Highly Reliable Reusable Launch System (HRRLS): Reference Vehicle Overview and Status

Fundamental Aeronautics Program

2nd Annual Meeting

Atlanta, GA

October 7-9, 2008

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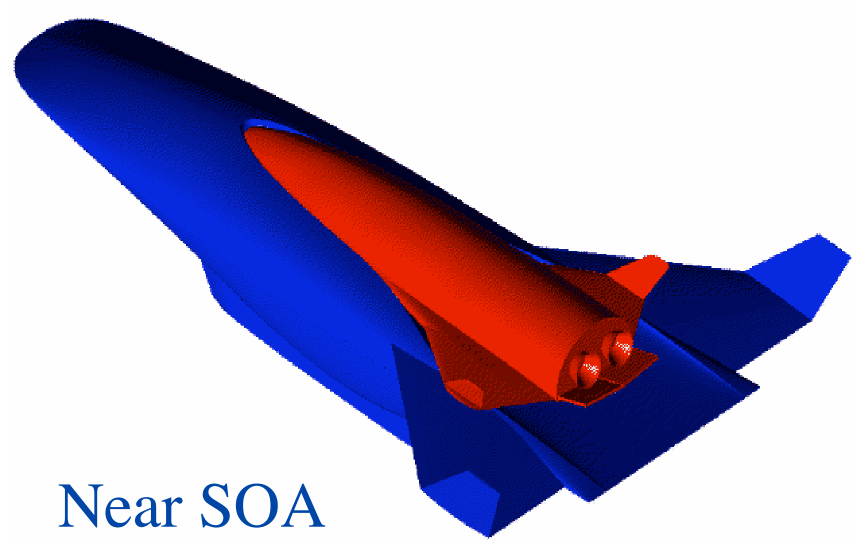
Introduction / Overview

- MDAO has and will continue to develop reference vehicle concepts for the Hypersonics Project Highly Reliable Reusable Launch System (HRRLS) mission
  - Provides MDAO an outlet to exercise design methods and tools
  - Provides relevant environments, design loads and data to other disciplines for use in developing / directing technology and tool development
  - Provides MDAO and the project a benchmarking capability for analyzing and assessing technologies and tools developed within the project
- MDAO developed mission and design ground-rules and assumptions
- First iteration of HRRLS design (-1A) completed this spring using near term technology assumptions

HRRLS TBCC Vehicle Matrix

Lowspeed Propulsion	Highspeed Propulsion	Upper Stage	Designation
F-135 w/ H_2O	M7SOL DMRS HC	HC/LOX Upper	HRRLS-1A
RTA - HC	M7SOL DMRS HC	HC/LOX Upper	HRRLS-1B
RTA - HC	M7SOL DMRS HC	H2/LOX Upper	HRRLS-1C
RTA - H2	M7SOL DMRS HC	HC/LOX Upper	HRRLS-2A
RTA - H2	M7SOL DMRS HC	H2/LOX Upper	HRRLS-2B
RTA - HC	M7SOL DMRS H2	HC/LOX Upper	HRRLS-3A
RTA - HC	M7SOL DMRS H2	H2/LOX Upper	HRRLS-3B
RTA - HC	M12SOL DMRS H2	HC/LOX Upper	HRRLS-3C
RTA - HC	M12SOL DMRS H2	H2/LOX Upper	HRRLS-3D
RTA - H2	M7SOL DMRS H2	HC/LOX Upper	HRRLS-4A
RTA - H2	M7SOL DMRS H2	H2/LOX Upper	HRRLS-4B
RTA - H2	M12SOL DMRS H2	HC/LOX Upper	HRRLS-4C
RTA - H2	M12SOL DMRS H2	H2/LOX Upper	HRRLS-4D
RTA - CH4	M7SOL DMRS CH4	CH4/LOX Upper	HRRLS-5

