"SSTO Technology Development: An Overview of Radian Aerospace and Radian One"

RADIAN AEROSPACE

FISO Telecon 07-10-24

SSTO Technology Development: An Overview of Radian Aerospace and Radian One

Livingston Holder, CTO and Co-Founder, Radian Aerospace

RADIAN ONE IS REQUIRED FOR THE FUTURE OF LOW EARTH ORBIT OPERATIONS

VERTICAL LAUNCH IS NECESSARY BUT INSUFFICIENT

VERTICAL

SIZED FOR INFRASTRUCTURE

BUILT FOR MASS TO ORBIT

LIMITED TO COASTAL LAUNCH SITES

HORIZONTAL

SIZED FOR SERVICING

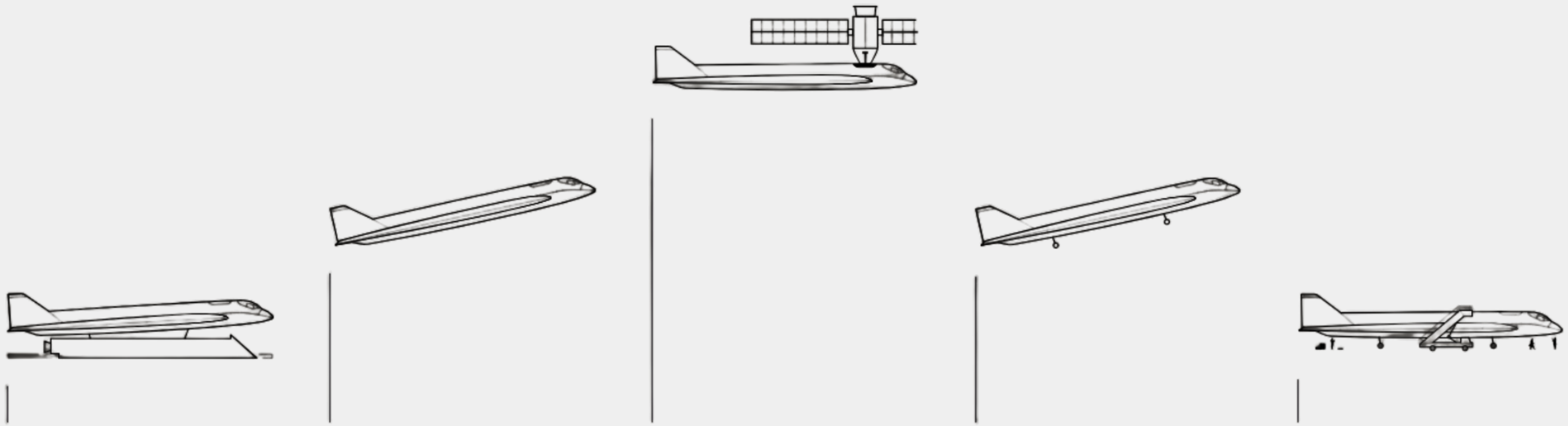
BUILT TO BRING MASS DOWN TO EARTH

ABILITY TO LAUNCH IN-LAND AND COASTAL

RADIAN ONE

- FULLY REUSABLE
- 1 | SINGLE STAGE
- 90 MIN | LAUNCH ON DEMAND
- 10K LBS | DOWN MASS
- 5 PEOPLE OR 5,000LB

FLEXIBLE LAUNCH AND LANDING
FROM ANY COMPATIBLE INLAND OR COASTAL SITE



SLED-ASSIST TAKEOFF

10,000’ rail sled system

LOW G ASCENT

Low-g environment for passengers and cargo

FLEXIBLE OPERATIONS

Supports multiple mission scenarios, such as quick resupply or longer duration scientific research

RENTRY AND LANDING

Robust reusable TPS
Lands on 10,000’ runway

RAPID REFLIGHT

Target 48-hour turnaround (77% faster than the fastest vertical rocket turnaround)

RADIAN AEROSPACE

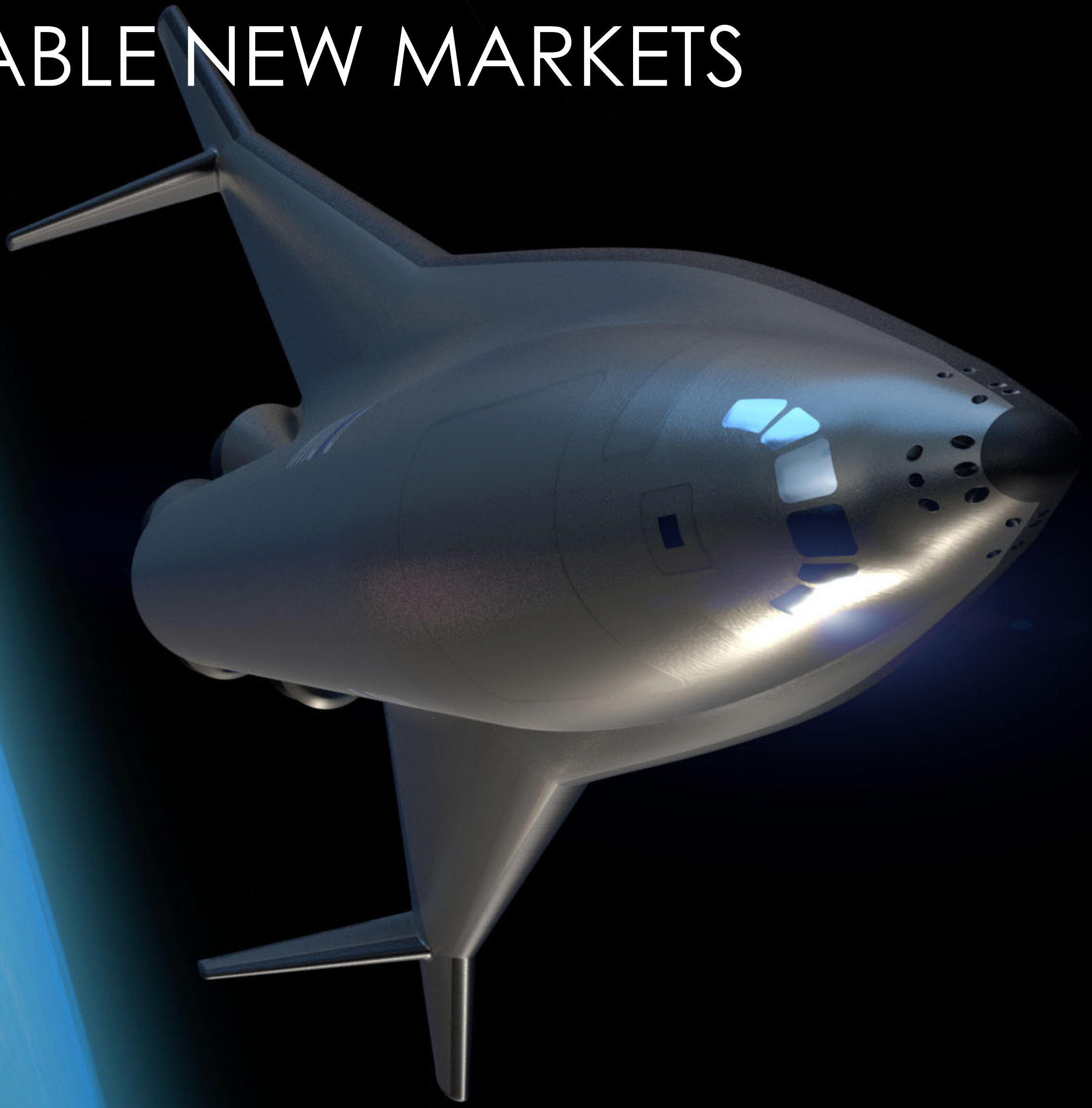
RADIAN ONE IS DESIGNED TO BUILD INDUSTRIES AND ENABLE NEW MARKETS

DEPLOY

FREE FLYING PLATFORM

RENDEZVOUS

DOWNMASS & POINT-TO-POINT



RADIAN ONE IS TARGETED TO BE SIGNIFICANTLY LESS EXPENSIVE AND BRING MORE DOWN TO EARTH THAN VERTICALLY-RELIANT ALTERNATIVES

