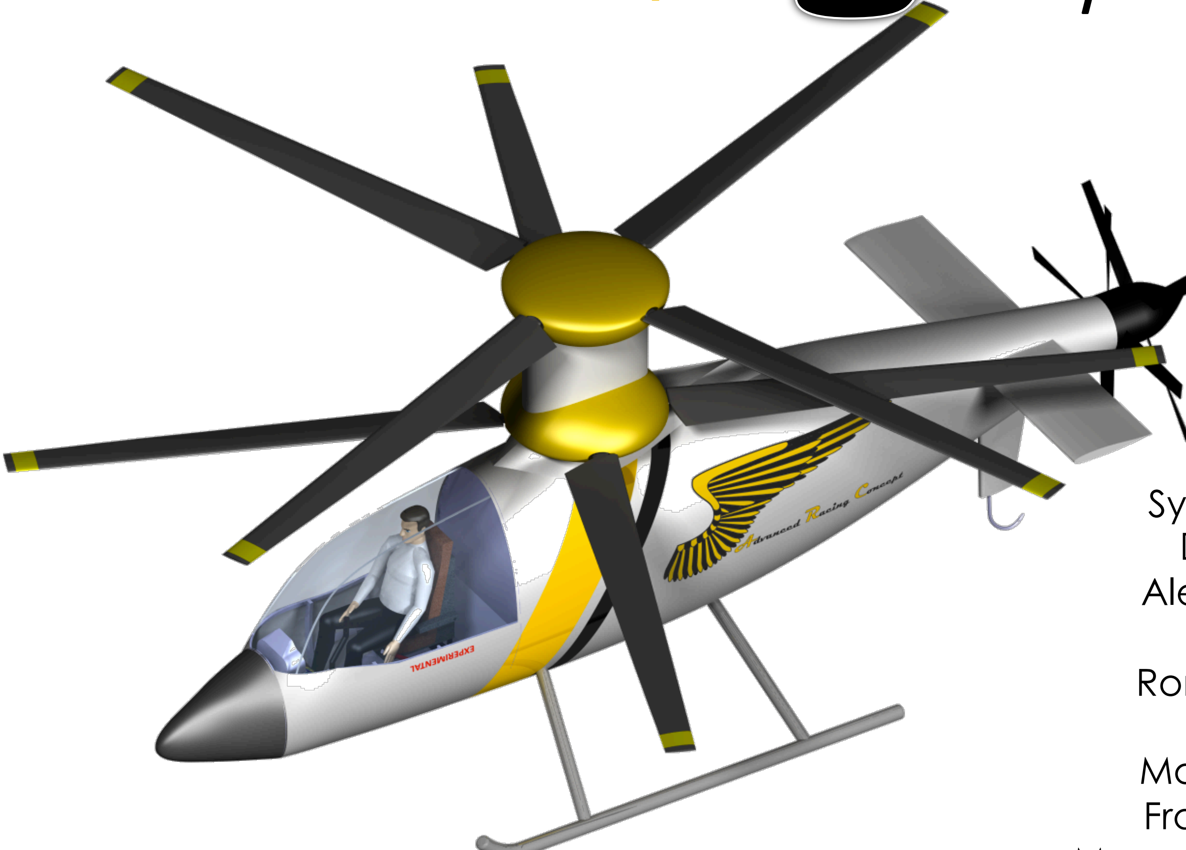
Advanced Racing Concept

Executive Summary



Sylvester Ashok
Dennis Garza
Alek Gavrilovski
Mike Jones
Romain Lamour
Ritu Marpu
Morgan Nowak
Frank Patterson
Manmohan Prasad
Venkatakrishnan Shankar
Emma Timson
Vatsal Vakharia

29th Annual American Helicopter Society
Student Design Competition
Graduate Team Submission

Georgia Institute of Technology & University of Liverpool, June 1, 2012

Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

Advanced Racing Concept

The Advanced Racing Concept (ARC) is a proposal for a rotary wing pylon racer response submitted by the Georgia Institute of Technology and the University of Liverpool graduate student team to the 2012 AHS Student Design Competition, co-sponsored by Sikorsky. Using advanced sizing, synthesis and optimization methods with careful design considerations, rather than immature and unproven technologies, the ARC meets all RFP requirements, and is poised for speedy development and production. The design was created, managed, and analyzed using cutting-edge tools, allowing for definitive system development.

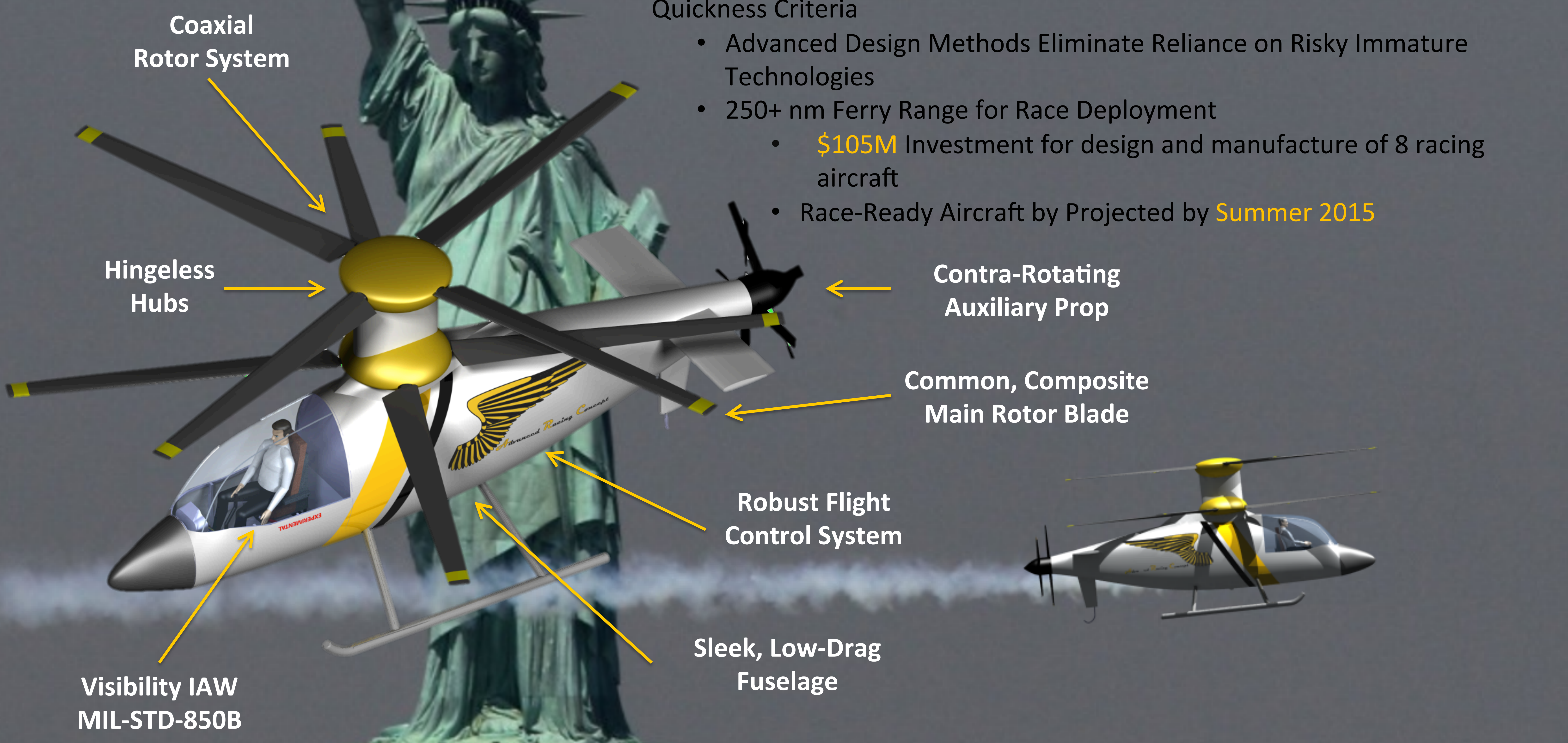
Designed for optimum performance, maneuverability, and agility, the ARC is a coaxial helicopter with a contra-rotating auxiliary propeller system. A stiff, hingeless hub with a common optimized blade provides an ideal platform for a racing vehicle while emphasizing risk adverse manufacturing simplicity. The flight control system uses state-of-the-art fly-by-wire control methods and advanced control laws to minimize pilot workload, balancing controllability and agility. With 655 installed horsepower and a sleek fuselage, the ARC can dash at 182 knots, and sustain a 3.9G turn.

Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

ARC Highlights

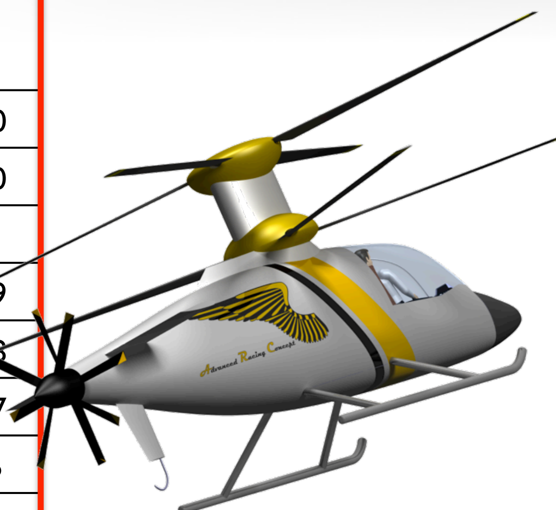
- Optimized for Maneuverability and Agility.
- 180+ knot Dash Speed
- 3.9 G Sustained Load Capability
- Compact System Design
    - Hingeless Coaxial Rotor System with Blade Root Actuated IBC
        - Common Rotor Blade Ideal for Low Power and Maximum Loading
            - ADS-33E-PRF Level 1 Handling Qualities for all Stability, Bandwidth, and Quickness Criteria
                - Advanced Design Methods Eliminate Reliance on Risky Immature Technologies
                - 250+ nm Ferry Range for Race Deployment
                    - $105M Investment for design and manufacture of 8 racing aircraft
                    - Race-Ready Aircraft by Projected by Summer 2015