HRRLS-1A Vehicle Concept

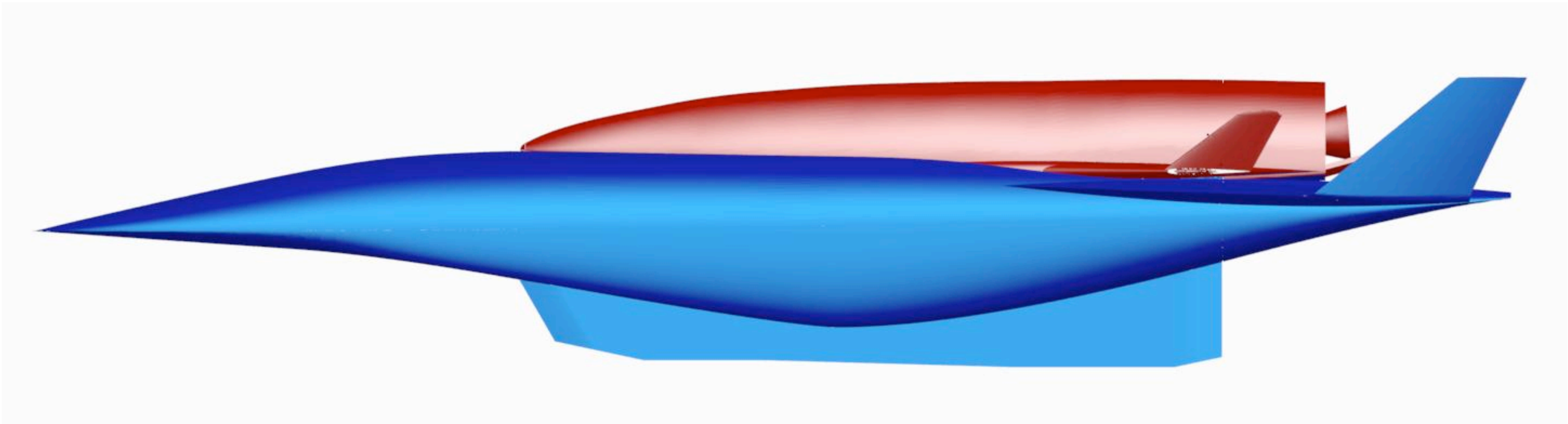


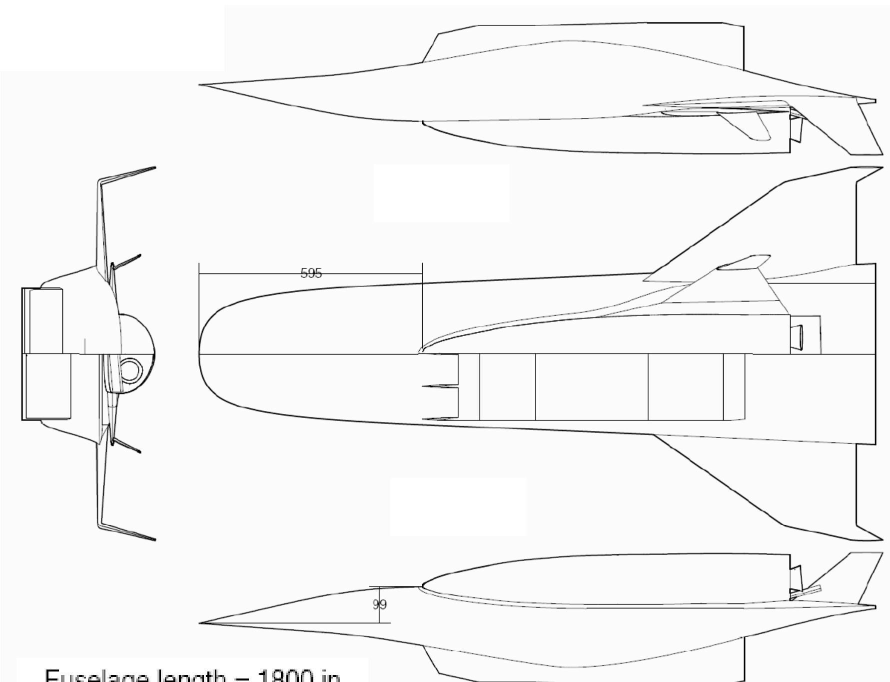
- **Airframe Technology Suite**
  Booster & Orbiter
  - Al-Li primary structure & fixed wings
  - Integral conformal Al-Li HC & H2O tanks
  - Multi-lobed Al-Li non-integral LOX tank (~30 psia)
  - AETB-12 / TUFI ceramic composite tile and AFRSI blanket TPS
  - Advanced polyimide foam (APF) insulation on cryo tanks
  - High temperature metallic wings, tails and control surfaces
  - Coated carbon-carbon leading & trailing edges

- **Architecture Information**
  - TSTO-horizontal takeoff & landing
  - 2-D lifting body booster, fully reusable winged-body rocket upper (will also examine expendables)
  - Booster initially all HC fueled, will examine dual fuel (HC & H2) as well as all H2
- **Reference Mission Characteristics**
  - Payload: 4 crew + 7 days provisions
  - Launch & landing site: KSC
  - Orbit: 30x160 nmi, 28.5° inclination
  - Supports baseline Exploration LEO rendezvous scenario (TRL=6 by 2017, IOC 2025)

