drum**
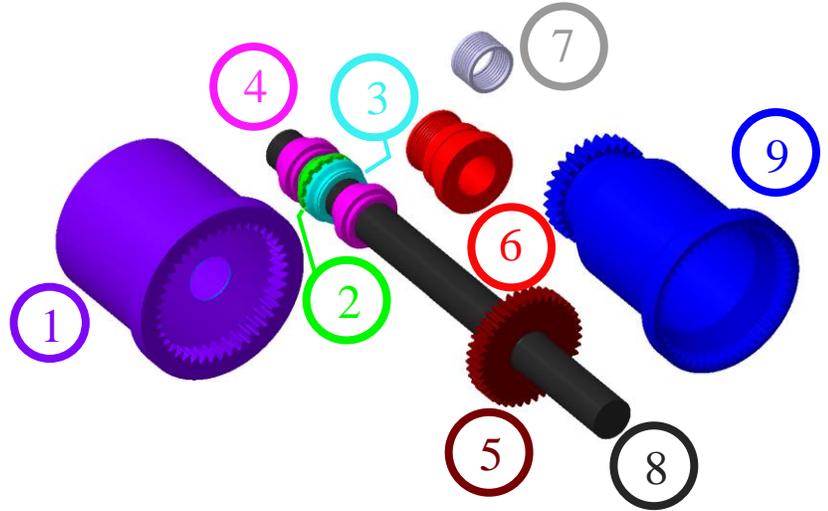
De-clutched, Slower RPM in cruise
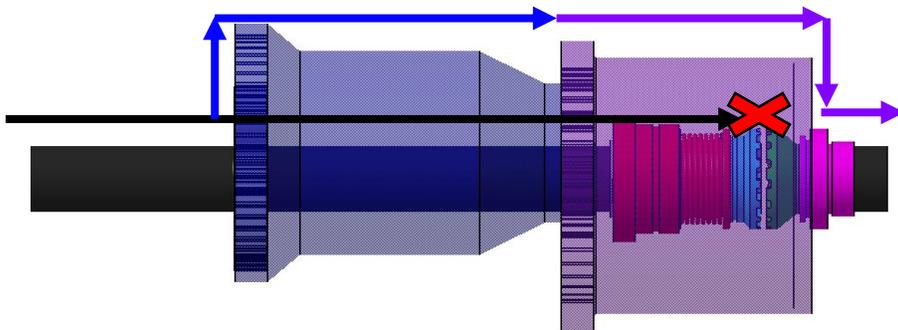
Spring loaded, declutched

Clutched, Fast RPM in hover

Sprag clutch passes faster RPM
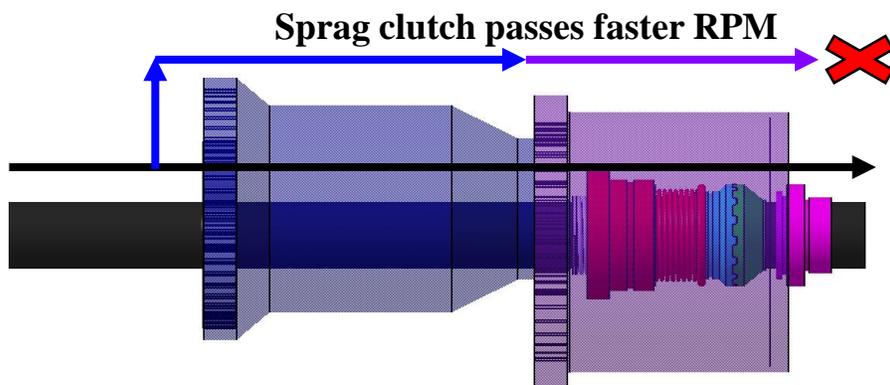
Spring engaged, clutched

UNIVERSITY OF
MARYLAND

Flutter-free Hingeless Hub

Hingeless for flutter-free flight. 5-bladed to minimize vibrations. Advanced in-house digital X3D design confirms dynamic stress limits.

1. **Mast Retention/Spinner Mount**
2. **Hingeless Flexbeam/Collar**
3. **Pitch Case/Pitch Horn**
4. **Pitch Links**
5. **Rotating Fastener**
6. **Low Friction Sleeve**
7. **Rotating Swashplate**
8. **Ball Bearings**
9. **Scissor Links (Top rotating, Bottom nonrotating)**
10. **Non-Rotating Swashplate**