Advanced Racing Concept

Un-Paralleled Performance

	MBB Bo 105	MD 500E	ARC
General Vehicle Performance			
Dash Speed (SLS/IRP) (KTAS)	140	152	182
Best Range Speed (SLS) (KTAS)	110	120	125
Rate of Climb at SL (ft/min)	2080	1776	4280
Vertical RoC at SL (ft/min)	1400	1000	3800
Vehicle Physical Characteristics			
Max Gross Weight (lbs)	5731	3550	3289
TakeOff Gross Weight (lbs)	5291	3000	2888
Empty Weight (lbs)	3024	1517	2587
Rotor Radius (ft)	16.2	13.7	12.6
Engine MRP (hp)	800	450	655
Disk Loading (lb/sqft)	6.95	6.02	6.57
Power Loading (hp/lb)	0.140	0.15	0.199
Range (external fuel) (nm)	482	290	271

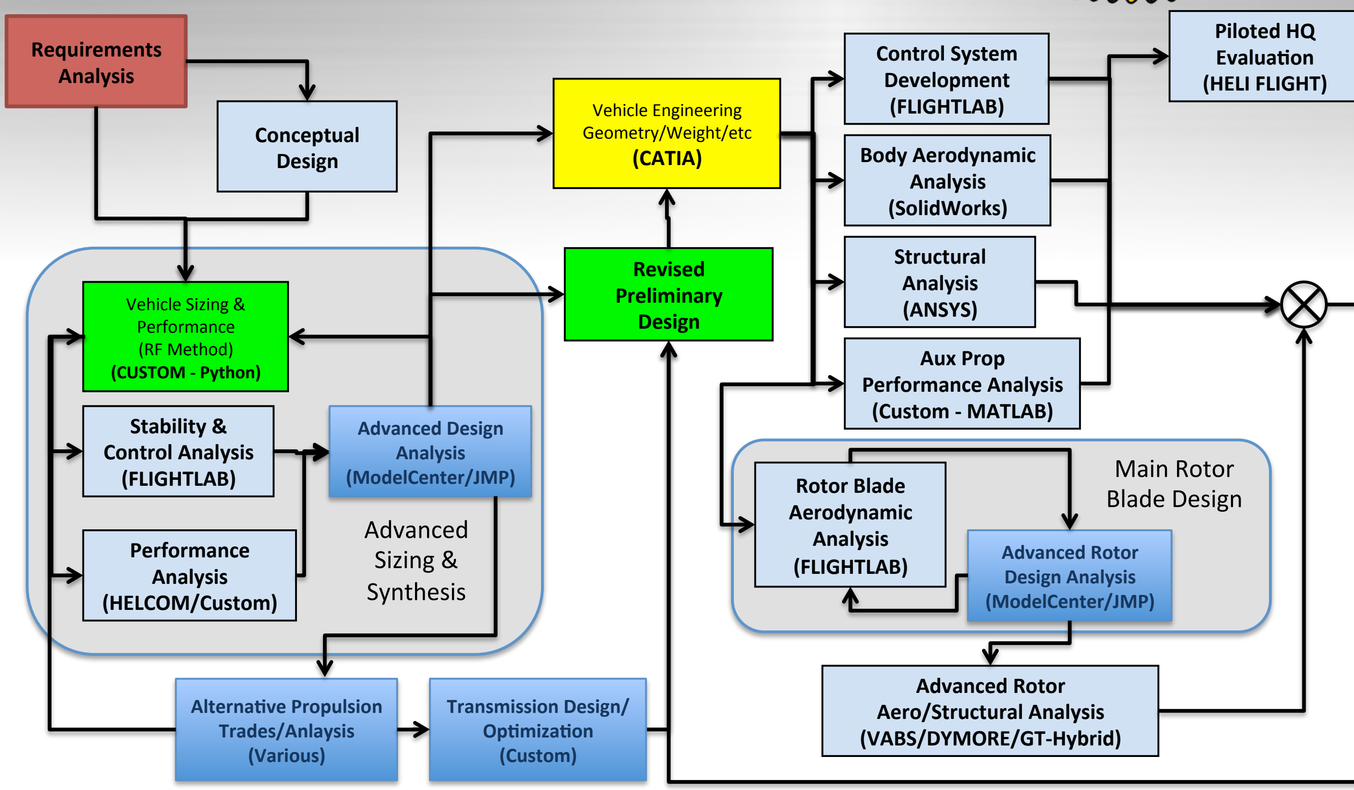


Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

Design Methodology Overview

Advanced Racing Concept



The ARC design methodology translates the requirements defined in the RFP into a premier performance, maneuverability and agility machine. This Integrated Product and Process Development (IPPD) cycle focuses on multi-objective tradeoffs, design for an accelerated program schedule, and system affordability. An advanced synthesis and sizing design loop, a main rotor blade optimization, a comprehensive propulsion study, and an advanced transmission optimization were among the critical elements of the design process. Ultimately, utilization of advanced methods and cutting-edge tools for design and analysis gave rise to convergence on an optimum solution.

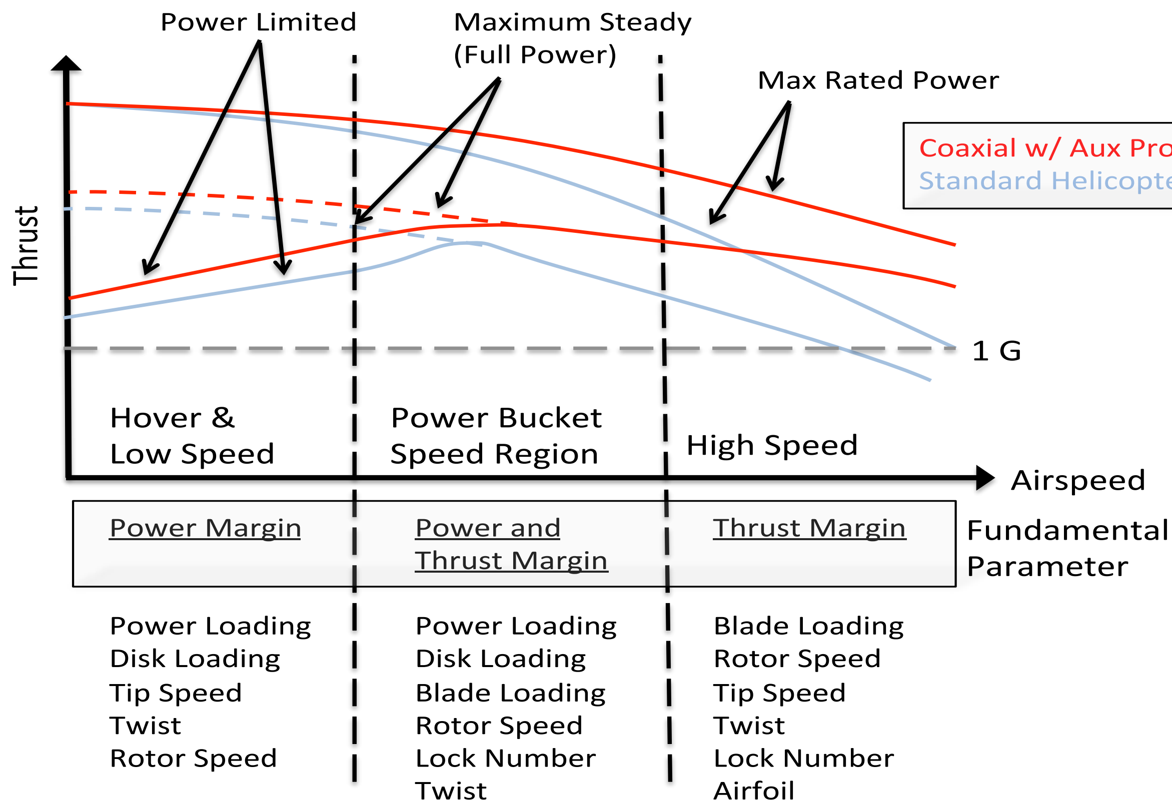
Georgia Institute of Technology

University of Liverpool

Ideal Racing Concept

Advanced Racing Concept

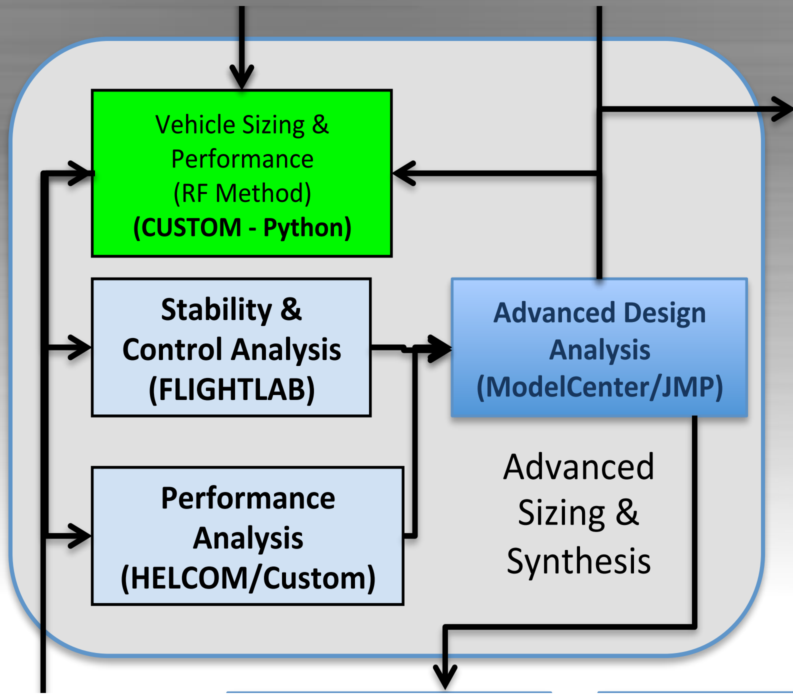
- **Blade Loading** – greater margin for maneuverability
- **Controllability** –symmetry of lift, increased control power, increased maneuverability at high speeds, reduction of control coupling
- **Compact** – smaller rotor diameter to fit through pylons
- **Efficiency** – no engine power for anti-torque, empirically lower gross weights for given power.
- **Partially Unloaded Main Rotor** – Aux prop provides large portion of propulsive force to partially unload main rotor for high speed maneuverability



- Improvement in all Parameters Fundamental to Maneuverability and Agility
- Increased Power and Thrust Margin Throughout Envelope
- Perfect Platform for Efficient Racing Machine