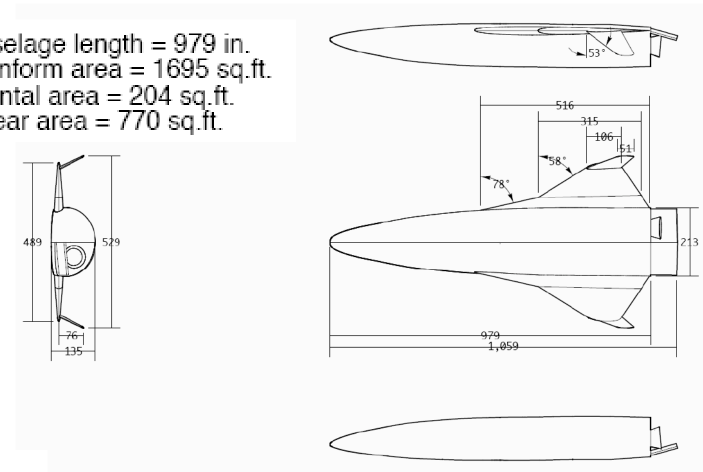
- **Propulsion Technology Suite**
  - Lowspeed (Mach 0-3.5)
    - F135 H2O injection afterburning turbojets
    - In over-under configuration with high speed propulsion system
  - Highspeed (Mach 3-8)
    - Fully variable geometry dual mode scramjet (inlet flap rotation, cowl vertical translation)
    - Mach 7 shock-on-lip, actively cooled, high temperature metallics
  - External Rocket System
    - Booster requires tail rocket system to assist with takeoff and transonic; aerospike in tail
  - Upper stage rocket
    - Conventional RP/LOX; rubberized
  - LOX / Ethanol OMS & RCS

HRRLS-1A Profile

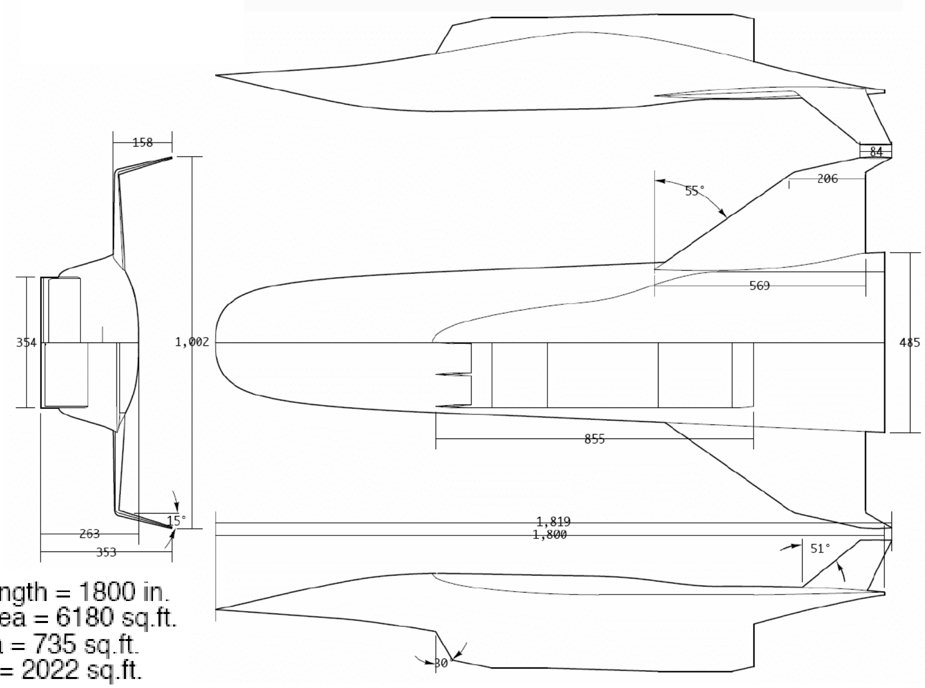




Fuselage length = 1800 in.
Planform area = 6180 sq.ft.
Frontal area = 874 sq.ft.
Shear area = 2628 sq.ft.