12% R
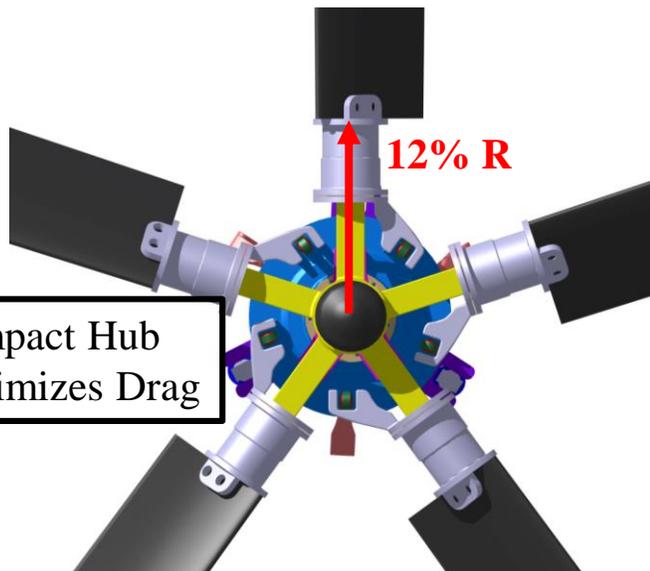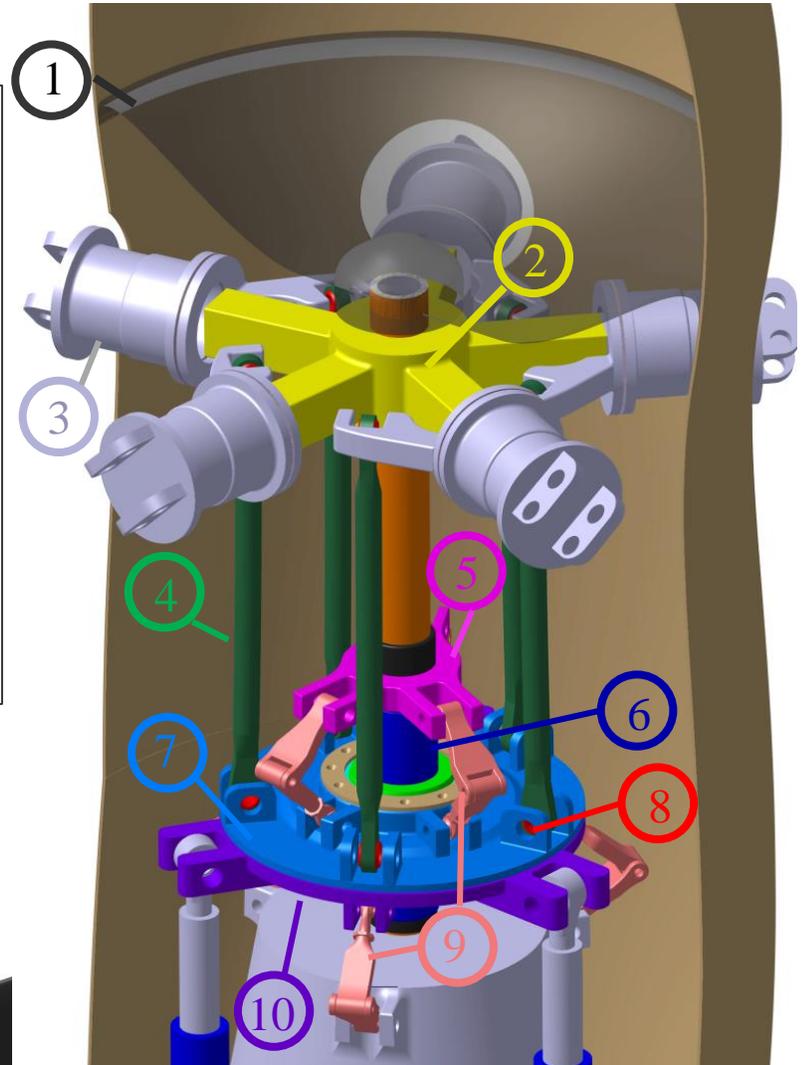
Compact Hub Minimizes Drag

- **Stiff in flap and lag** prevents ground resonance, mitigates whirl flutter
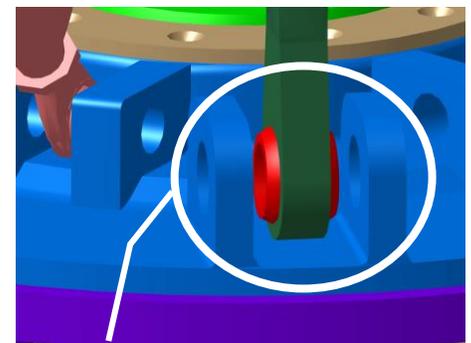
Ball Bearing, Spacing Ensures 80^0 Collective Range

Aerodynamically Optimized Fuselage

- **Fast deployable rear ramp**
- **Fuselage shape optimized for min compressibility & vortex drag**
- **Advanced in-house multi-solver CFD**

Initial Fuselage
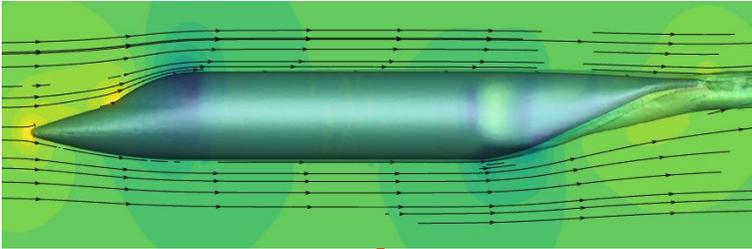
Final Streamlined Fuselage
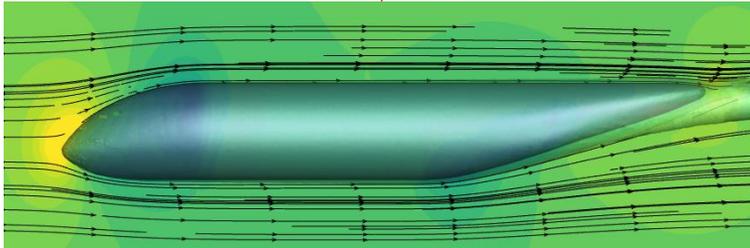
54% Reduction in Download
45% Reduction in