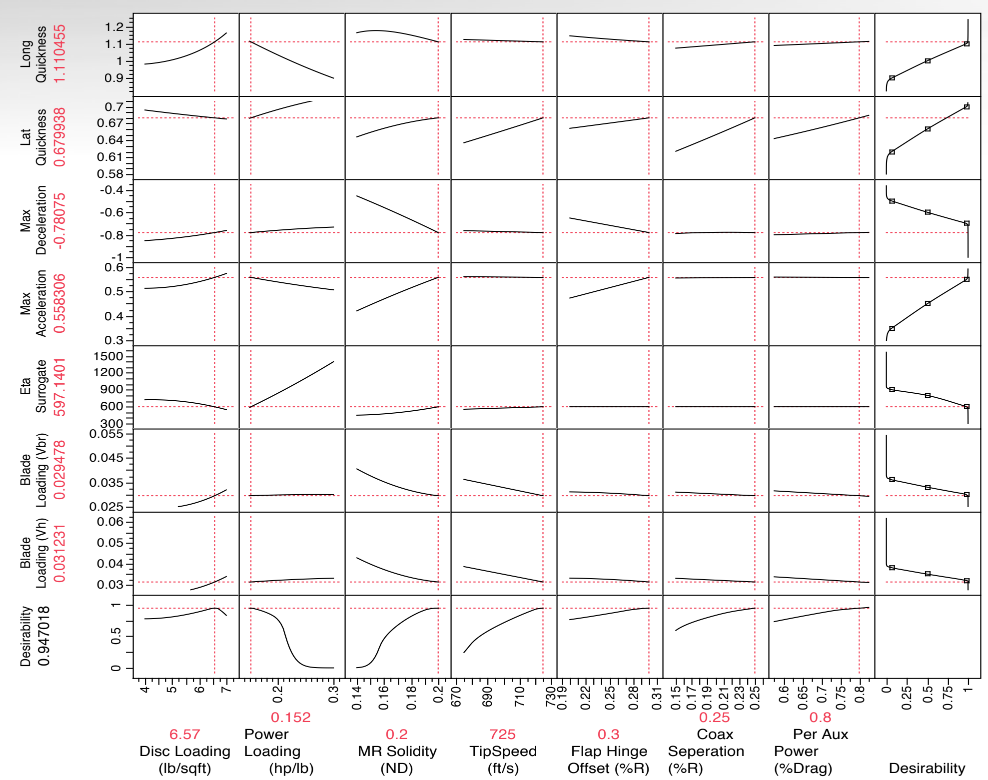
Georgia Institute of Technology

University of Liverpool

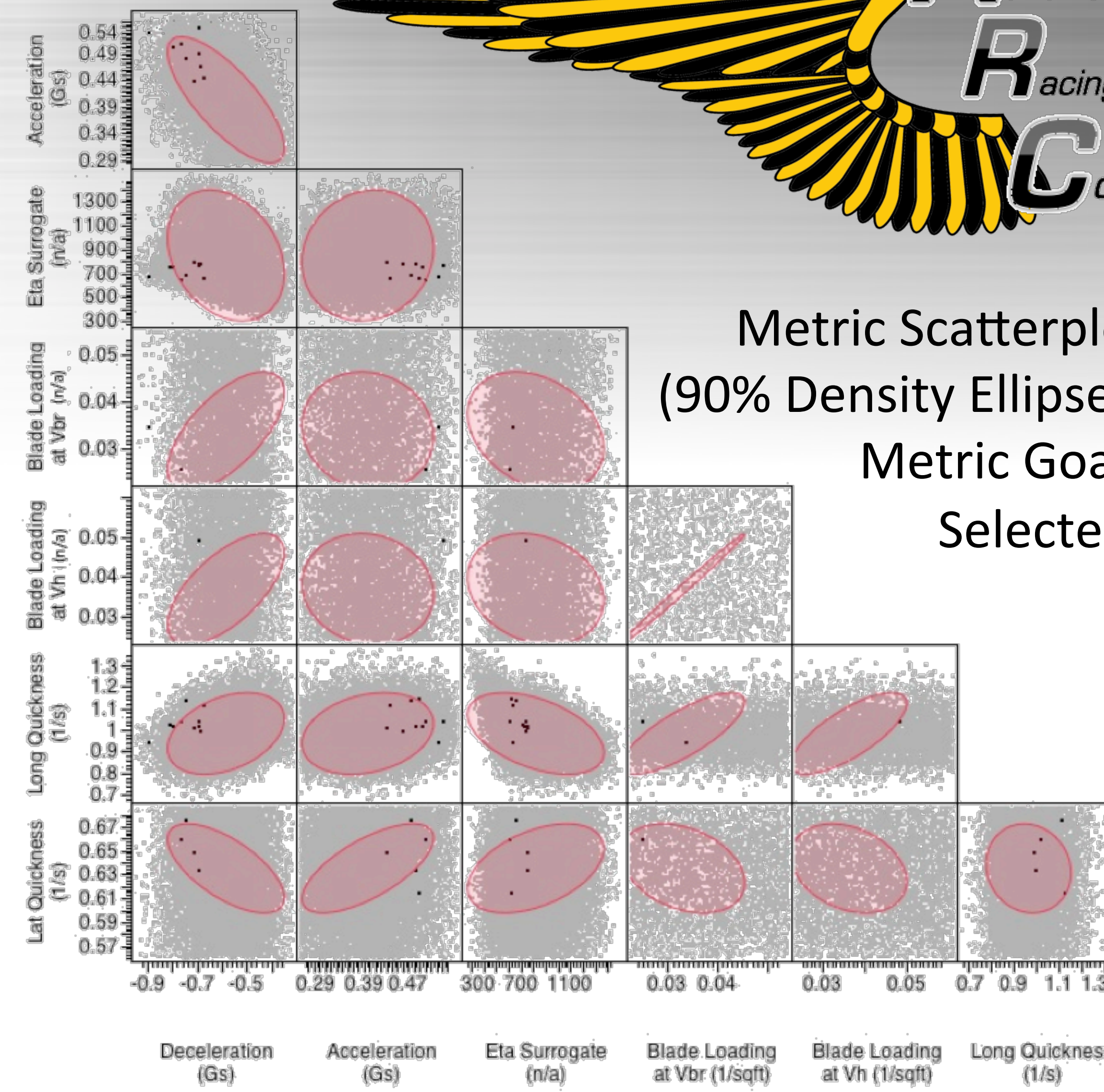


Advanced Design Methodology

Sensitivities & Desirability



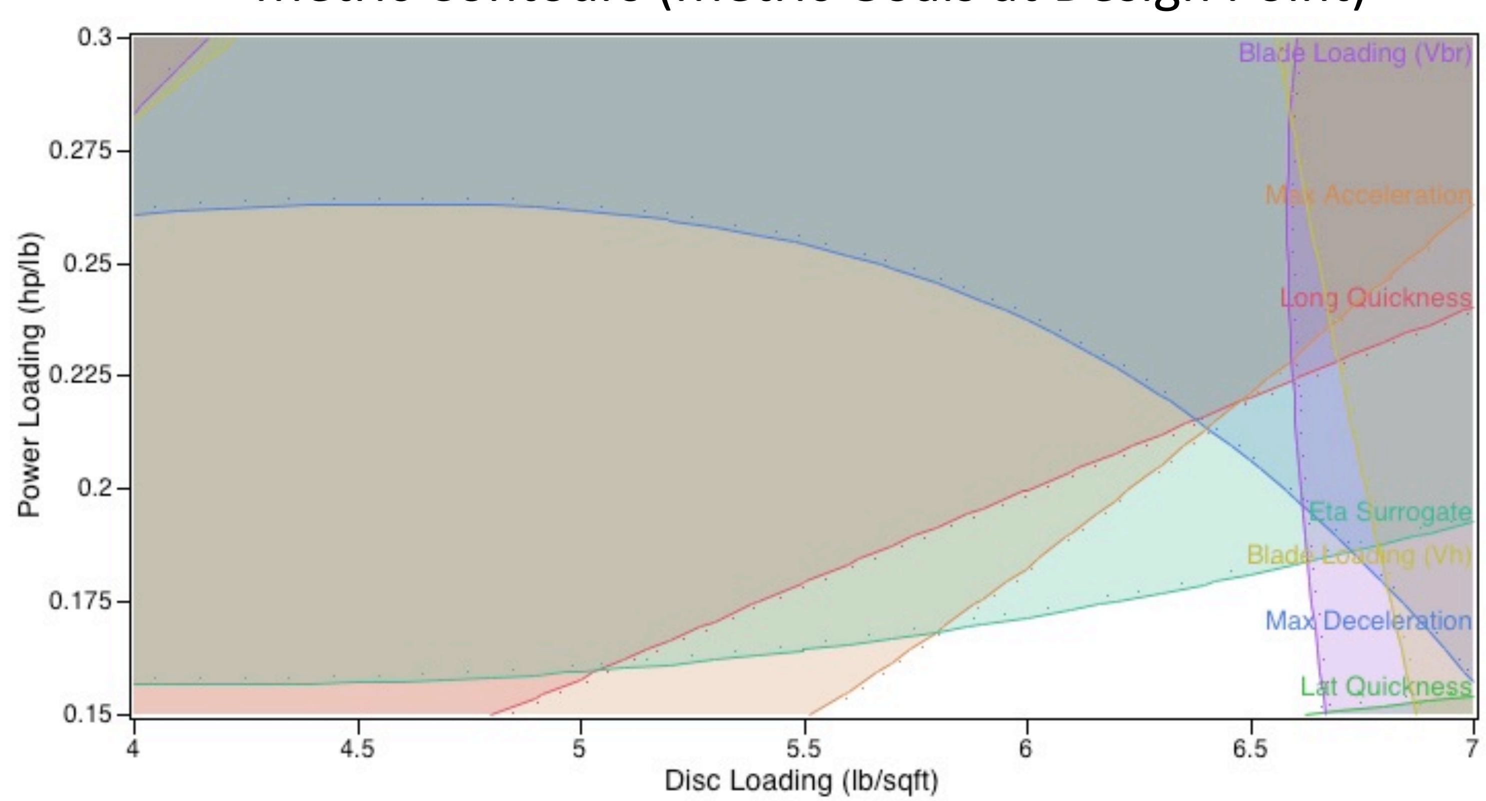
Metric Scatterplot (90% Density Ellipses, Metric Goals Selected)



Using ModelCenter®, a custom Augmented RF method script was integrated with FLIGHTLAB and custom analysis in MATLAB to quickly perform sizing, synthesis, and analysis on proposed designs. Surrogate models were employed through Design of Experiments to thoroughly but quickly explore a large design space. Exploration allowed for an understanding of design metric interaction. JMP® statistical software was utilized to perform probabilistic design techniques, and select the optimum design for a coaxial pylon racer.