83%

LESS EXPENSIVE

ON A PER-SEAT BASIS

81%

LESS EXPENSIVE

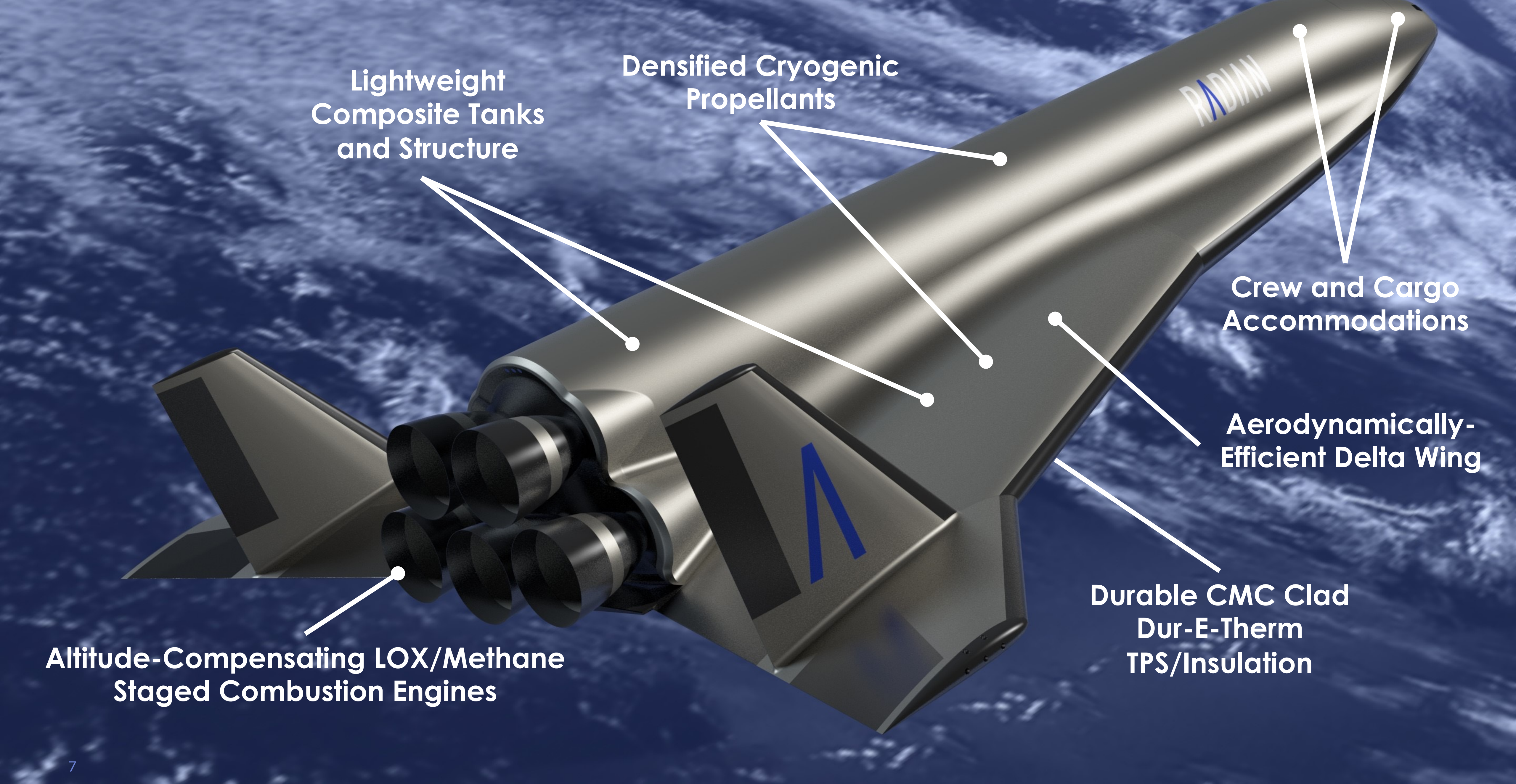
PER MISSION TO THE ISS

4,473 lbs

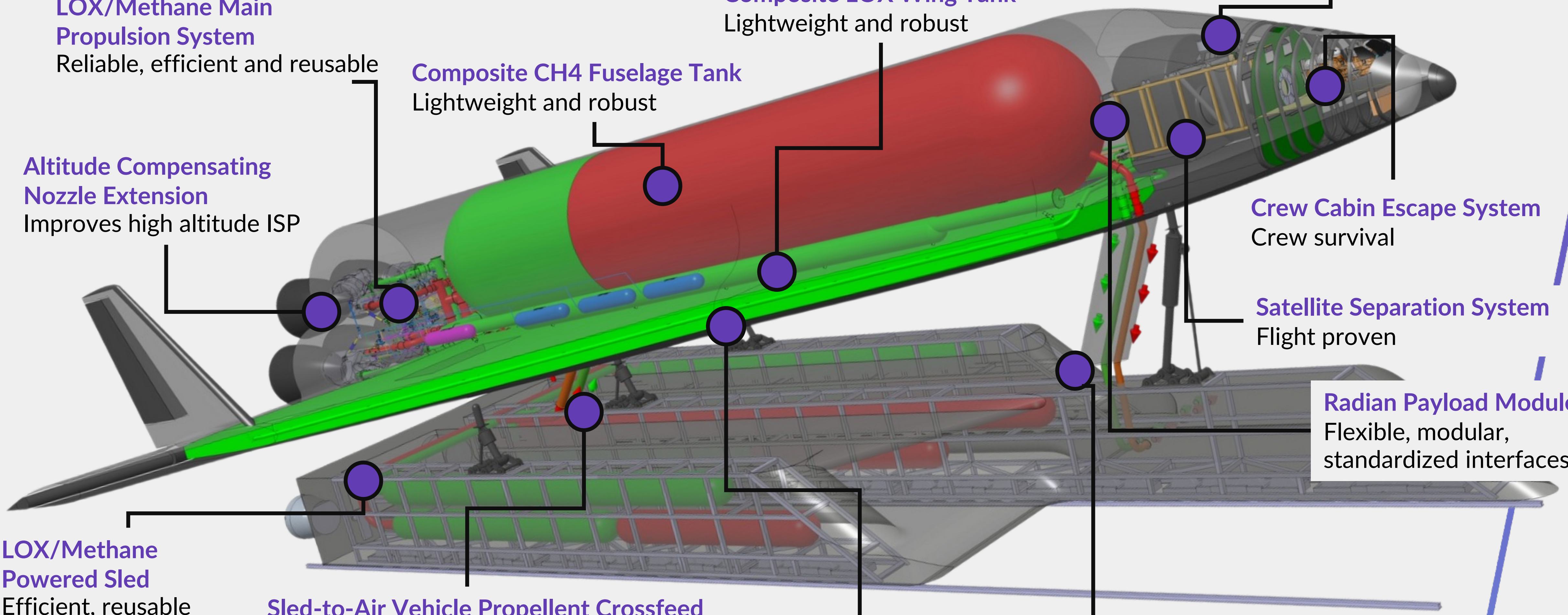
MORE DOWNMASS

(PRESSURIZED) FROM THE ISS

RADIAN ONE ENABLING TECHNOLOGIES AND FEATURES

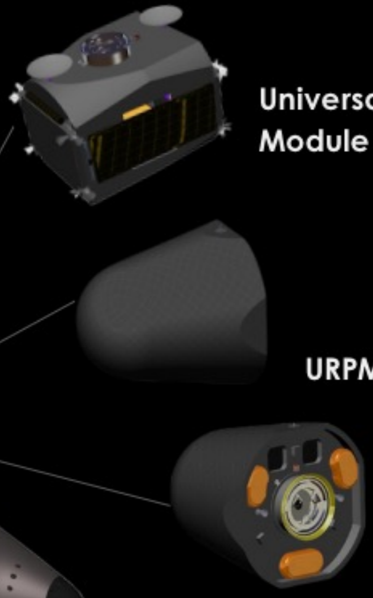


VEHICLE AND SLED CONFIGURATION



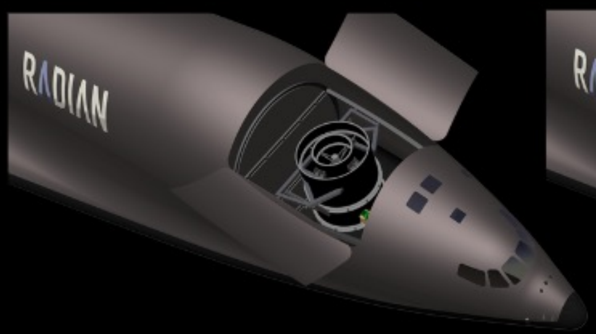
RADIAN ONE FLEXIBLE MISSION CARGO BAY

Radian One +
Payload Module

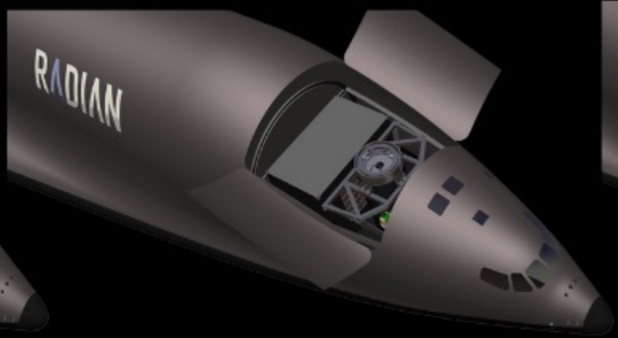


Universal Radian Payload Module (URPM)

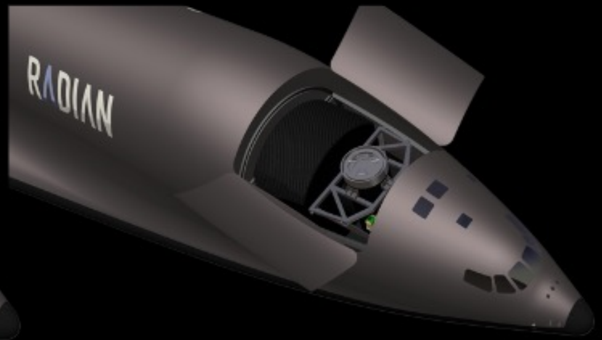
URPM: Re-entry Model



Radian One +
Integrated ISR Sensor



Radian One + Crew Transfer
Tunnel + Cubesat Deploy



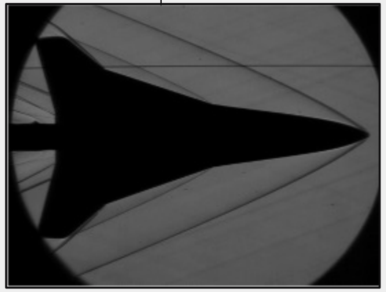
Radian One + Crew Transfer Tunnel +
Pressurized Payload Module

SPECIFICATIONS

CREW	2-5
UPMASS	up to 4,400 kg to 410 km , 37.8° up to 2,270 kg to 410 km, 51.7°
DOWNMASS	up to 4,540 kg
PAYLOAD BAY	
LENGTH	5.2 m
WIDTH	3.8 m (fwd) 5.6 m (aft)
HEIGHT	2.7 m (fwd) 4.0 m (aft)
VOLUME	~93 m^3