## Final Fuselage
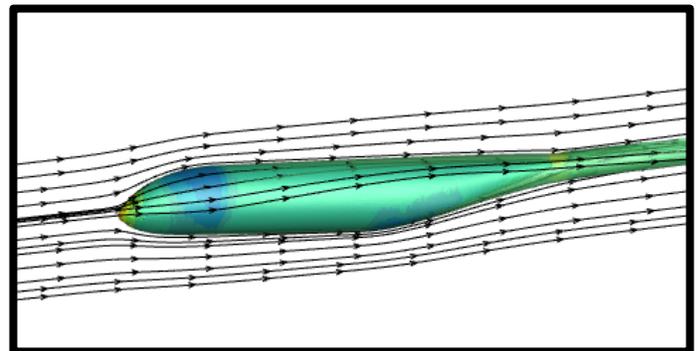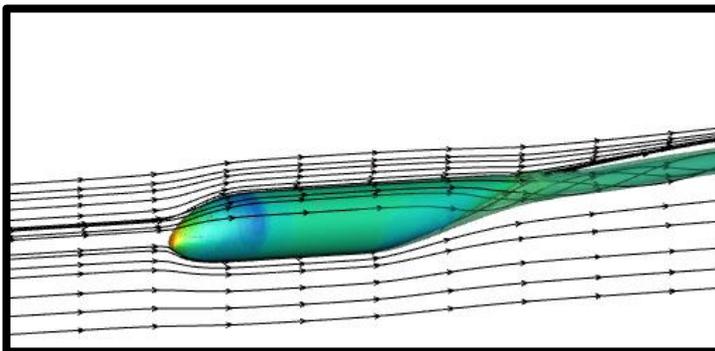
Optimal fuselage angle in cruise: 2.5 degrees
Minimizes rear vortex

Low-drag Lightweight Dipped Transonic Nacelle

Swashplate Actuators

Two Speed Transmission

Bevel Gear

Conversion Actuator
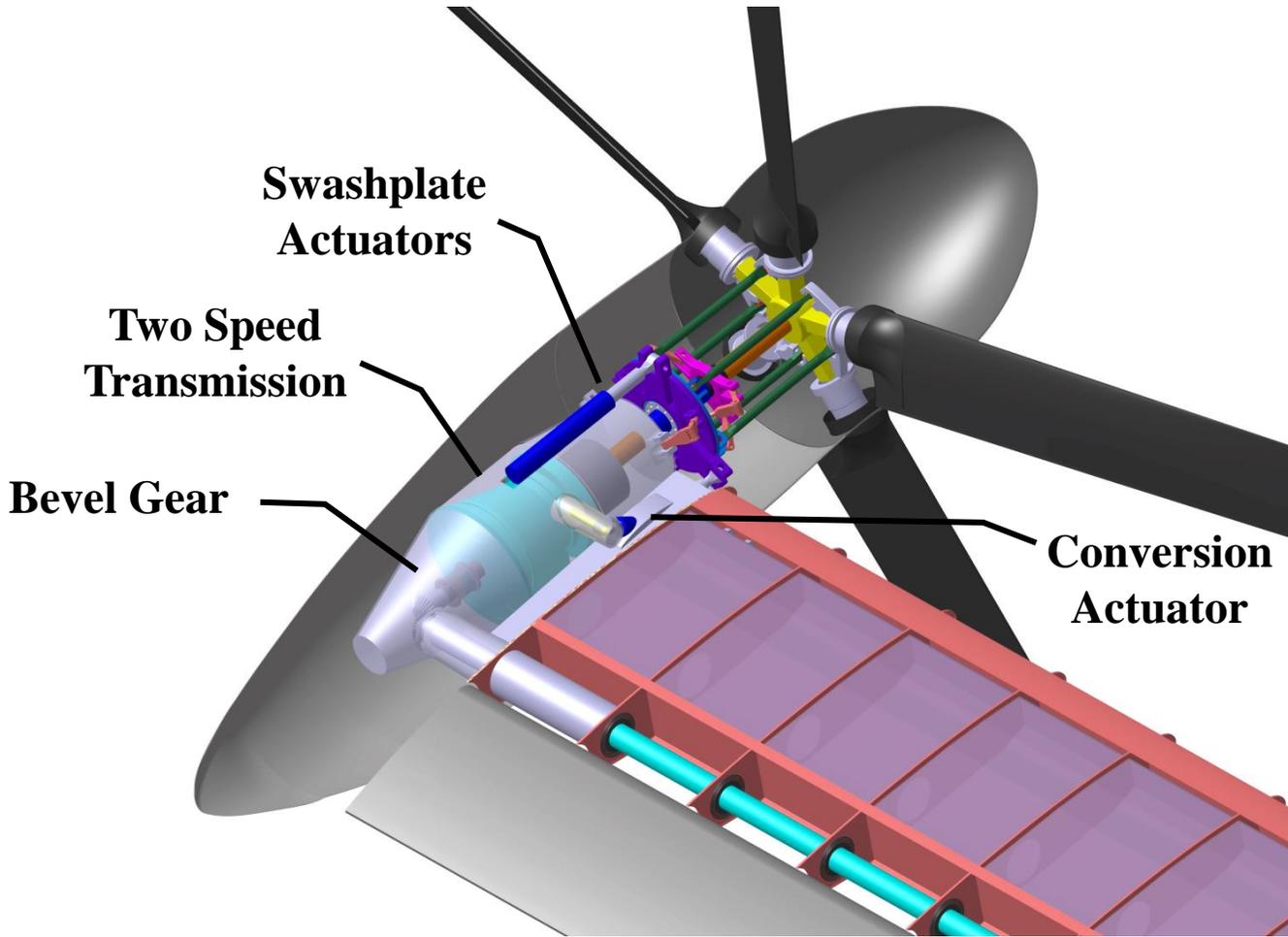
Engineless nacelle leads to no additional outwash due to engine exhaust in hover, minimizing FOD.