Design Metric	Units	Desire	Goal Value
Steady Blade Loading at V_{BR}	1/ft^2	Minimize	< 0.033
Steady Blade Loading at V_H	1/ft^2	Minimize	< 0.035
Max Longitudinal Acceleration	Gs	Maximize	> 0.45
Max Longitudinal Deceleration	Gs	Maximize	< -0.6
Lateral Quickness	1/s	Maximize	> 0.66
Longitudinal Quickness	1/s	Maximize	> 1.0
Surrogate Eta Function (η_{sur})	n/a	Minimize	< 800

Metric Contours (Metric Goals at Design Point)



Optimized Design Point

Design Parameter	Optimized Value
Disk Loading	6.57 lb/sqft
Power Loading	0.152 hp/lb
Solidity	0.2
V_{tip}	725 ft/s
Aux Prop Power	80 % Drag
Rotor Hinge Offset	30 % radius
Rotor Separation	25% radius

Advanced Racing Concept

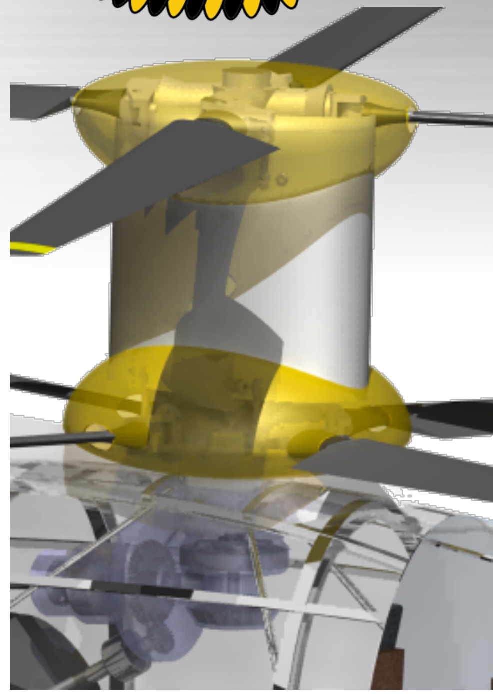
Georgia Institute of Technology

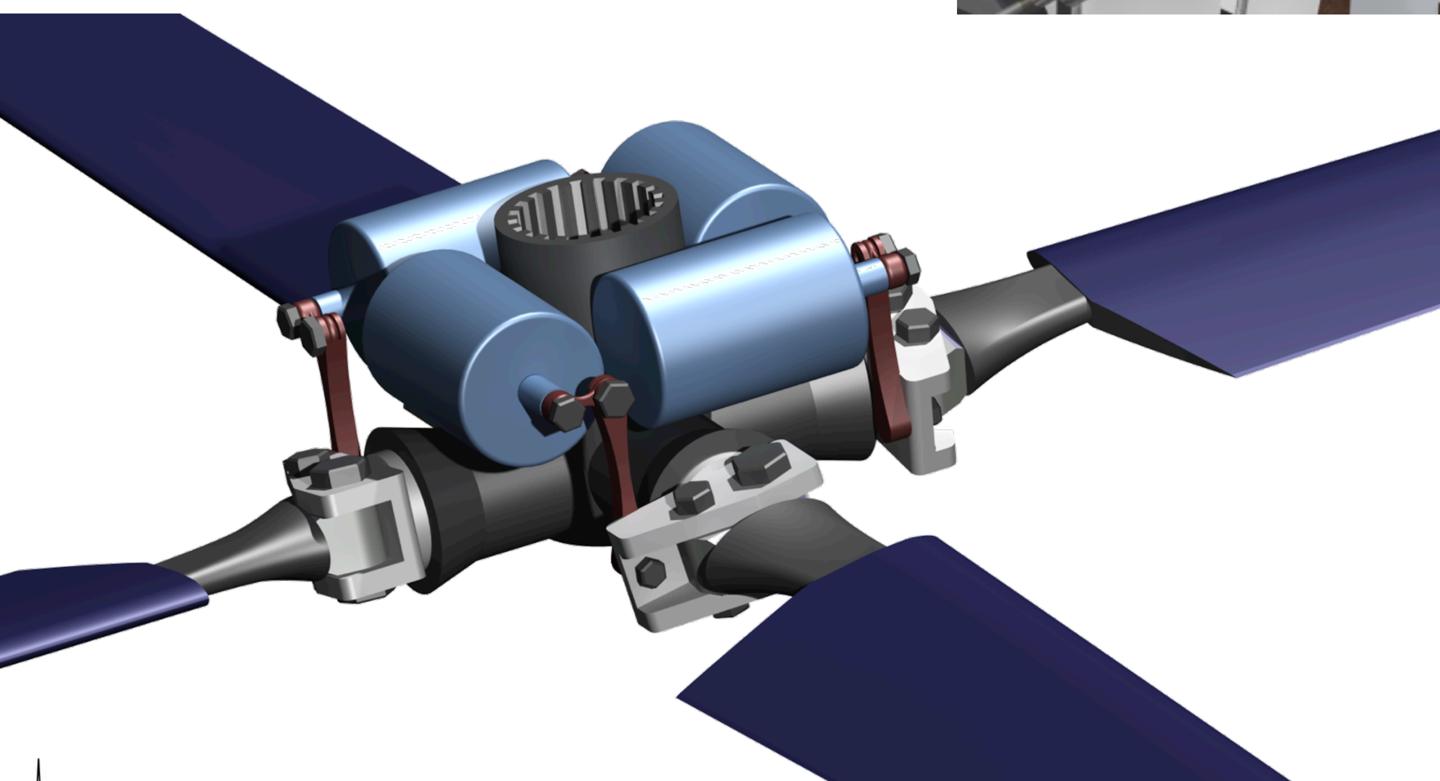
UNIVERSITY OF LIVERPOOL

Main Rotor System

Advanced Racing Concept

A state-of-the-art, hingeless coaxial rotor system has been designed to provide the ideal base for a highly maneuverable and agile aircraft. A common rotor blade for both rotors reduces manufacturing complexity and system cost. The optimized blades use a simple linear taper and twist to further reduce cost and risk. Each hingeless, titanium hub houses the blade root actuators, which are powered through a hydraulic slip ring, and controlled by the robust flight control system. A static mast system has been incorporated in order to relieve transmission and transmission mount loads, transferring hub moments and loads to the main fuselage structure.





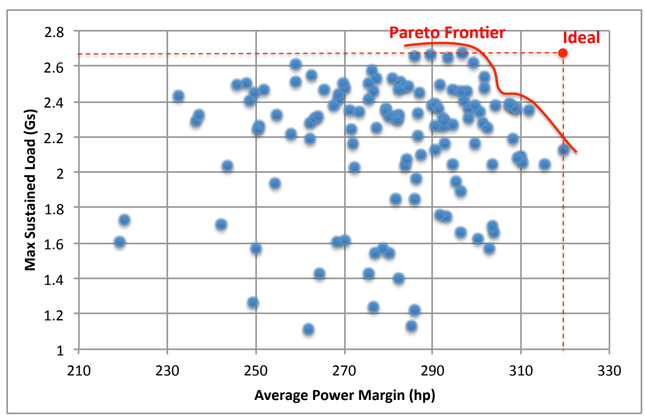
Georgia Institute of Technology

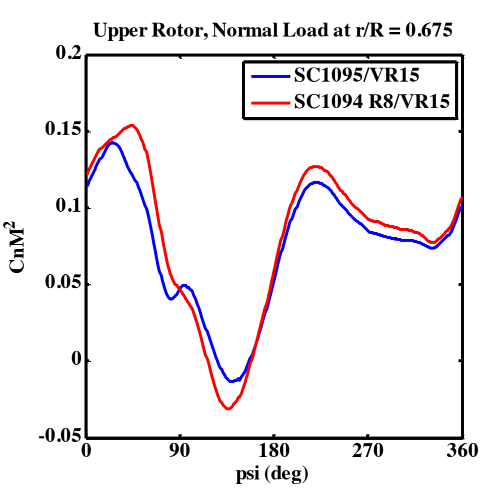
University of Liverpool

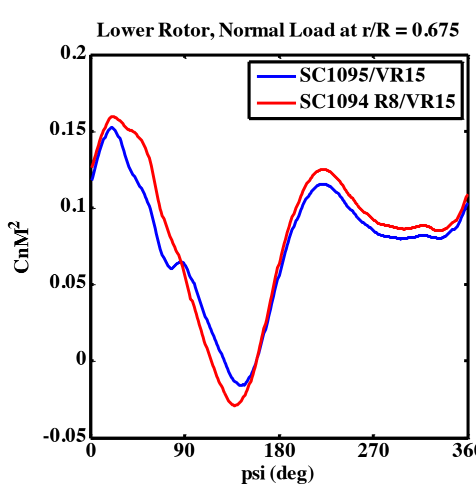
Ideal Rotor Blade

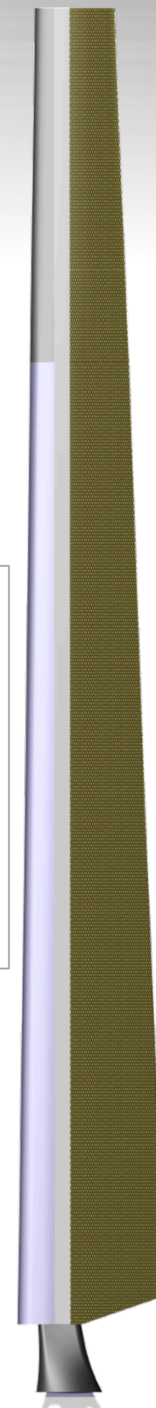
- Advanced blade optimization used to design the ideal blade for both minimum power consumption and maximum blade loading
- Common blade for both rotors with relatively simple design to minimize manufacturing development and cost
- Carbon/Epoxy composite reduces weight and provides optimum stiffness
- Blade designed and analyzed using GT-Hybrid, with advanced Navier-Stokes methods to account for turbulence, viscosity, compressibility, swirl and tip losses.