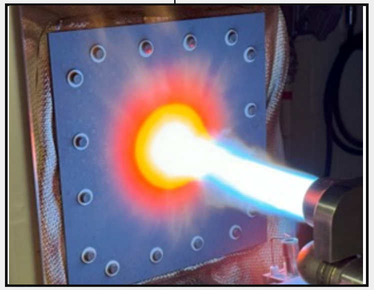
NOTABLE PROGRAM MILESTONES

FIRST WIND TUNNEL TESTS COMPLETED



UNITED STATES AIR FORCE ACADEMY

FIRST TPS/INSULATION TORCH TEST COMPLETED



GE Aerospace NASA

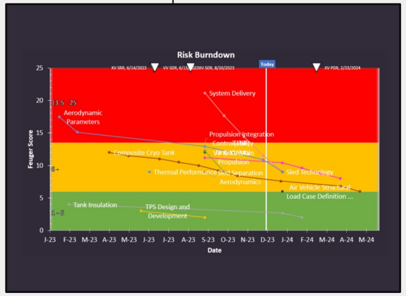
FIRST COOPERATIVE AGREEMENT SIGNED

UNITED STATES AIR FORCE ACADEMY

FLIGHT SIM SYSTEMS IN DEVELOPMENT

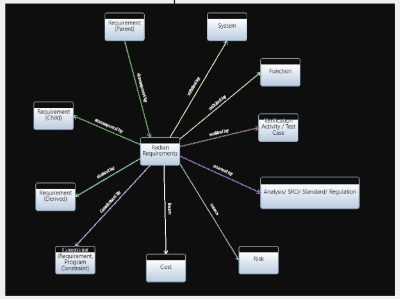
LOCKHEED MARTIN

RISK REDUCTION PLAN DEVELOPED

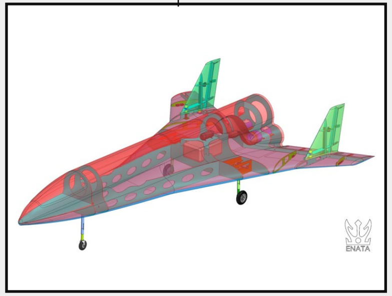


MANDALA SPACE VENTURES LOCKHEED MARTIN

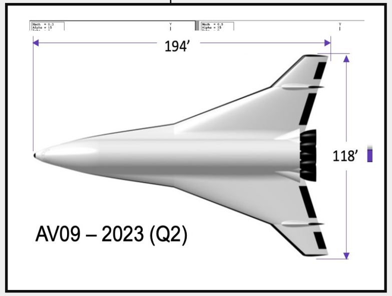
SYSTEMS REQUIREMENTS + DEFINITION REVIEWS COMPLETED



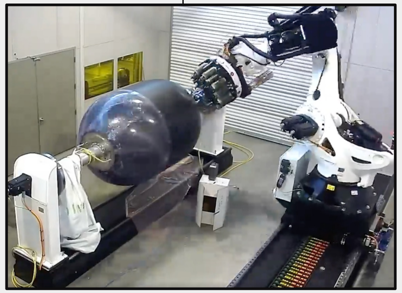
PROTOTYPE FLIGHT VEHICLE CONSTRUCTION STARTED



MULTIPLE SYSTEM DESIGN CYCLES COMPLETED



TEST TANK PATHFINDER CONSTRUCTION COMPLETED



UNIVERSITY of WASHINGTON

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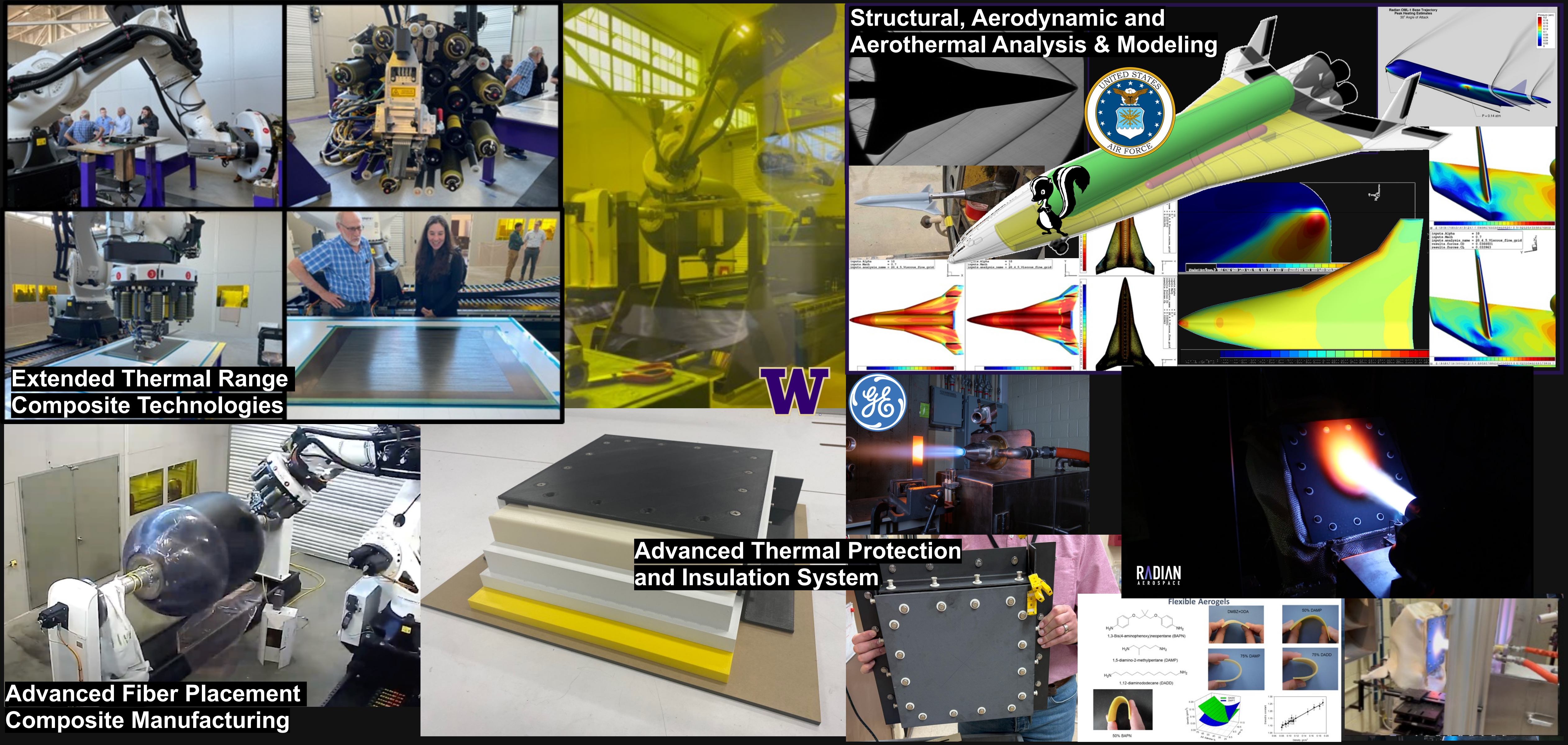
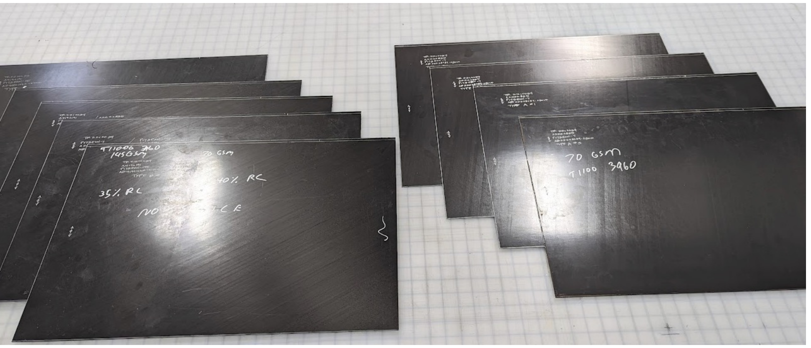
DEVELOPMENTAL TESTING



MATERIAL CHARACTERIZATION AND COUPON TESTING

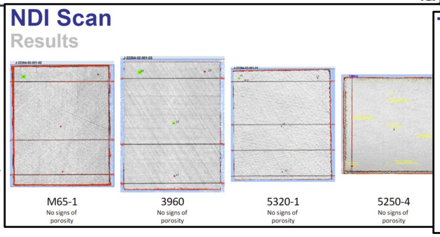
1A Testing – **Initial Material Compatibility Selection**

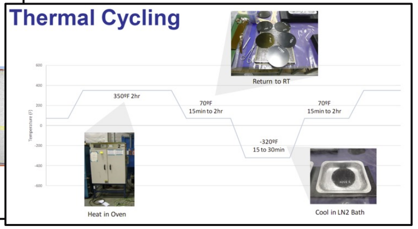


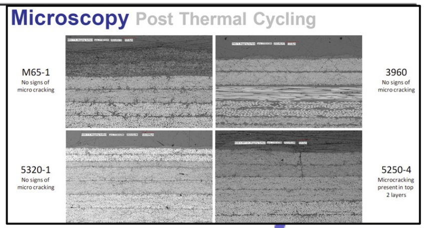
1a Material Acceptance Criteria:

- Material meets application requirements
  - -320F – 350F temperature range
  - 65psi
- Material available in desired formats
- Can be applied by Automated Fiber Placement (AFP)
- Cure/Consolidation process can be scaled
- Produces acceptable laminate quality (<2% porosity)