Area ruled flow over spinner decreases transonic drag
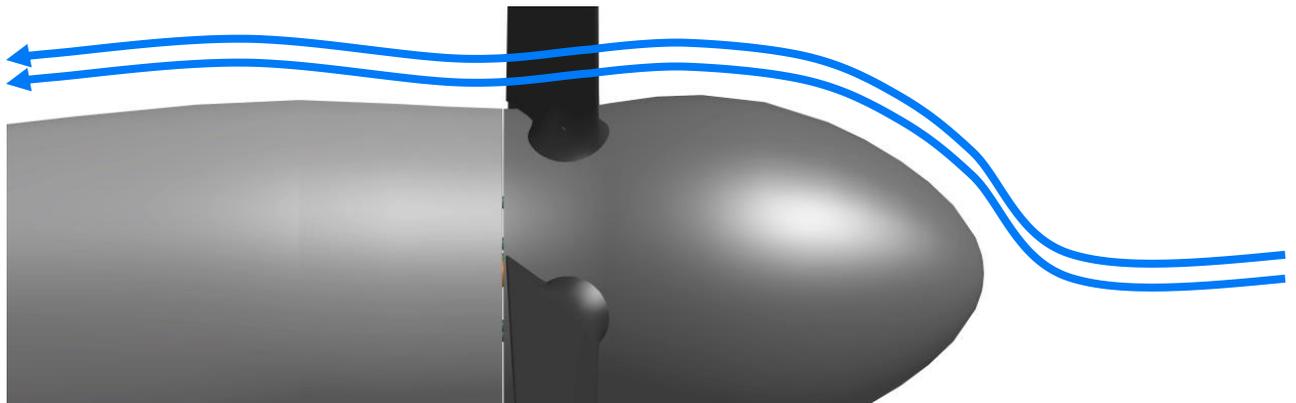
Innovative Lightweight Airframe

Anisometric geodesic fuselage pattern
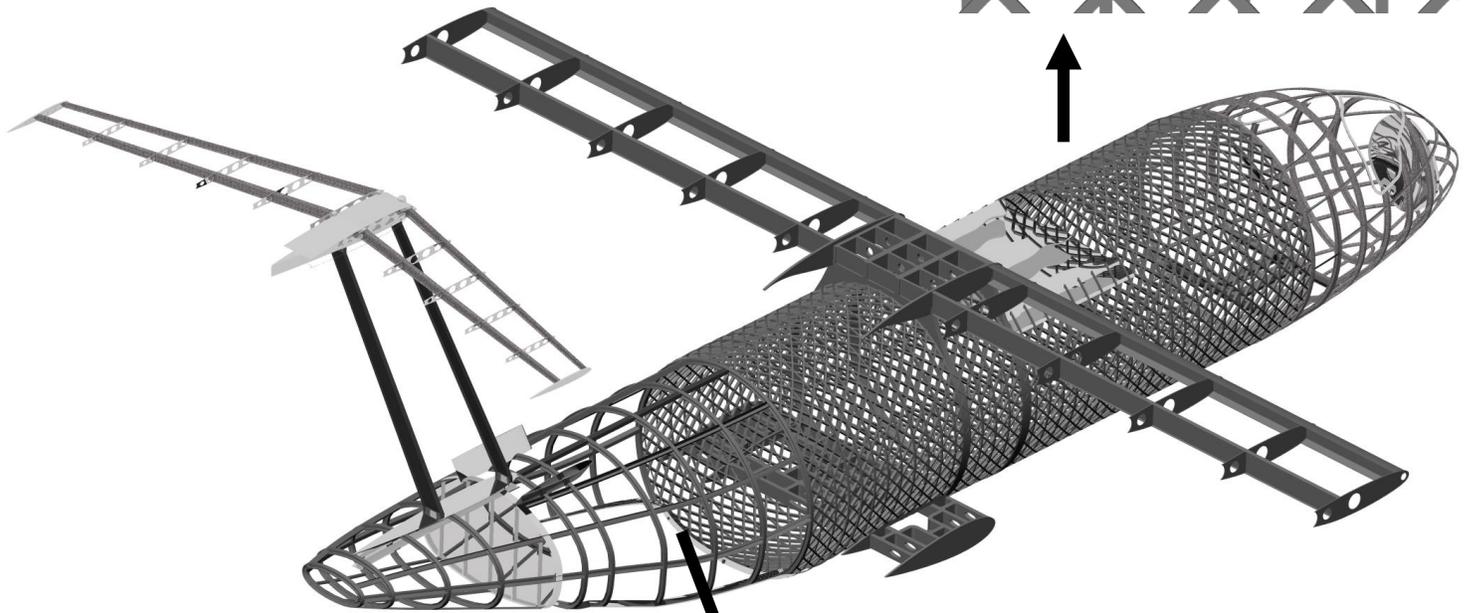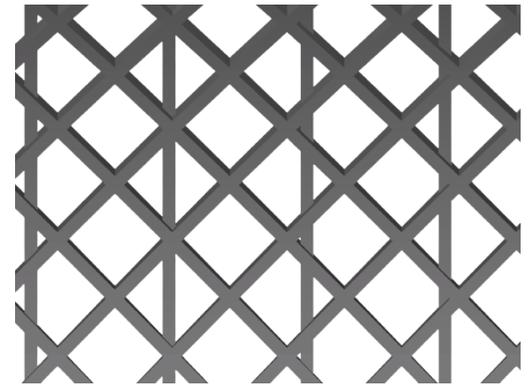
Bulkhead for ramp
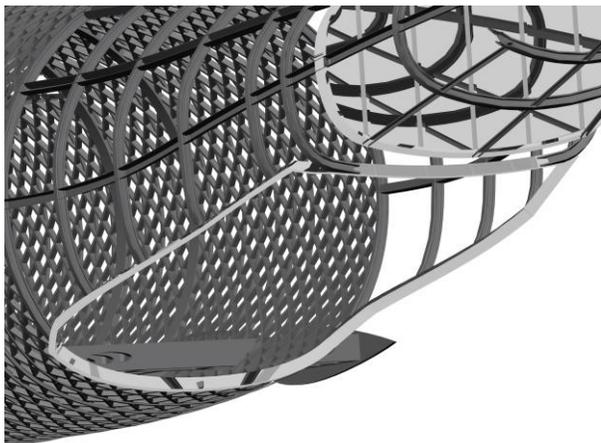
Composite longerons and bulkheads