Parameter	Blade
Linear Twist	-10.5 deg
Chord at Tip	0.667
Chord at Root	1.33 ft
Airfoil from Root to 80% Span	SC1095
Airfoil from 80% Span to Tip	VR15









Advanced Racing Concept

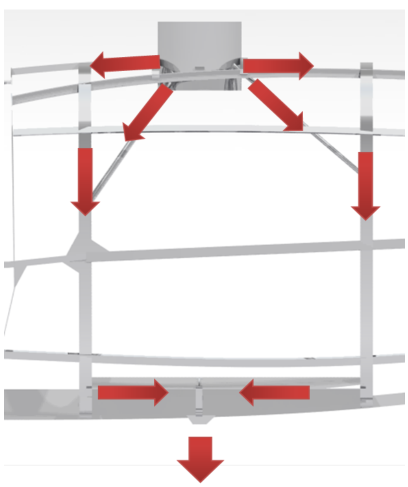
Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

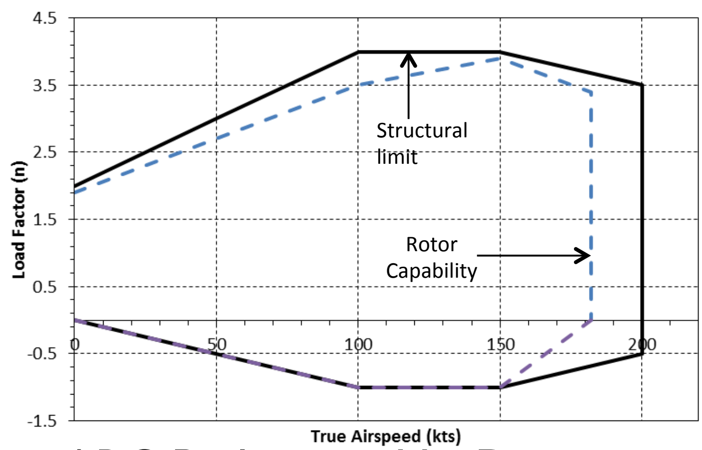
Fuselage & Structural Design

Advanced Racing Concept

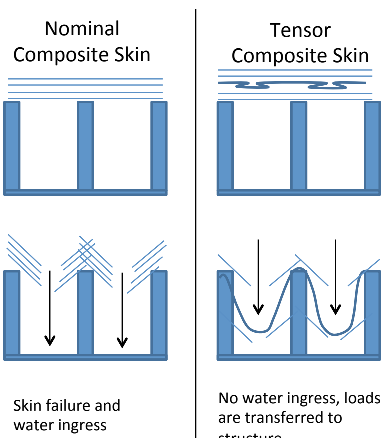
The main fuselage structure was designed in CATIA and analyzed with ANSYS to satisfice structural strength, pilot visibility, weight and balance, and volumetric requirements and constraints. Appropriate structural load paths enable the aircraft to safely carry a sling load and act to protect the pilot from the heavy rotor and transmission in the unfortunate event of a crash. Stressed composite skin beneath the cabin floor helps to absorb impact and keep water out of the vehicle if the crash occurs over the water.

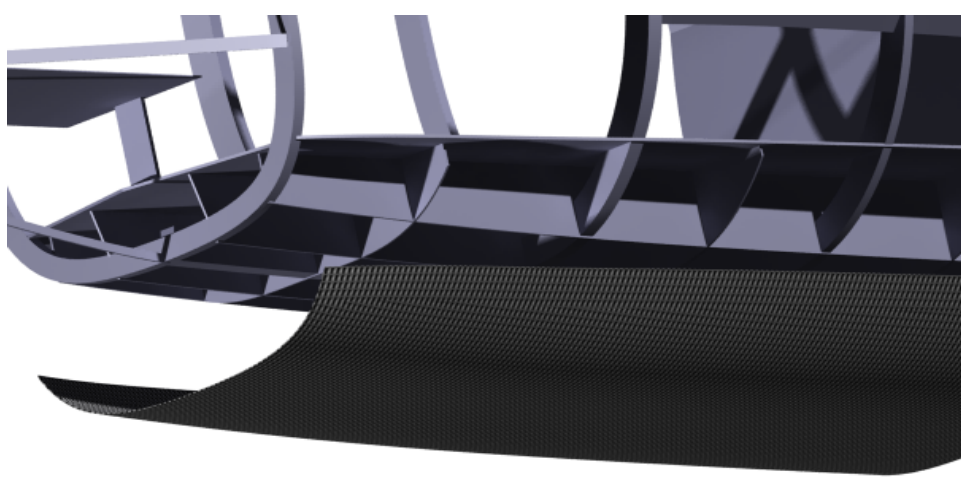


Primary Load Paths



ARC Preliminary V-n Diagram





Subfloor and Stressed Composite Skin

Georgia Institute of Technology

University of Liverpool

Engine & Propulsion Systems

Advanced Racing Concept

Uninstalled Engine (SL/ISA)

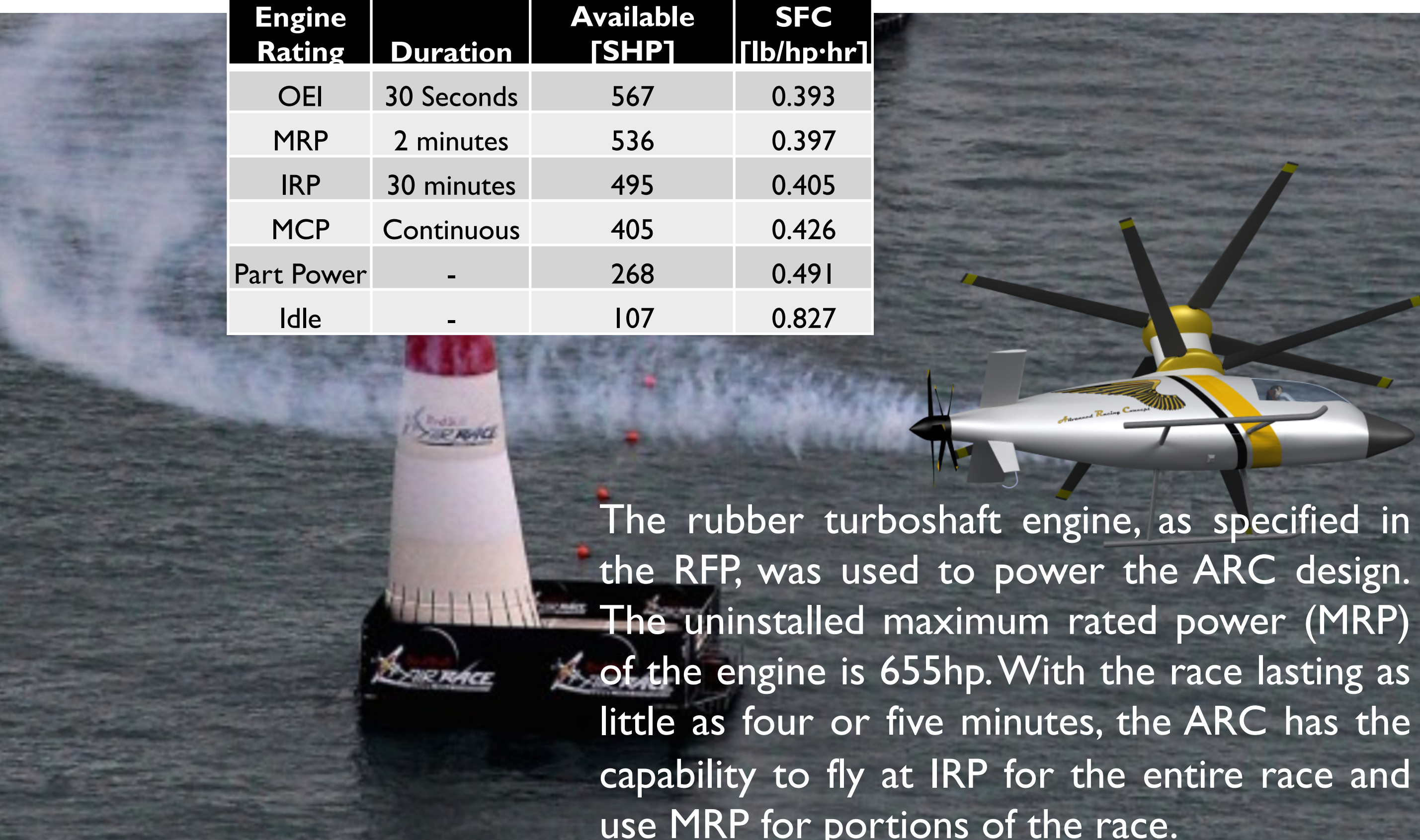
Engine Rating	Duration	Power Available [SHP]	SFC [lb/hp·hr]
OEI	30 Seconds	686	0.380
MRP	2 minutes	655	0.381
IRP	30 minutes	611	0.385
MCP	Continuous	499	0.400
Part Power	-	328	0.449
Idle	-	131	0.708

Uninstalled Engine (6K/95F)

Engine Rating	Duration	Power Available [SHP]	SFC [lb/hp·hr]
OEI	30 Seconds	462	0.391
MRP	2 minutes	434	0.396
IRP	30 minutes	399	0.404
MCP	Continuous	329	0.424
Part Power	-	217	0.488
Idle	-	87	0.819

Uninstalled Engine (SL/103F)

Engine Rating	Duration	Power Available [SHP]	SFC [lb/hp·hr]
OEI	30 Seconds	567	0.393
MRP	2 minutes	536	0.397
IRP	30 minutes	495	0.405
MCP	Continuous	405	0.426
Part Power	-	268	0.491
Idle	-	107	0.827



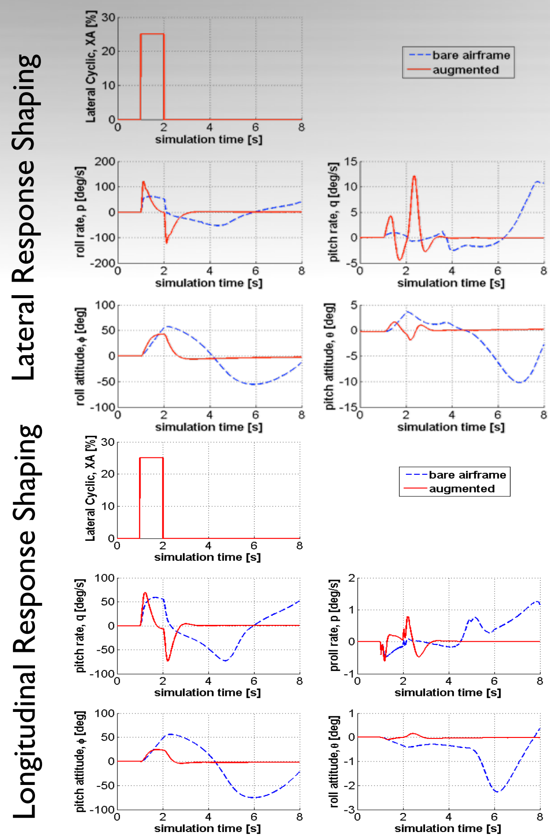
The rubber turboshaft engine, as specified in the RFP, was used to power the ARC design. The uninstalled maximum rated power (MRP) of the engine is 655hp. With the race lasting as little as four or five minutes, the ARC has the capability to fly at IRP for the entire race and use MRP for portions of the race.