Material	NDI	Microscopy	FV/RC & Porosity	Glass Transition (Wet)	Permeation	LOX Compatibility
M65-1, IM7	No indications	No cracking	Minimal porosity	307°F	None	Best
3960, T1100	No indications	No cracking	Minimal porosity	241°F	None	Good
5320-1, IM7	No indications	No cracking	Minimal porosity	260°F	None	Good
5250-4, IM7	No indications	Cracking in top 2 layers	Minimal porosity	318°F	Slight	Better

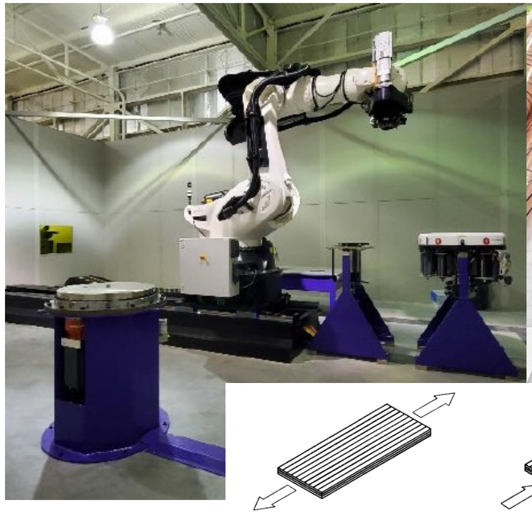


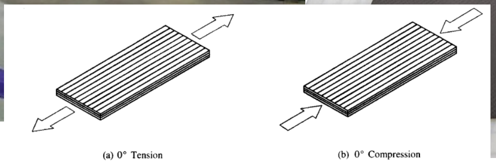


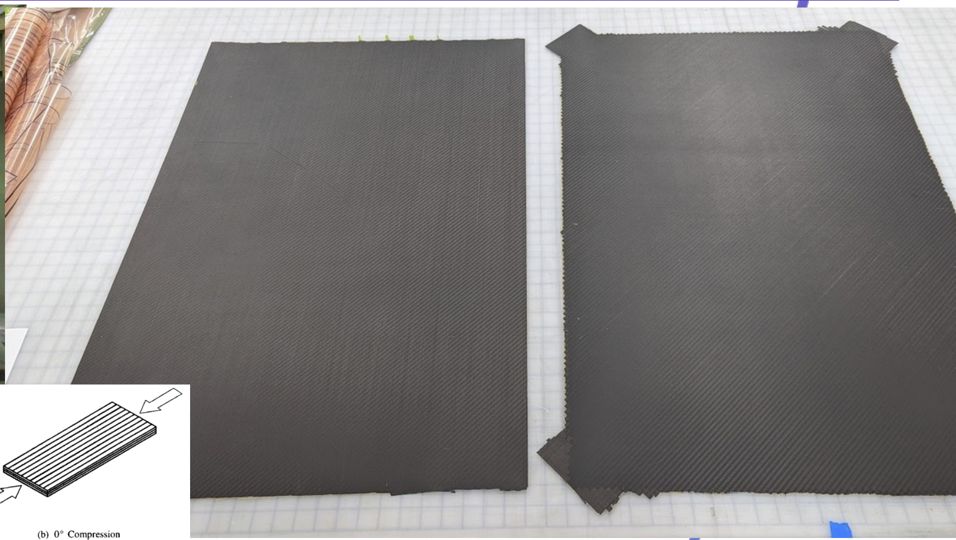


1C/1D Testing – **Mechanical Property Testing of Selected Composite System**

- Establish Stiffness and Strength Values
- Establish preliminary allowables for initial sizing and analysis
- Build Material Property data at cryogenic temperatures
- Notched allowables account for damage / presence of holes







Coupon testing performed at ambient, cold, hot conditions to develop material properties and design allowables

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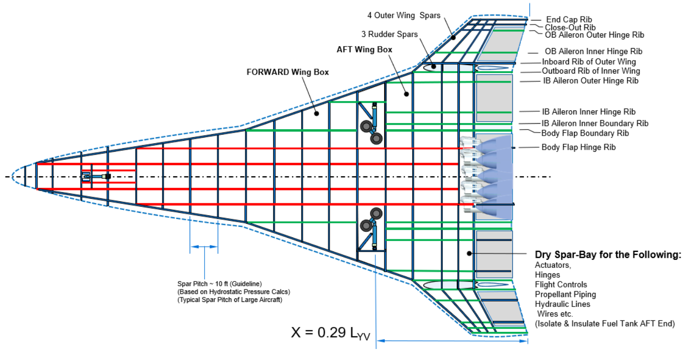
“BIG BONES” STRUCTURAL APPROACH TO LOAD PATH DESIGN

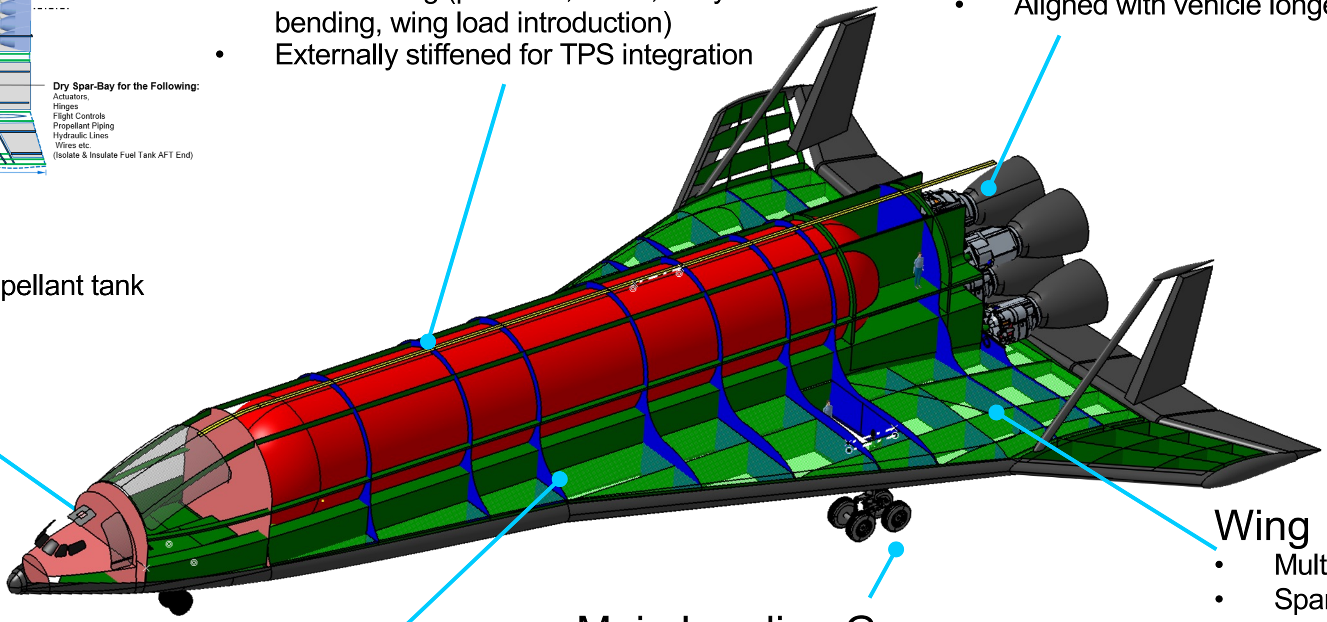


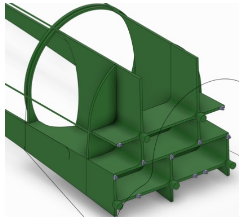
Fuselage

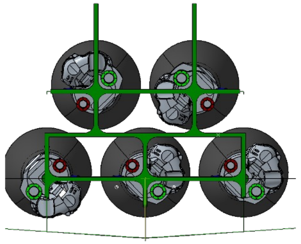
- Cryogenic tank serves as fuselage as part of integrated airframe structure
- Composite construction
- Load bearing (pressure, thrust, body bending, wing load introduction)
- Externally stiffened for TPS integration

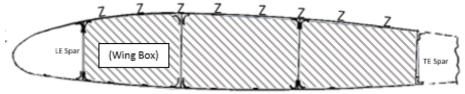
Thrust Structure

- System of vertical and horizontal beams collect thrust and TVC Loads
- Lower engines aligned with keel structures
- Upper engines transmit thrust to fuse skin
- Aligned with vehicle longerons



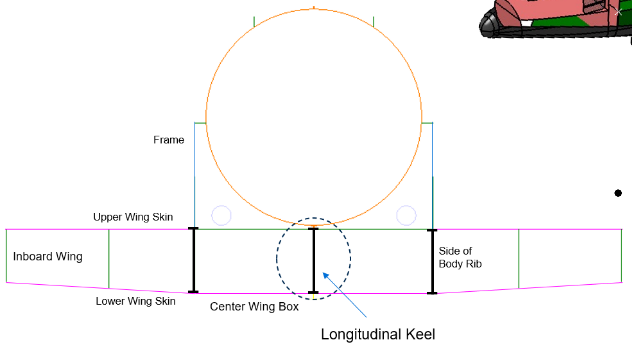






Nose Landing Gear

- Keel Mounted forward of Propellant tank
- Forward Stowing
- Use existing keel structure



Wing to Fuselage

- System of wing skins, keel, spars, ribs, and longerons transmit loads between fuse and wing

Main Landing Gear

- Wing Mounted
- Inboard Stowing
- Sized to Design Landing Weight
- Location satisfies geometric criteria, avoids fuse penetrations, and fits within OML
- Uses existing wing structure fwd of main wing torque box