Structurally Efficient Flutter-free Thin Wing

- **13.4% thin wing needed for highspeed flight**
- **Wing/Fuselage structure must survive 3.5 limit load factor**
- **Composites, continuous wing structure, and skin torque box maximize thin wings capabilities**

Carbon-Epoxy Skin

Continuous composite I-beam
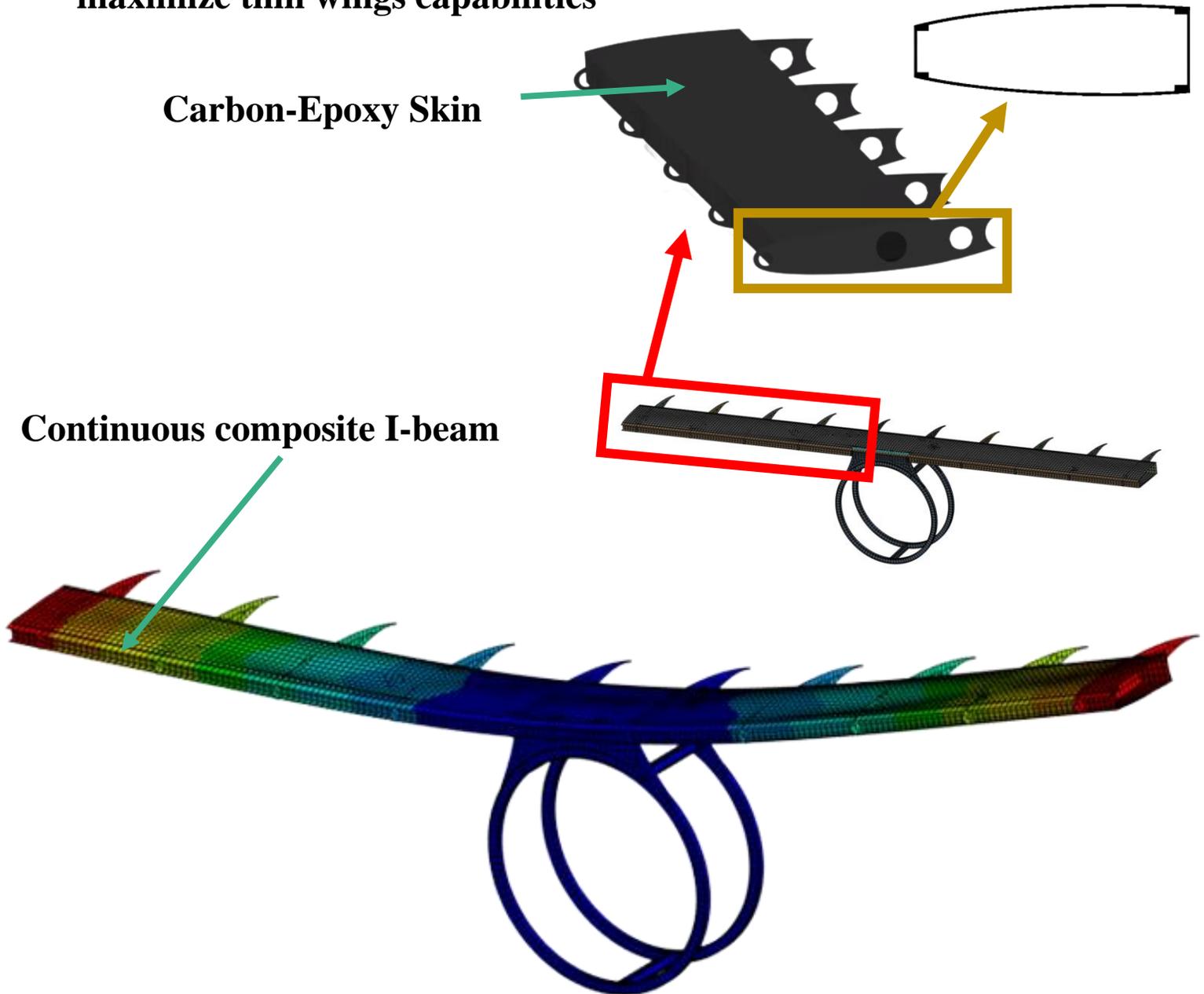
- **FEM: 3.5g distributed load on continuous wing structure**
- **Factor of Safety of 3.8**
- **Flutter-free up to 500 knots**

UNIVERSITY OF
MARYLAND

X3D-based Blade Structural Design

Carbon Epoxy

Rohacell-51

Unidirectional Carbon Epoxy D Spar

Tungsten Carbide LE weight

Deicing System

Polyurethane FOD resistant strip

Factor of Safety of 4.0

5% Thick

7% Thick

15% Thick

Axial Stresses (Pa)

S11: -5E+07 -3E+07 -1E+07 1E+07 3E+07 5E+07

Hover - θ_{75}=13.66°

3F/T/L

1T

2F/T

1L/F/T

1F/L

Natural Frequency (Hz)

Ω (RPM)

8/rev 7/rev 6/rev 5/rev 4/rev 3/rev 2/rev 1/rev

Flap: 1.14
Lag: 1.44

Cruise - θ_{75}=74.06°

3F/T/L

1T/F

2F/T/L

1L/F

1F/L

Natural Frequency (Hz)