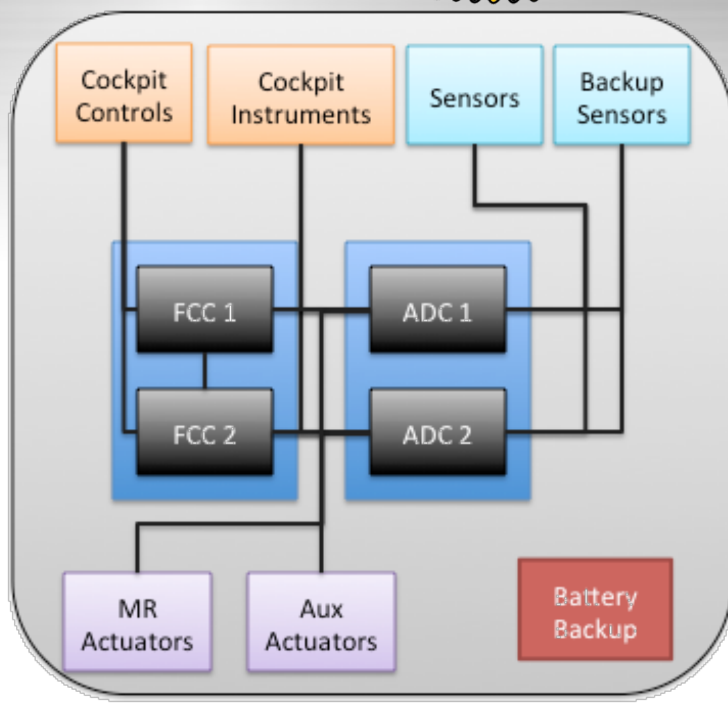
Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

Advanced Fly-By-Wire Flight Control System

Advanced Racing Concept





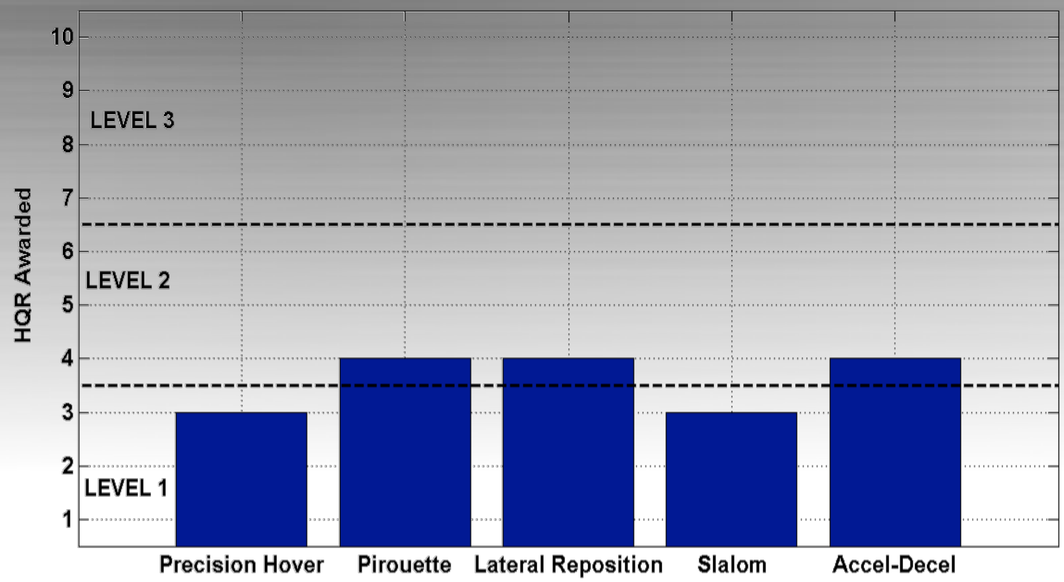
- ACAH Response at low FWD speeds (approx. 0-50 KTAS)
- Rate Response at high FWD speed (> 100 KTAS)
- Height Hold and Position Hold systems
- Auxiliary Prop Scheduled to Optimally Unload the Main Rotor System
  - Allows for Accel/Decel through Spring-Loaded Aux Control
- Level 1 Handling Qualities Evaluation
  - Low Speed Quickness (Pitch, Roll, Yaw)
  - High Speed Quickness (Roll)
  - Low Speed Bandwidth (Pitch, Roll, Yaw)
  - High Speed Bandwidth (Pitch, Roll, Yaw)
  - Low Speed Pitch/Roll Coupling
  - High Speed Collective to Pitch Coupling (+ ΔQ)