Wing

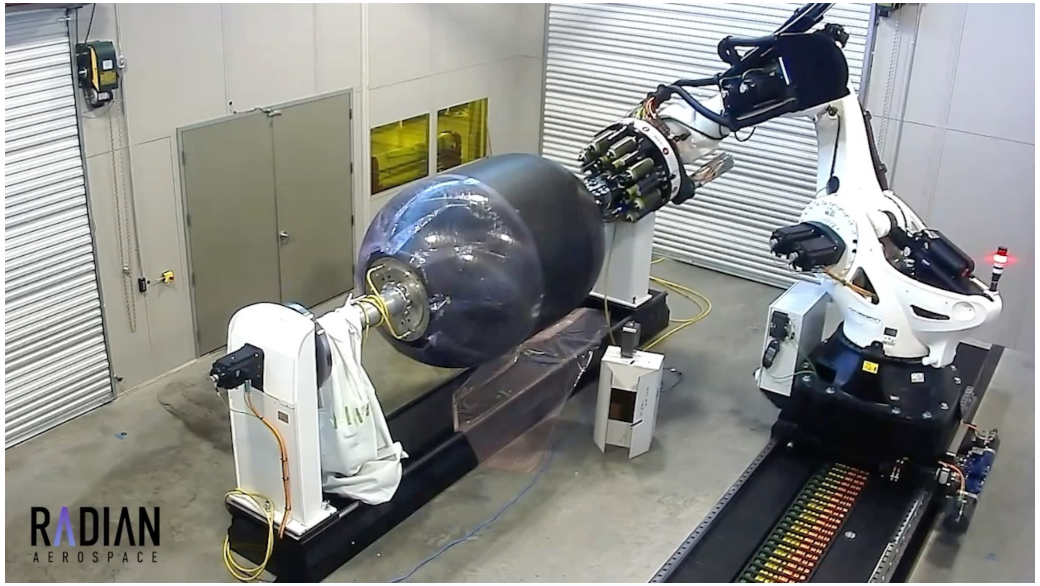
- Multi-spar stressed skin and stringer
- Spar and rib internal construction
- Continuous skins - cross-ship bending load path avoids discrete attachment and introducing bending loads into fuselage propellant tank
- Side of Body Rib wing to fuse attachment
- Wetted wing
- Externally stiffened for synergistic TPS integration

Each structural element performs multiples functions to ensure structural / weight efficiency

TEST TANK 1 (TT1) COMPOSITE CRYOGENIC DEVELOPMENT TANK

TT1 Pathfinder Development at University of Washington Advanced Composites Center (ACC)

- Develop detailed manufacturing processes
- Face and solve manufacturing and assembly challenges
- Gain experience with high-precision AFP machines and processes without the capital expense required to build up facilities and capabilities
- Leverage the experience of technical experts who have built similar tanks
- Mature structural design and analysis



W ADVANCED COMPOSITES CENTER

JANICKI

TT1 Pathfinder Domes

- Reveal parameters that influence the design/analysis
- Retires risks prior to build up of larger tank

Test Tank 1 is Radian's first major cryogenic composite element to be built

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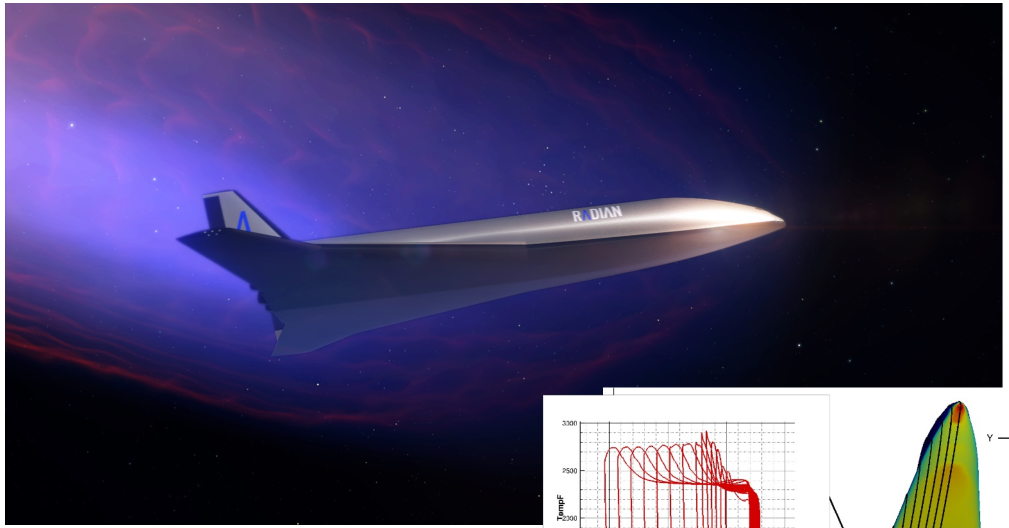
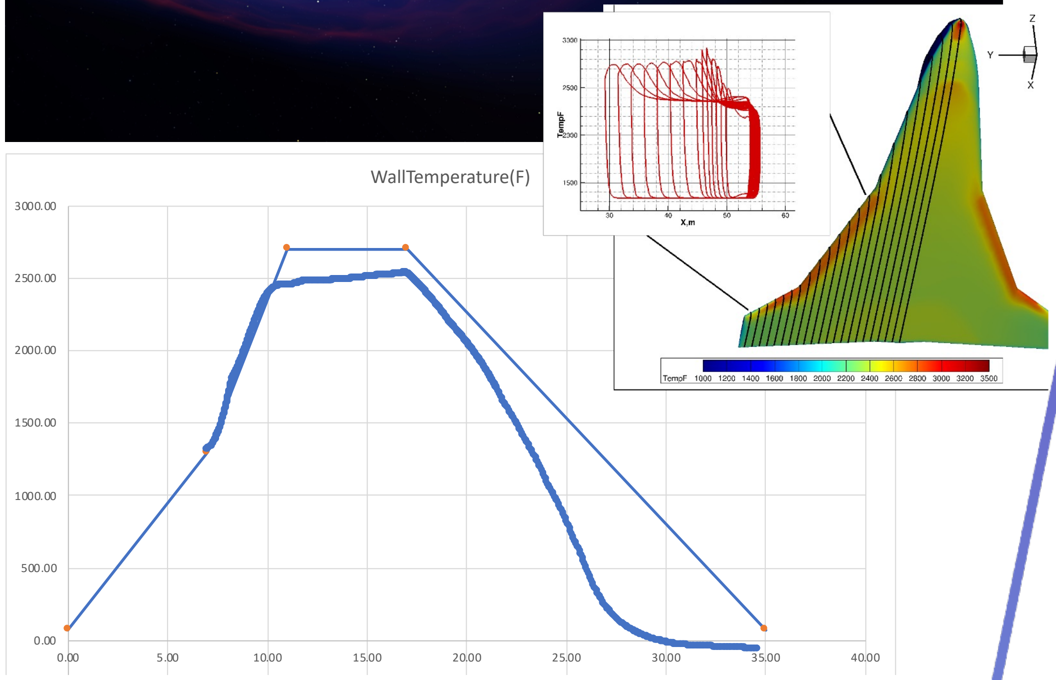
THERMAL PROTECTION SYSTEM (TPS) REQUIREMENTS

- **Protect** underlying structure and systems from the severe thermal environments encountered during hypersonic flight
- **Minimize Weight** – avoid parasitic weight by providing some load bearing capabilities
- **Durability** – survive flight conditions, impact events, weather, etc. without critical damage
- **Reusability** – minimize need for replacement; initial goal of 100 flights
- **Repairability** – ability to easily identify and repair damage between flights
- **Structural Integrity** – structural needs must be maintained through thermal flight environment





High heat load for long durations (8 min ascent and 30 min entry) puts this system at the nexus between traditional launch vehicles (moderate heat over long durations) and hypersonic systems (high heat over short durations)