Ω (RPM)

8/rev 7/rev 6/rev 5/rev 4/rev 3/rev 2/rev 1/rev

Flap: 1.67
Lag: 3.45

UNIVERSITY OF MARYLAND

Advanced Cockpit: Maximizing Pilot Performance

- Extra visibility despite high-speed nose configuration
- Controls optimized for power sharing tiltrotor operations
- Ergonomic arm rest included for both thrust and cyclic controls
- Adjustable crashworthy seats to meet 98% percentile pilots

Fused LIDAR/IR Landing Zone Evaluation

Electronic Navigation References

Weather Radar

Synthetic Terrain Visuals

Pylon Tilt Angle Control

Active Side-Stick Controller

Arm Rests for Pilot Ergonomics

Turbofan Thrust

Proprotor Thrust
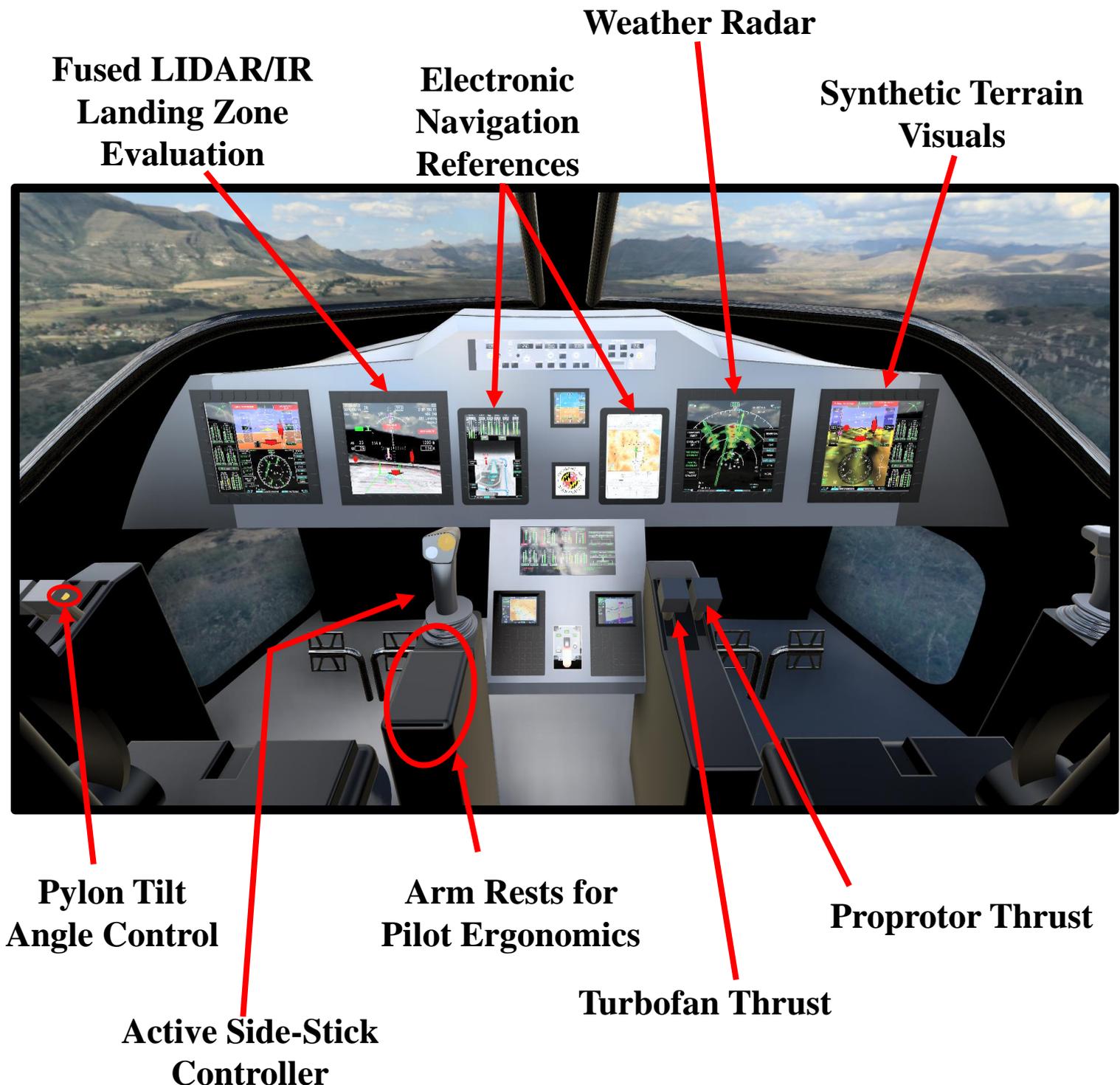
Advanced Avionics: Optimizing Pilot Performance

Arion's avionics architecture incorporates state of the art technologies for communication, navigation, control, and hostile threat countermeasures (CM). The fly-by-wire architecture makes piloting easy with dynamic inversion control laws to stabilize the aircraft in all modes and reduce workload. Smartly scheduled automation lets the aviator fight the mission, not the aircraft.

Source: Sierra Nevada Corp
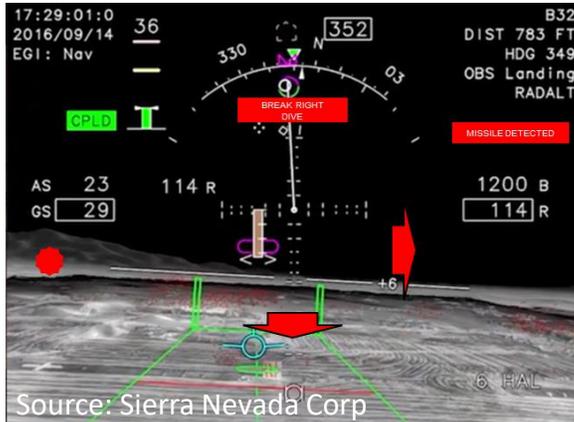
Arion boasts the first operational Landing Zone Situational Awareness, Guidance, and Evaluation (LZ-SAGE) system, adding obscurant penetrating LIDAR and EO/IR sensors into the navigation and control solution so degraded visibility doesn't mean degraded mission.