Georgia Institute of Technology

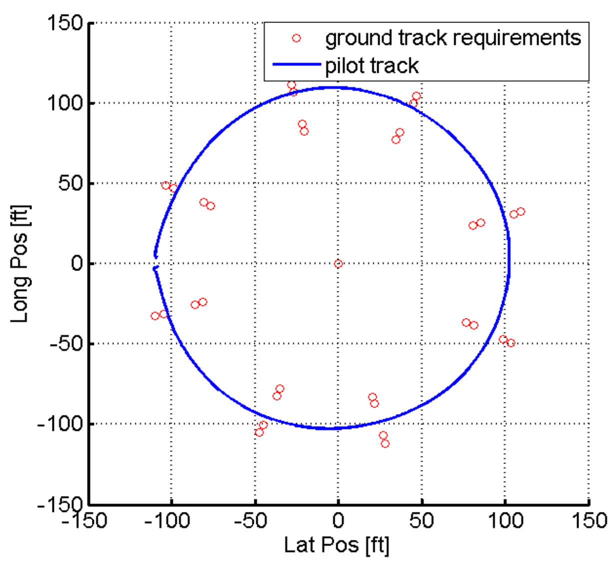
UNIVERSITY OF LIVERPOOL

Excellent Handling Qualities

Piloted Handling Qualities Evaluation Results

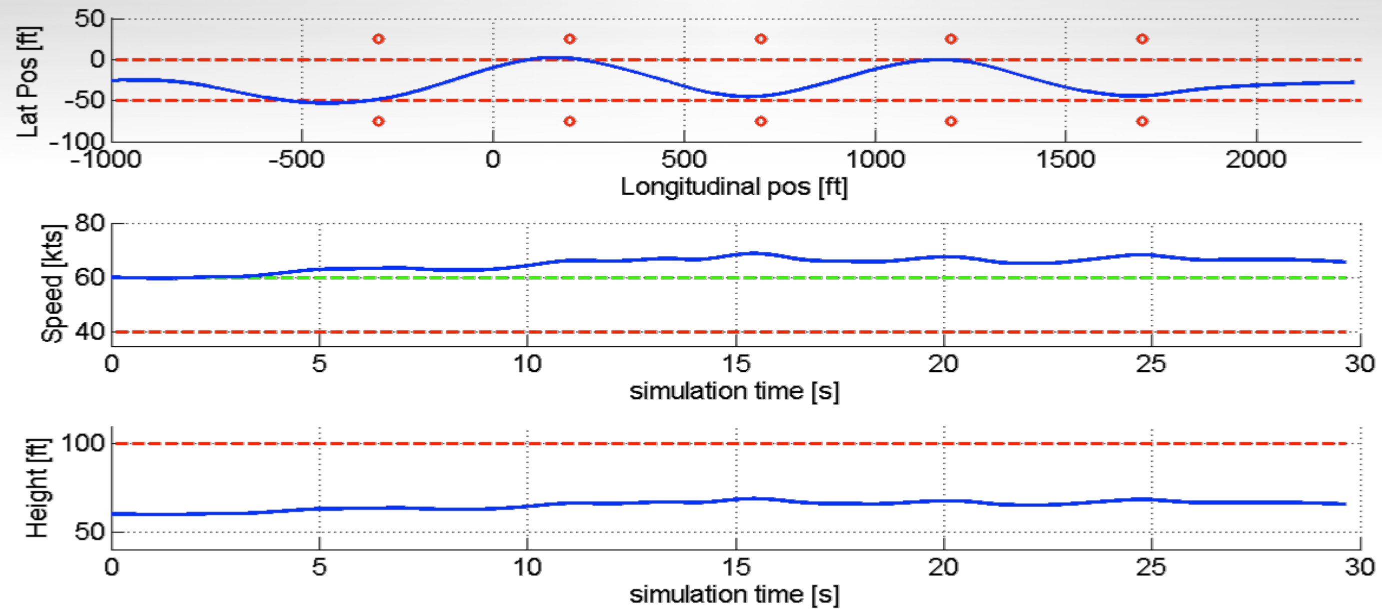


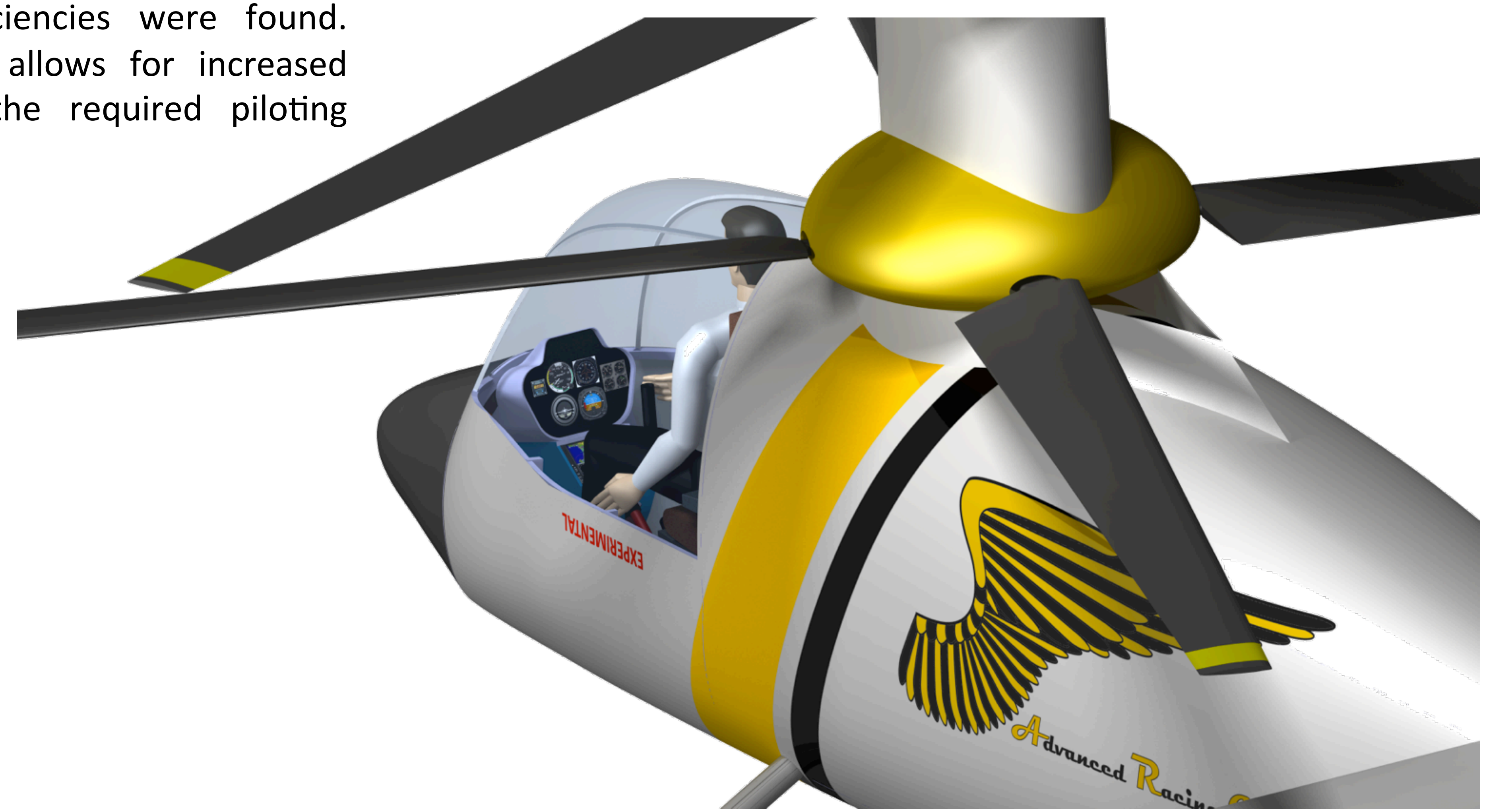
In addition to a comprehensive handling qualities analysis, a piloted evaluation was flown using a high fidelity FLIGHTLAB model and the Heli Flight Simulator. Testing was performed IAW ADS-33E-PRF, using mission task elements (MTE) selected to simulate course maneuvers. All maneuvers scored HQRs of 4 or lower (Level 1 and 2), and no deficiencies were found. Minimalistic cockpit design also allows for increased visibility while still containing the required piloting equipment



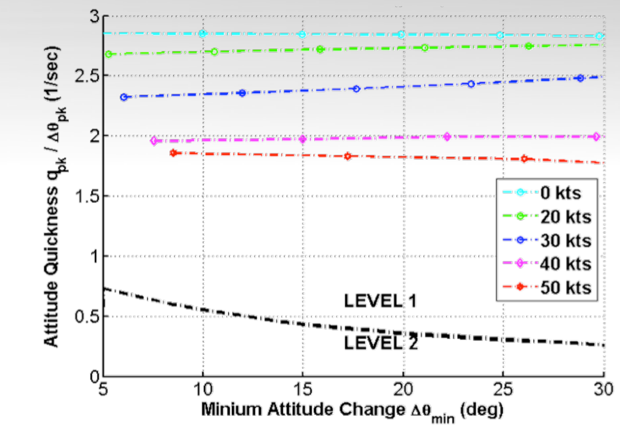
Piloted Pirouette Track

Pilot Evaluation of ADS-33E-PRF Slalom Course

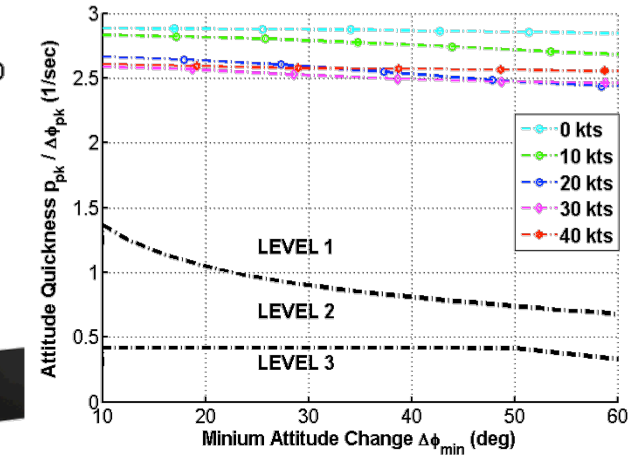




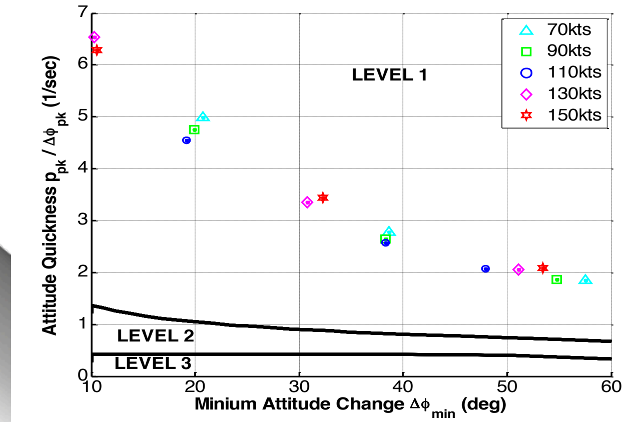
Low Speed Pitch Quickness



Low Speed Roll Quickness



High Speed Roll Quickness



Advanced Racing Concept

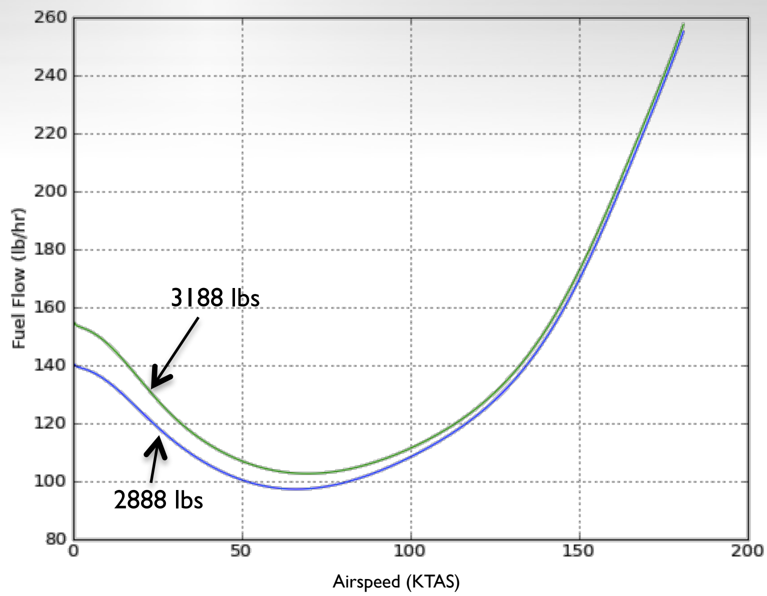
Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

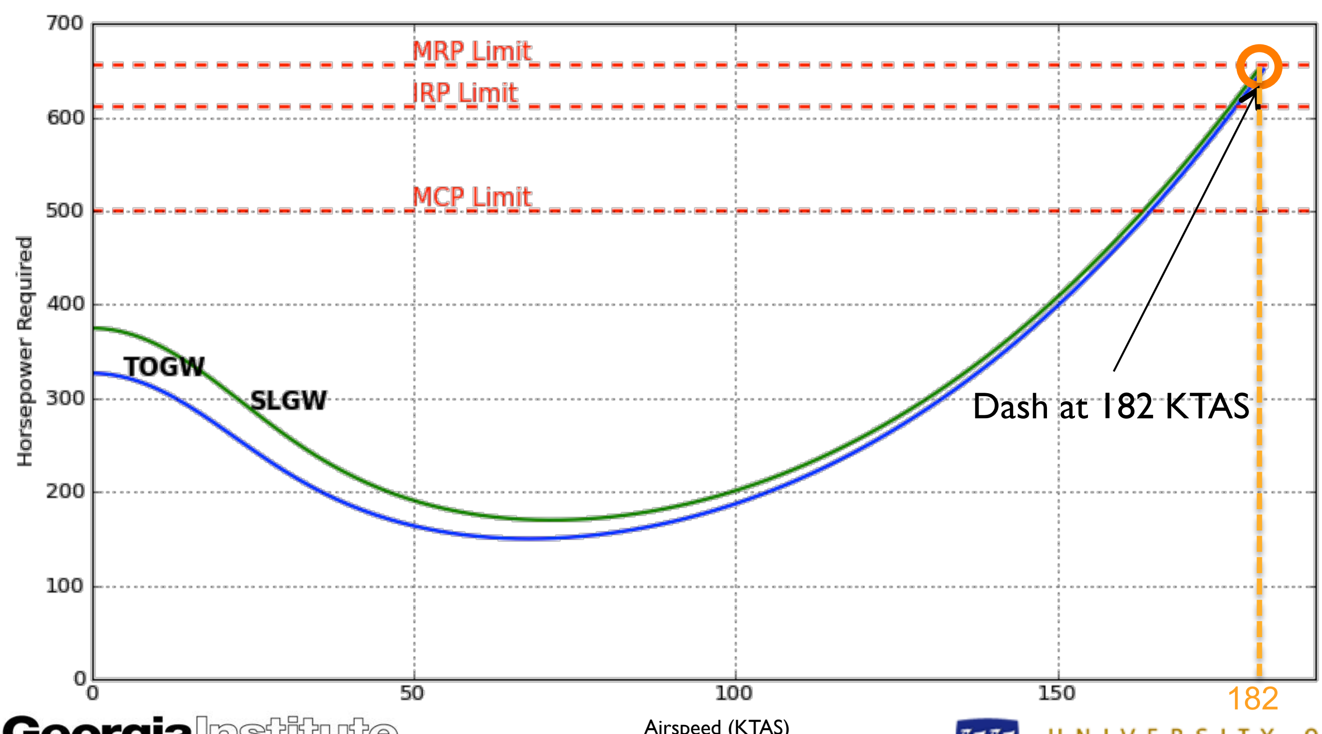
Performance

The Advanced Racing Concept (ARC) has been designed for superior performance. A sea-level dash capability of 182 knots, exceeds all currently available helicopters. With best range and endurance speeds of 125 and 67 knots respectively, and a high performance engine, the ARC also exhibits excellent fuel efficiency throughout the operational envelope.