INSULATION REQUIREMENT

- **Minimize Thermal Conductivity** – keep propellant temperature below boiling to minimize re-cooling, boiloff losses, prevent cyropumping, and ensure flight readiness
- **Minimize Weight** – minimize areal weight/density
- **Maximize Hydrophobicity** – minimize moisture permeation, condensation and eliminate icing
- **Flexibility** – ability to conform to vehicle shape
- **Durability** – survive flight conditions, impact events, weather, etc. without critical damage
- **Reusability** – minimize need for replacement; initial goal of 100 flights
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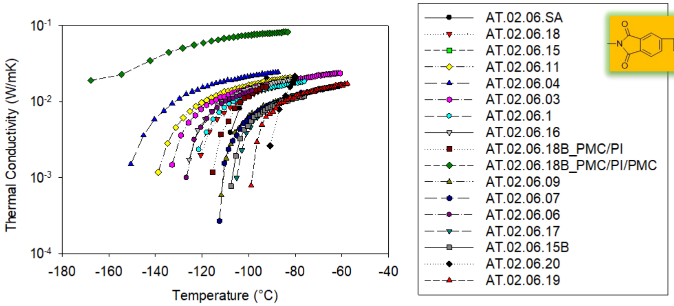
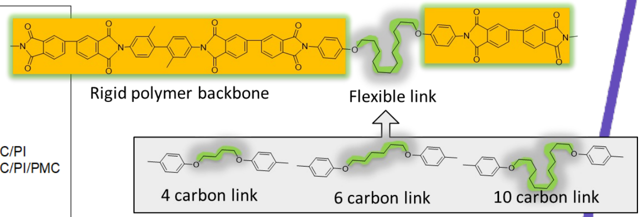
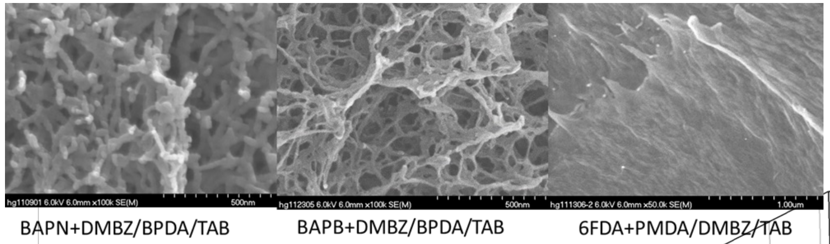
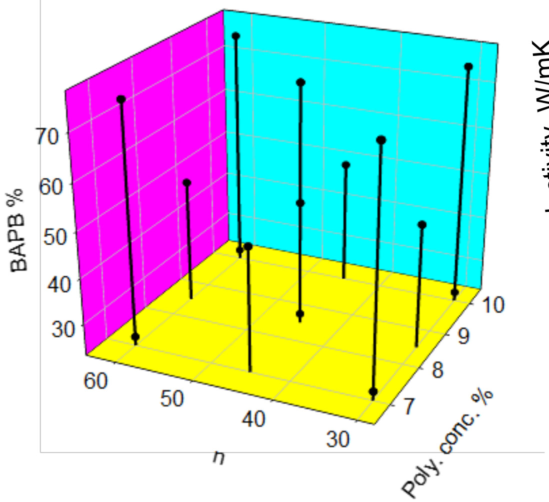
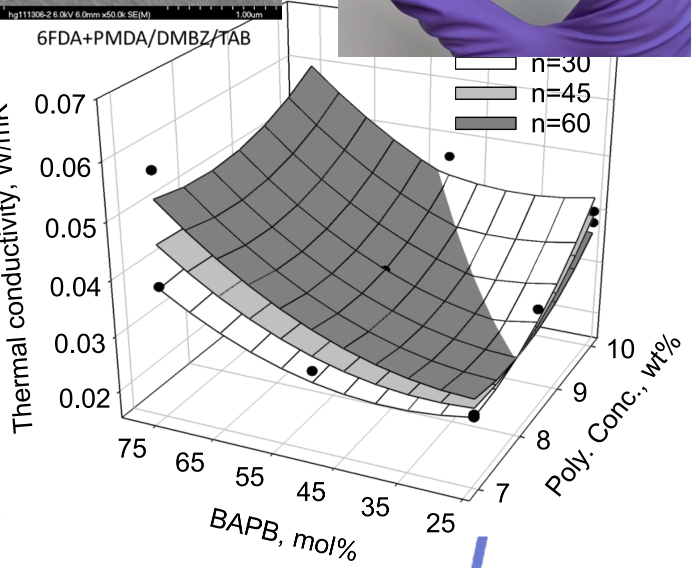






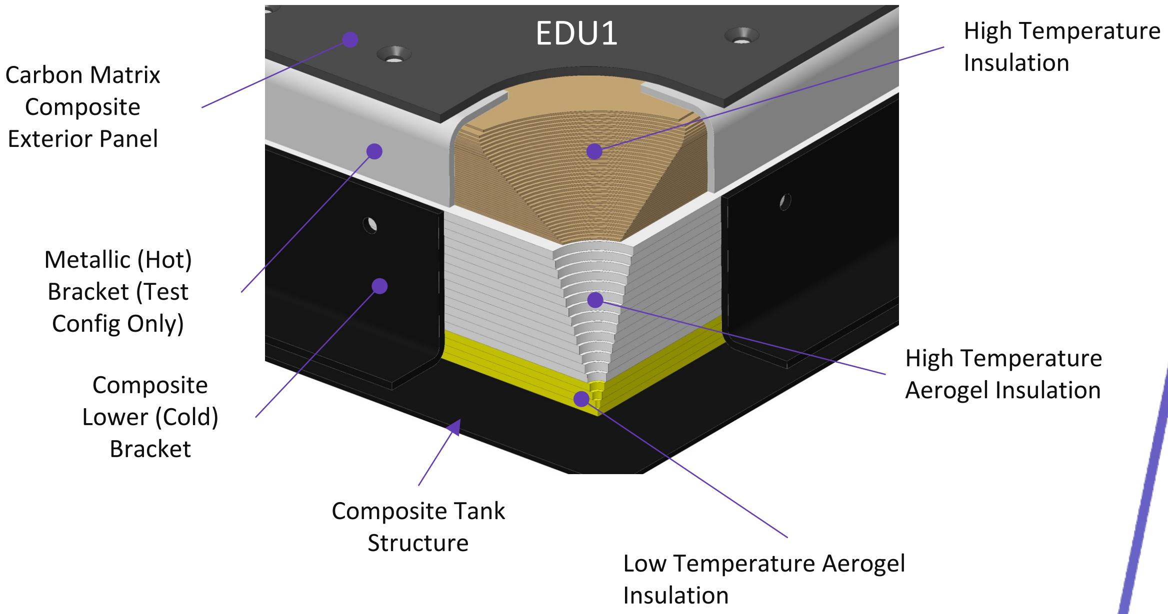


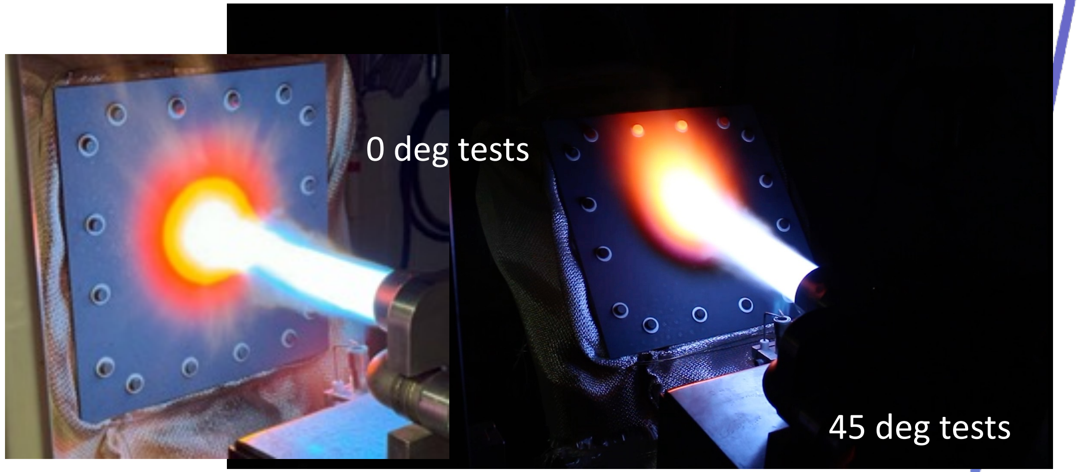


High heat load for long durations (8 min ascent and 30 min entry) puts this system at the nexus between traditional launch vehicles (moderate heat over long durations) and hypersonic systems (high heat over short durations)

THERMAL PROTECTION SYSTEM (TPS) QUICK LOOK TEST RESULTS

- GRC team assembled EDU1 adding the insulation layers with thermocouples and enclosing them with the tank panel
- Runs:
  - **1-3** - up to 2700F at a 0-degree orientation for 35 minutes following an ascent and reentry profile
    - Backside of High Temp layer did not exceed 900F
  - **4-5** - up to 2700F at a 45-degree orientation for 35 minutes following an ascent and reentry profile
  - **6** - “hypersonic” run up to 2700F at a 45-degree orientation for 120 minutes following same ascent and reentry profile
    - Backside of High Temp layer reached 1600F
    - Backside of High Temp Aerogel layer reached 668F



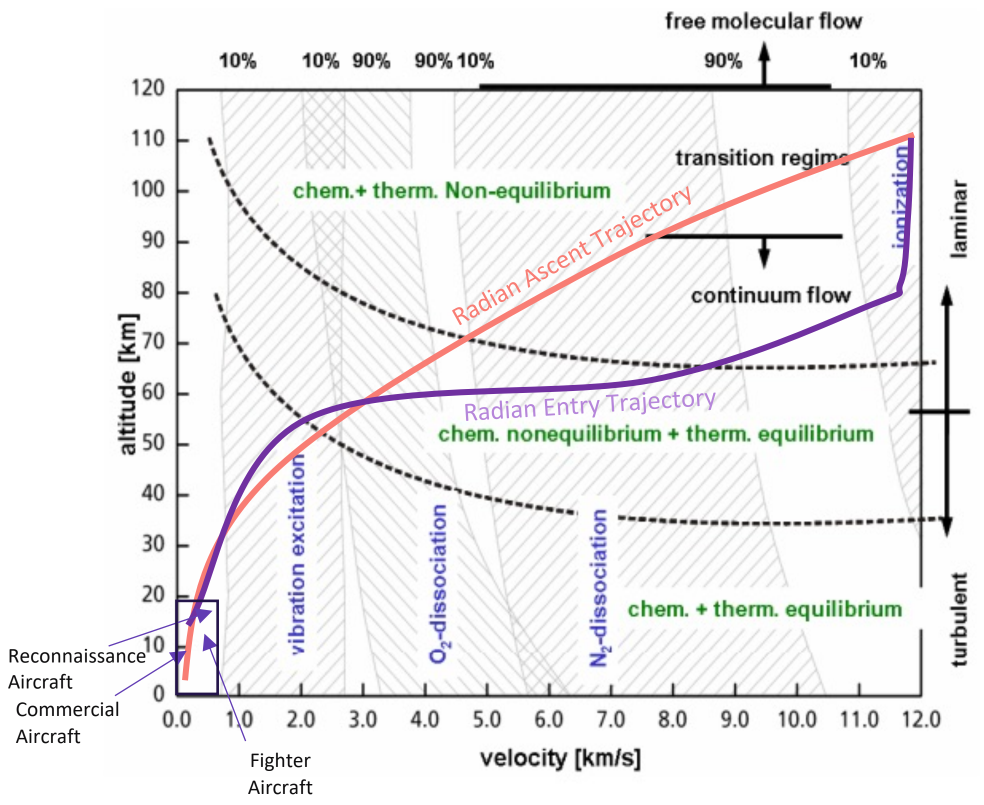


Temperatures stayed below use temperatures of all material for Radian Mission Profile runs