Modern communications suite features inter-aircraft mesh network allowing unprecedented collaboration for multi-ship missions. A full complement of line-of-sight and over-the-horizon comms enables real-time mission coordination.


Directed IR CM and flares

Self-defense systems automatically detect and respond to incoming threats, from small arms to missiles guided by laser, radar, and infrared (IR). Smart countermeasure (CM) dispensing characterizes the threat and deploys the optimal CM load to deny and defeat the threat.

UNIVERSITY OF MARYLAND

Stability and Control

Full aircraft in-house Non-Linear Stability and Control Modeling
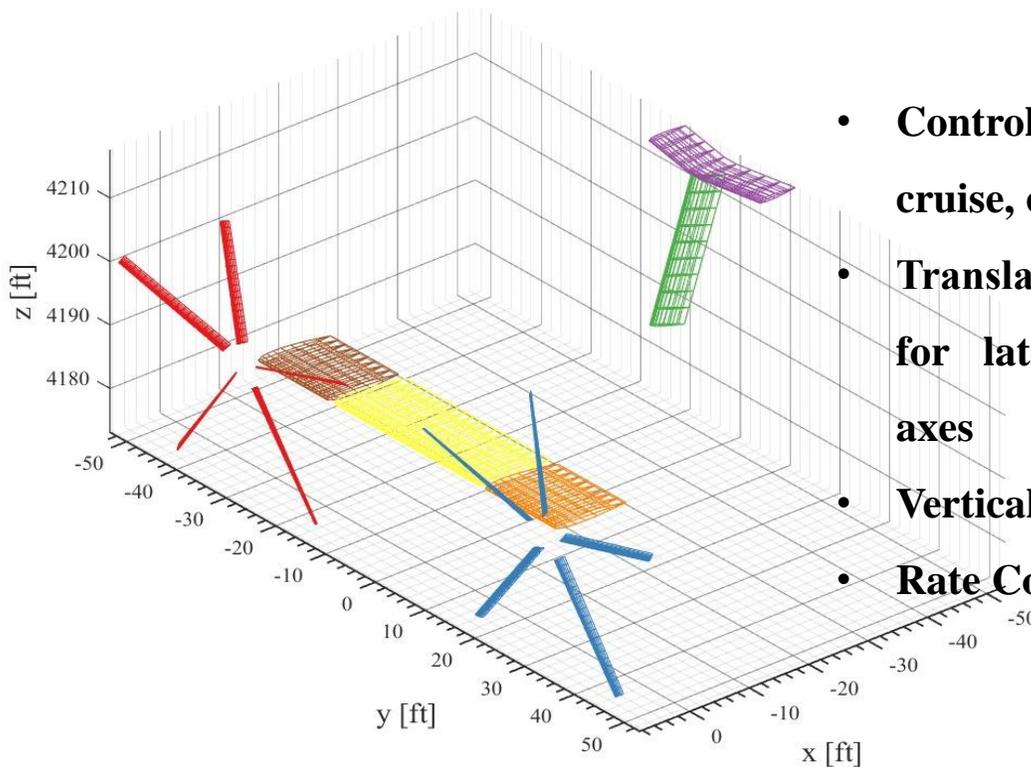
- **Control law design in hover, cruise, conversion**
- **Translational Rate Command for lateral and longitudinal axes**
- **Vertical Rate Command**
- **Rate Command Heading Hold**

Piloted Flight Simulation in X-plane:

- **V-22 pilot successfully flew hover, conversion, cruise at 450 kts, and returned to hover and land**
- **Automatic turbofan thrust management**
- **V-22 pilot successfully flew two-aircraft formation flight**