Fuel Flow Performance – ISA Sea Level Standard



Sea-Level Standard Performance



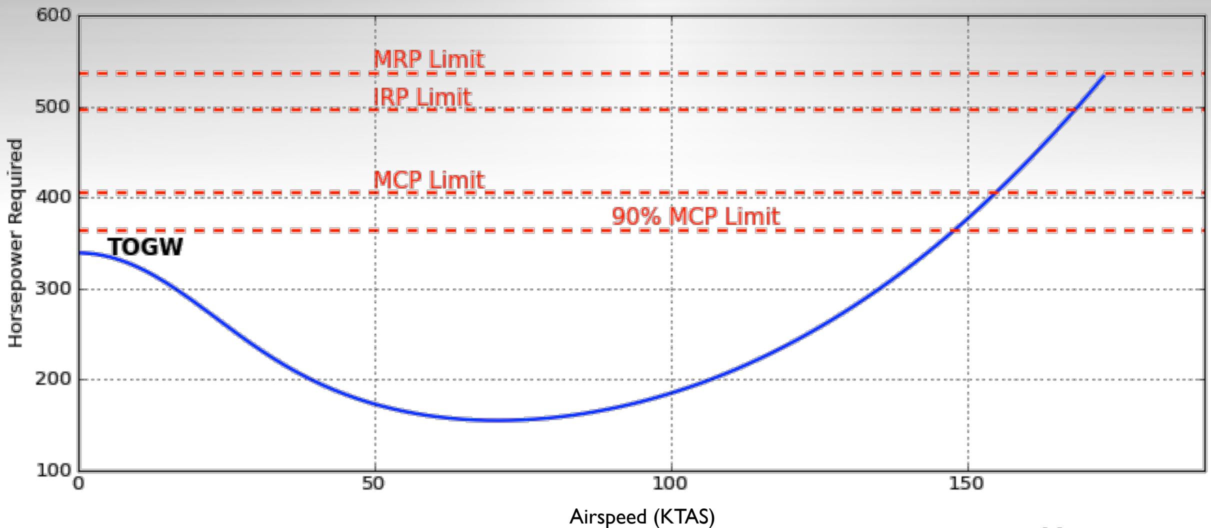
Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

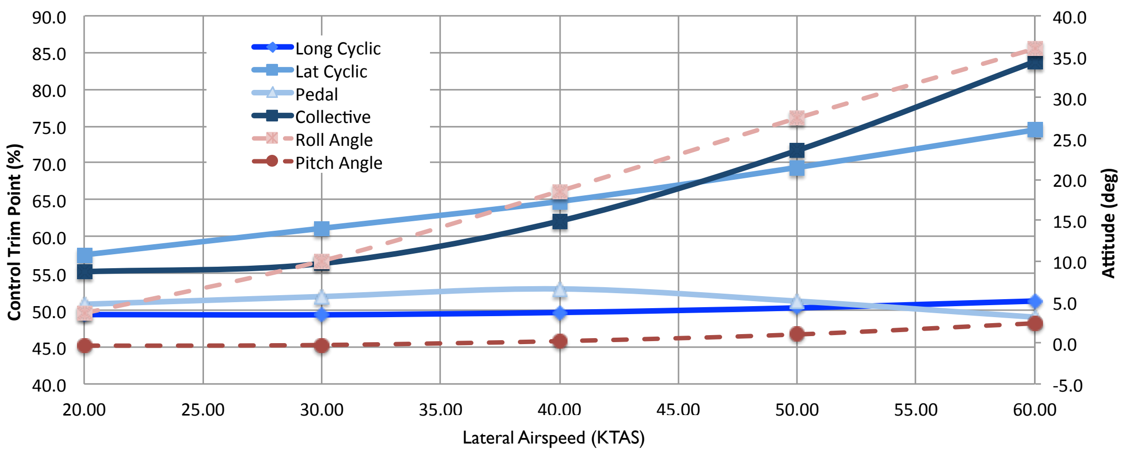
Meets All RFP Hot-Day Performance Requirements

Advanced Racing Concept

Power Required (S.L. 103° F)



Right Sideward Flight Control Positions (S.L. 103° F)

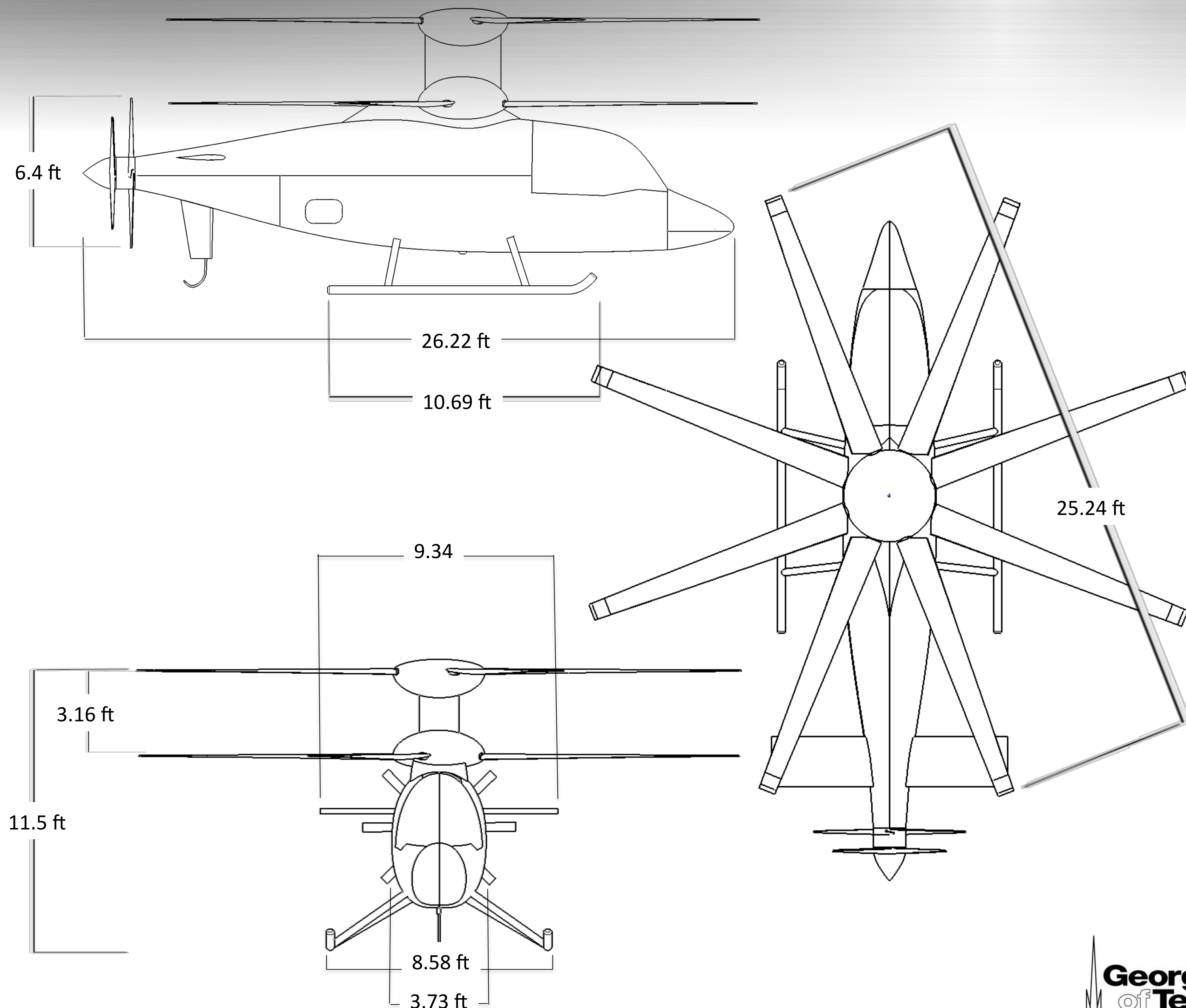


- Capable of Hover OGE at SL 103° F, TOGW
  - Dash at 173 KTAS at SL 103° F, TOGW
- Capable of 149 KTAS at 90% MCP at S.L., 103° F , TOGW
- Capable of Sideward Flight (both directions) at 60 KTAS, S.L., 103° F, TOGW

Georgia Institute of Technology

University of Liverpool

ARC Specifications



Advanced Racing Concept

Parameter	Value	Units
General		
Maximum Gross Weight	3188	lbs
Takeoff Gross Weight	2888	lbs
Empty Weight	2587	lbs
Disc Loading	6.57	lbs/ft^2
Power Loading (MCP)	0.199	hp/lbs
Estimated Flat Plate Drag (frontal)	5.53	ft^2
Estimated Flat Plate Drag (side)	19.9	ft^2
Main Rotor		
Rotor Radius (both)	12.62	ft
Solidity (total)	0.20	-
Airfoils	SC1095/VR15	-
Twist (linear)	-10.5	deg
Propulsion		
Engines	1	-
Max Rated Power (MRP)	655	hp
Max Continuous Power (MCP)	499	hp
Fuel Consumption (MCP/SLS)	0.400	lb/SHP-hr
Performance		
Dash Speed (V_H)	182	KIAS
Best Range Speed (V_{BR})	125	KIAS
Best Edurance Speed (V_E)	67	KIAS
Vertical Rate of Climb (S.L.)	3800	ft/min
Max Rate of Climb (S.L.)	4280	ft/min
Range (external fuel) (nm)	271	nm

Georgia Institute of Technology

UNIVERSITY OF LIVERPOOL

Advanced Racing Concept

- Ultra-maneuverable, ultra-agile, high-performance race vehicle
- Helicopter maneuverability at fixed-wing speeds
- Thoroughly optimized for racing performance
- Safe and ready for certification
- Not reliant on uncertain, immature technologies
- Low setup investment of $105M for eight race aircraft.
- Race-ready aircraft projected for Summer 2015