RADIAN AEROSPACE

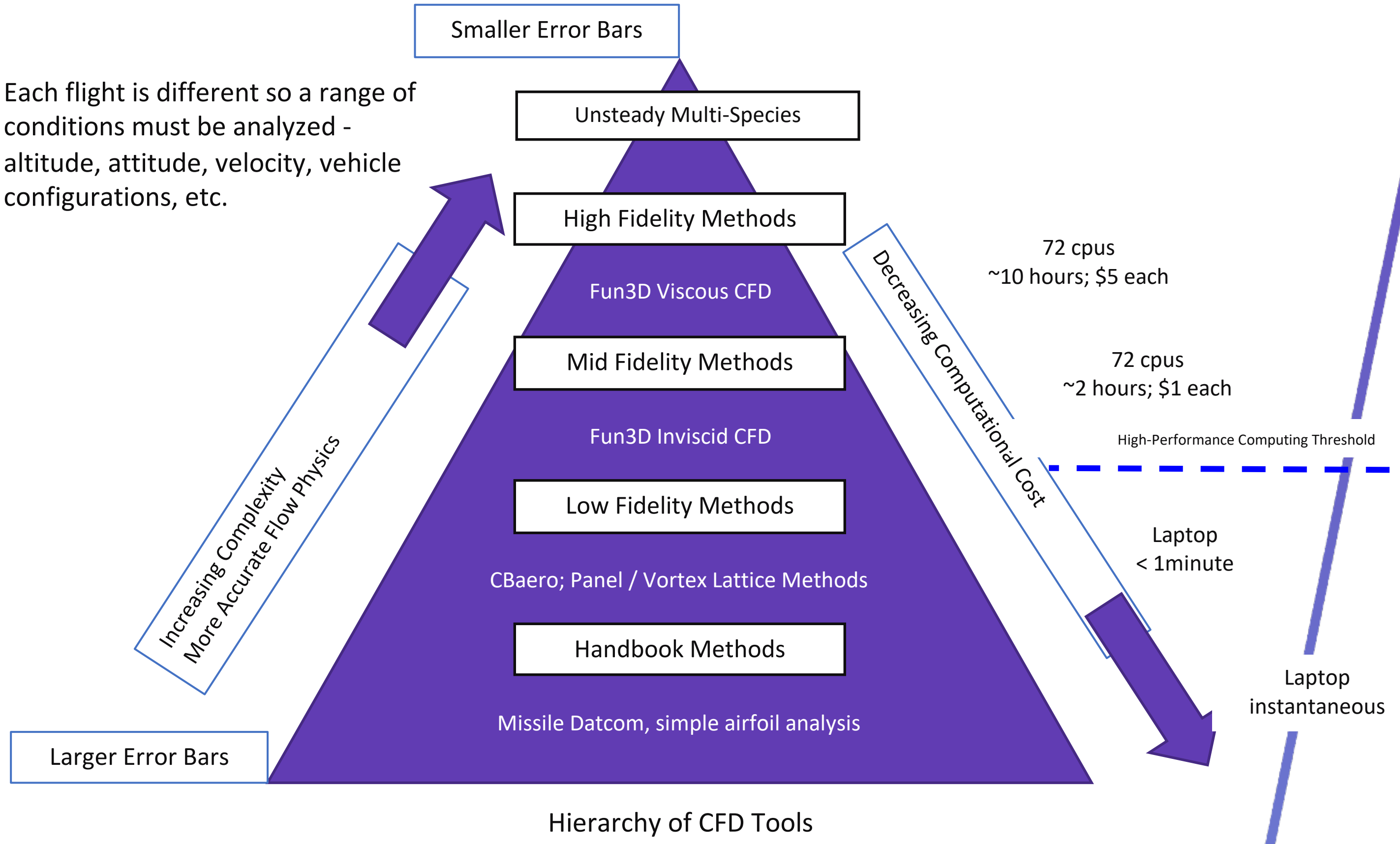
AERODYNAMIC ENVIRONMENT AND ANALYSIS TOOLS

Aerodynamic data is produced from **Computational Fluid Dynamics (CFD)** and **Wind Tunnel** tests



Radian Flight Envelope
Mach: 0.2 - 28 (~140kts landing speed – orbit insertion)
Alpha: –10 to + 55
Altitude: Sea Level – Space (near-zero density)

Each flight is different so a range of conditions must be analyzed - altitude, attitude, velocity, vehicle configurations, etc.



Hierarchy of CFD Tools

The Radian flight envelope presents unique aerodynamic analysis challenges

CFD Runs to Date
5,100 high fidelity runs
275,000 low fidelity runs

Efficient use of Computing Resources Yields Cost Effective Aerodynamic Solutions

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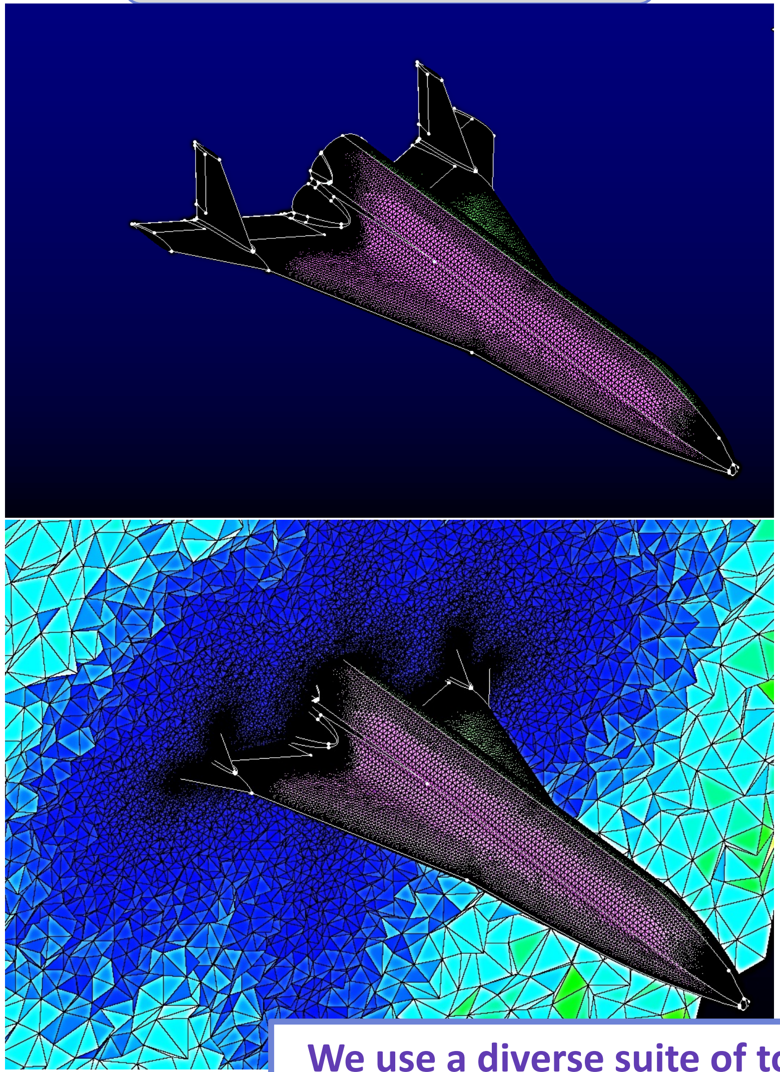
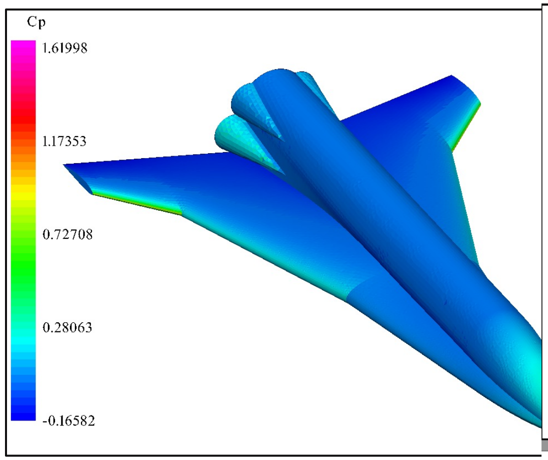
CFD TOOLS