Screenshot of formation flight in X-Plane 12

Arion: Exceptional Performance

- **Superior L/D at high speeds and high altitudes**
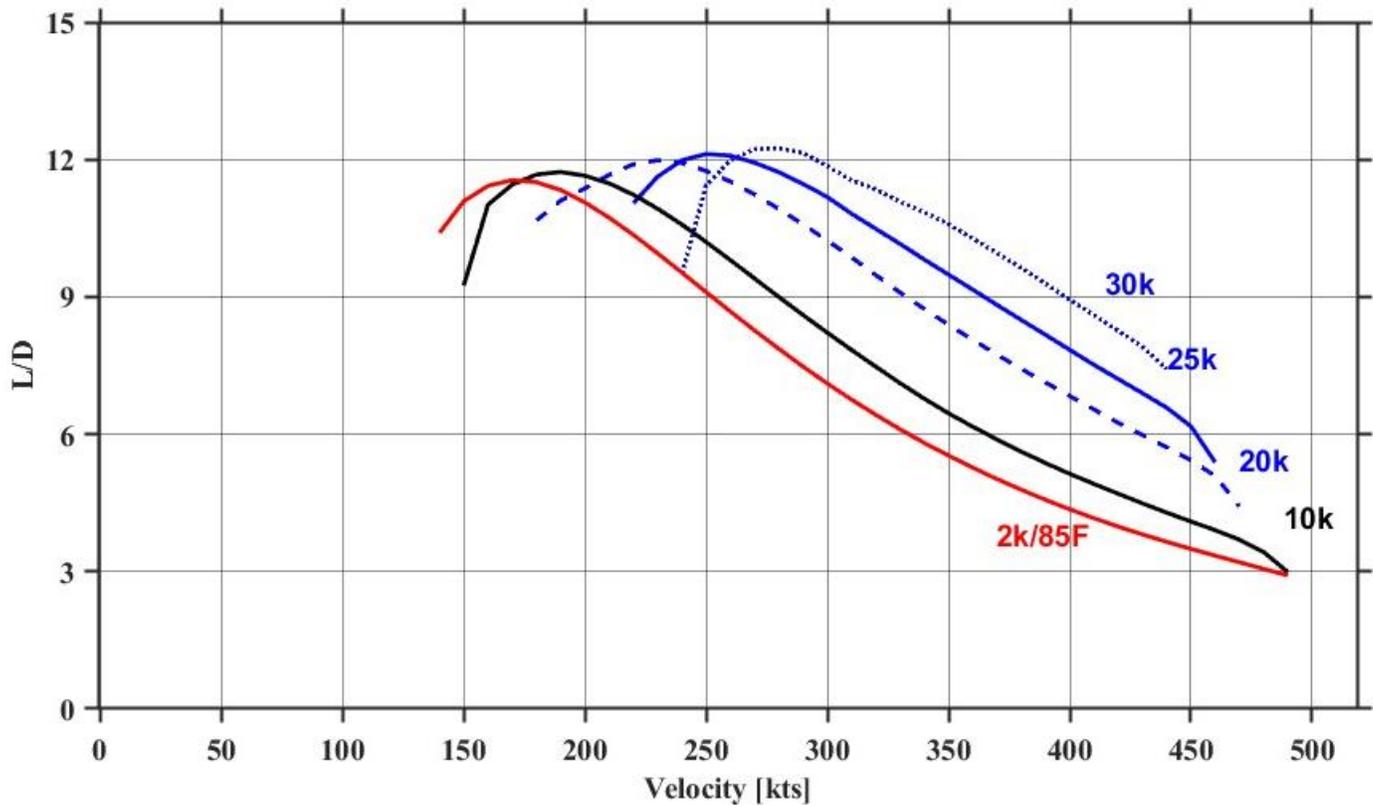
- **Above and beyond hover performance**
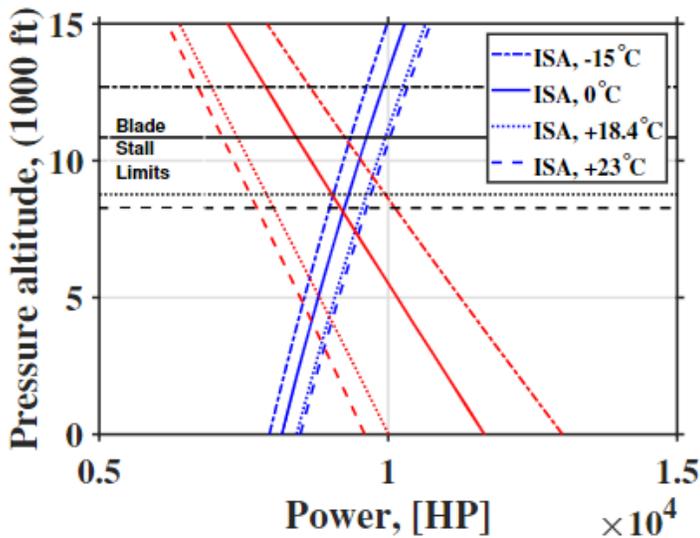
Hover Ceiling, 90% MRP
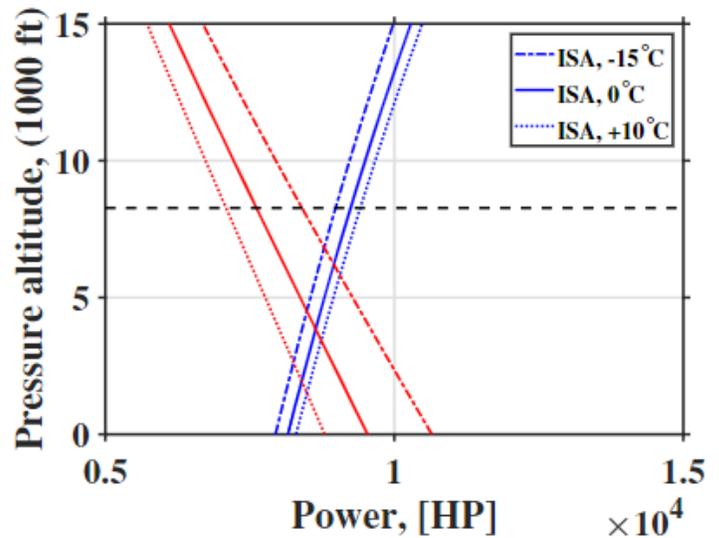
Hover Ceiling, 90% MRP

Summary

A modern vehicle for a modern military:

- **Exceptional performance in hover and cruise unlocks adaptability needed in a modern, highly contested environment**

Range:
- Maximum Range: 2562 nm
- Maximum Endurance: ~ 17 hours

Ground Operational capabilities:
- Rear ramp allows for rapid troop egress
- High rotor ground clearance
- Low disk loading minimizes outwash and FOD

High Speed VTOL Capabilities
- High speed flutter free operation past 450 knots at 28,000 ft
- Top speed: 490 knots
- Rapid climb speed: 9800 ft/min
- Low Altitude Dash: 450 knots

Affordability in a modern military:

- **US $116.5 million per unit cost**

- **$5949 per flight hour**

UNIVERSITY OF MARYLAND