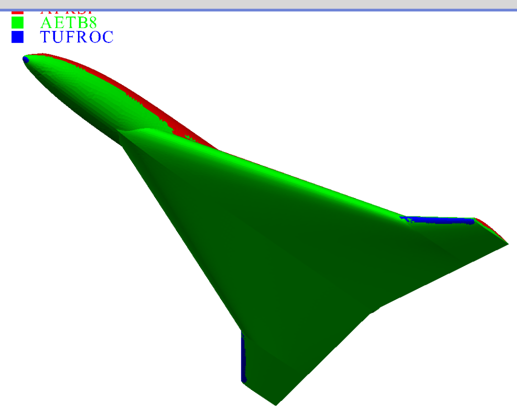
Grid Generation:
Pointwise



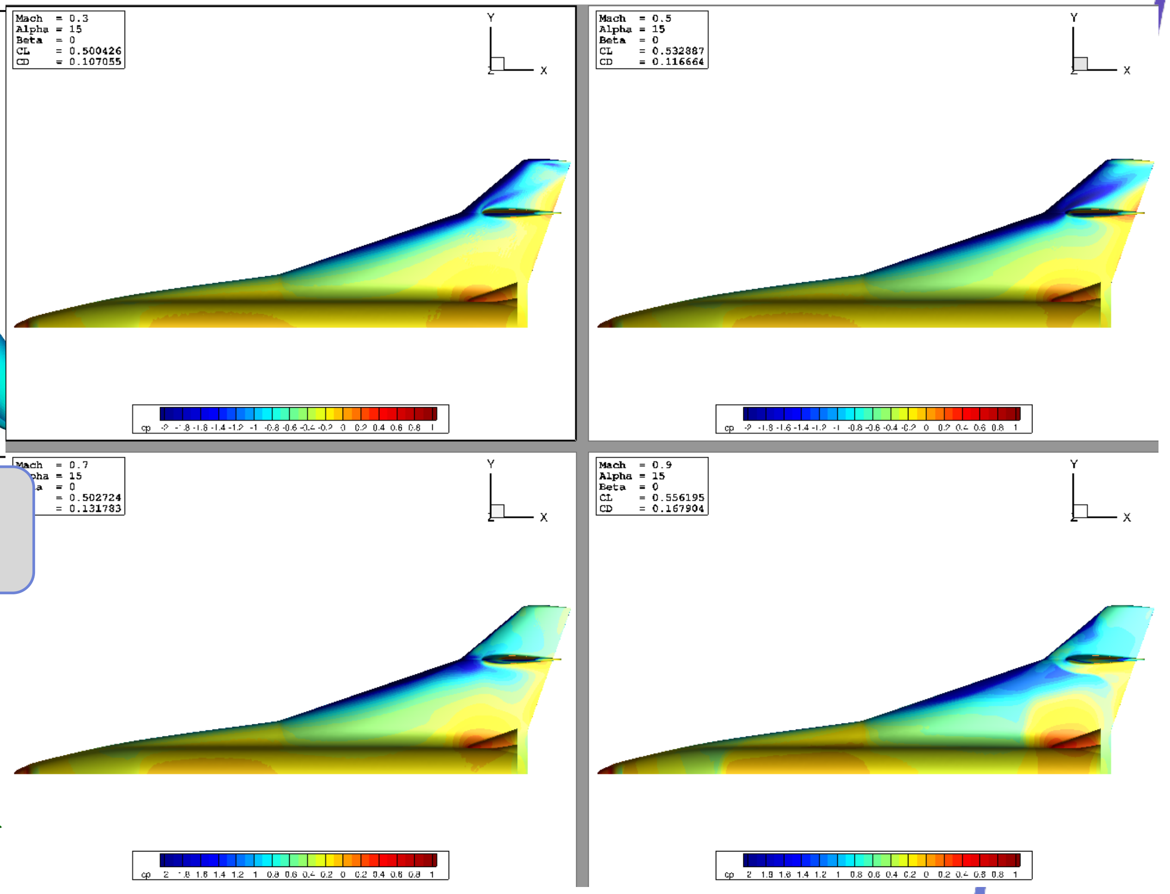
CFD Solvers (NASA):
CBaero, Fun3D



Thermal Analysis (NASA):
CBTPS, TPSSIZER



Post-processing:
Tecplot

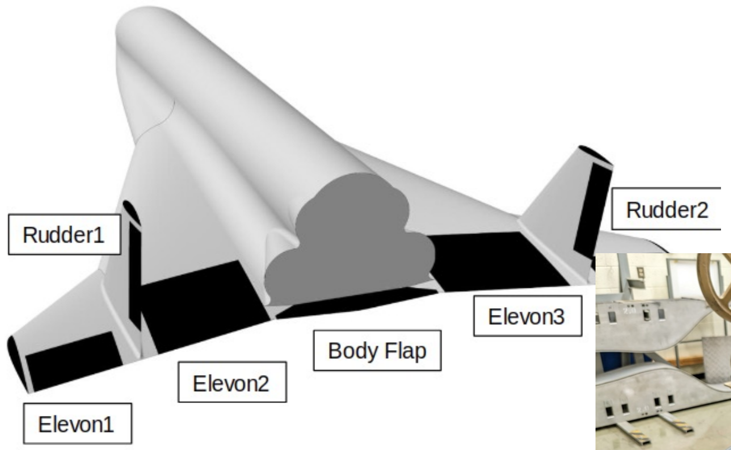


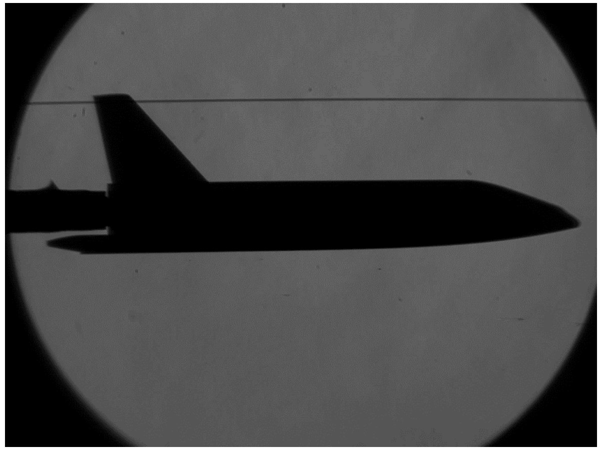
We use a diverse suite of tools to analyze the aerodynamics of the vehicle across the flight envelope

RADIAN AEROSPACE

AERODYNAMIC ANALYSIS - WIND TUNNEL TEST

- Executed Cooperative Research and Development Agreement (CRADA) with the US Air Force Academy
- Acquire data for CFD comparisons
  - More insight into appropriate boundaries for various CFD solvers in the flight envelope
  - Obtain rudder effectiveness data
  - Compare twin tail vs. single vertical tail
- US Air Force Academy Tri-Sonic Wind Tunnel Test
  - Mach: 0.9, 1.2, 2.0, 3.0
  - 88 independent wind tunnel runs
  - 4 unique geometries

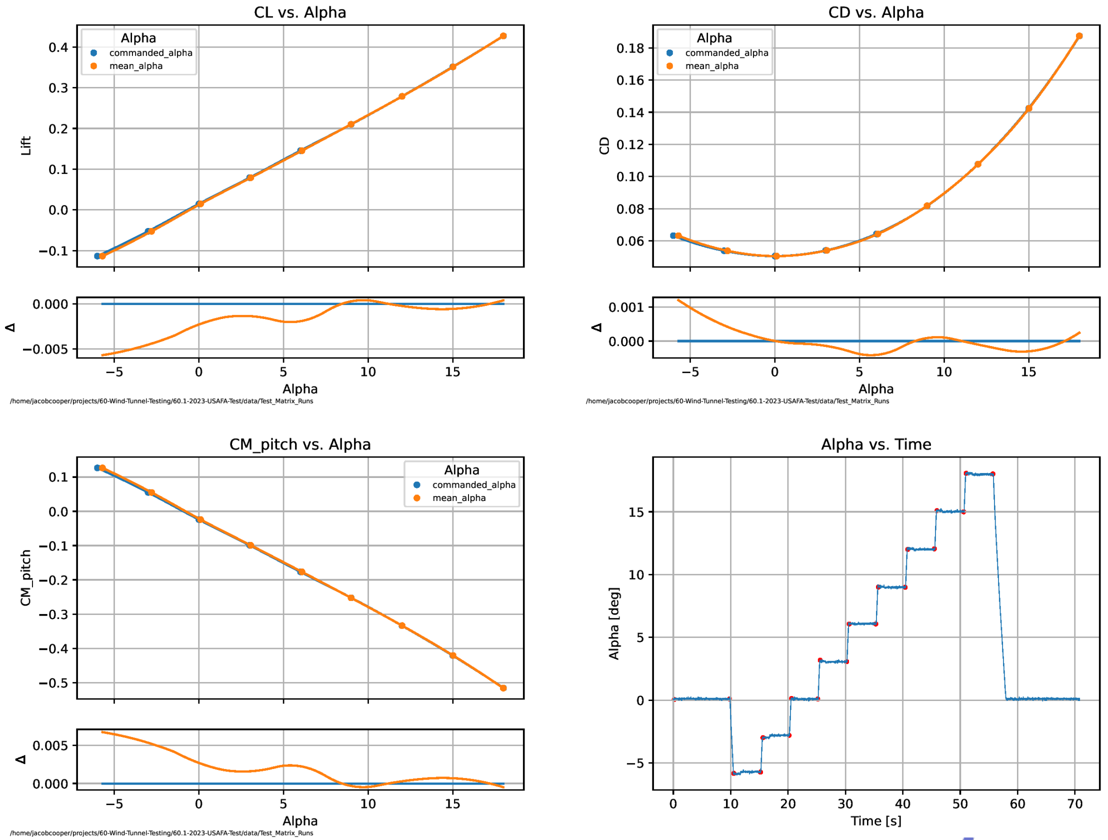




Radian collaborated with the current and future USAF leaders to successfully complete initial Wind Tunnel Test

WIND TUNNEL DATA

Mach 3; Single Vertical Tail; No Rudder Deflection; Alpha sweep



Example Initial wind tunnel data

Wind Tunnel Test provided data critical for the design of Radian One

THE RADIAN ROADMAP

2024	2025	2028	2029
Subscale Runway Flight Test	Subscale Sled Test	First Flight To Space	Radian One To Orbit

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