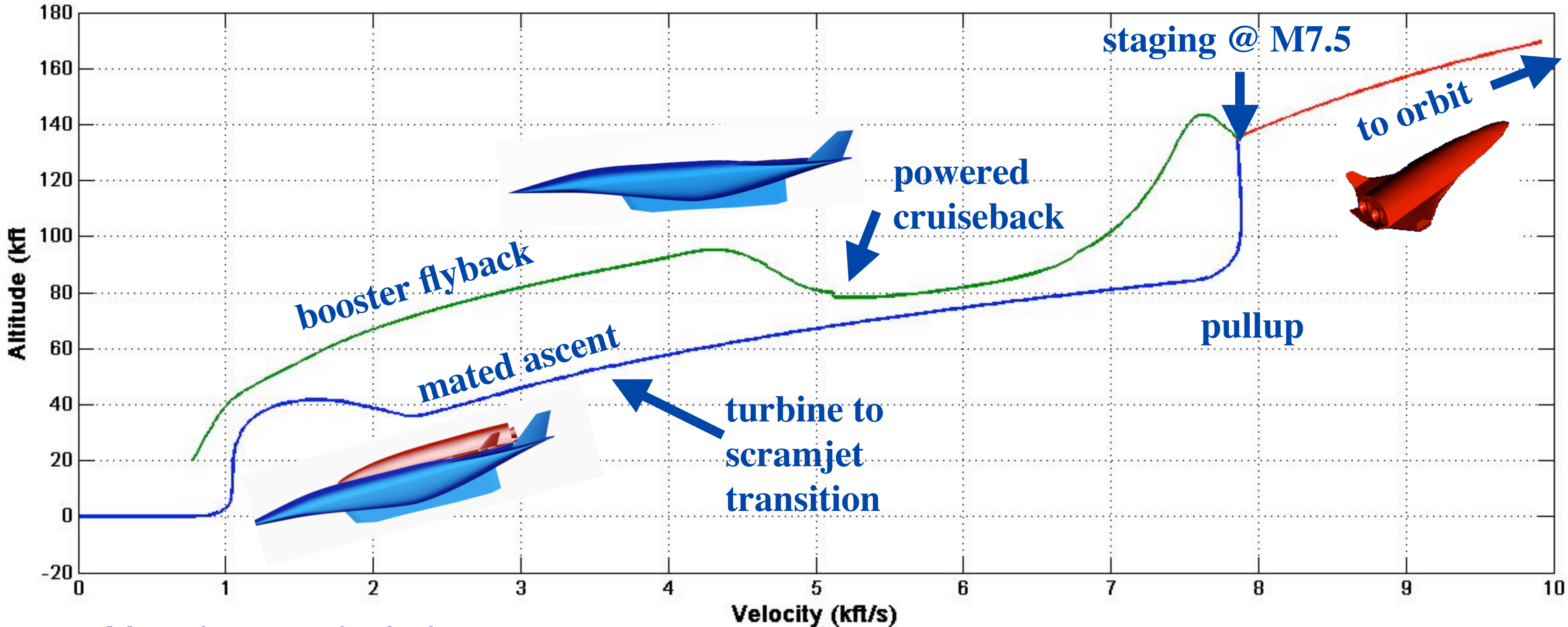


Fuselage length = 979 in.
Planform area = 1695 sq.ft.
Frontal area = 204 sq.ft.
Shear area = 770 sq.ft.



Fuselage length = 1800 in.
Planform area = 6180 sq.ft.
Frontal area = 735 sq.ft.
Shear area = 2022 sq.ft.

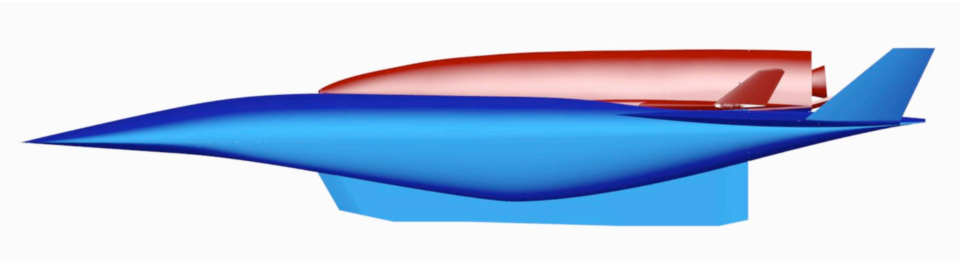
Mission Profile

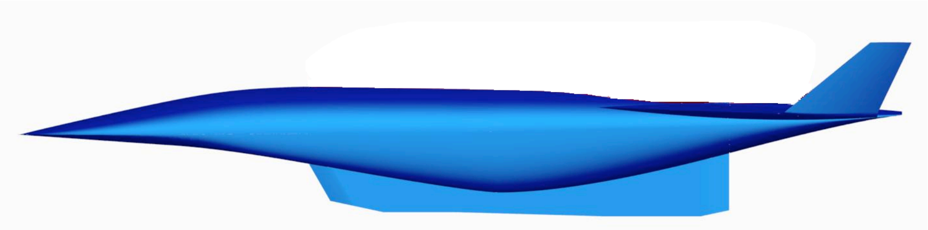


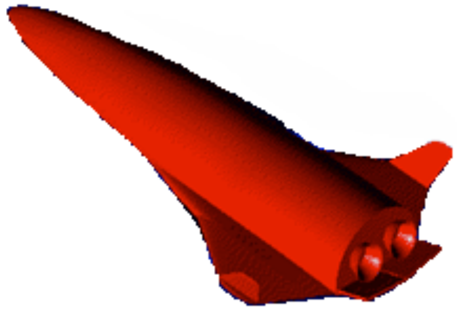
- Mated ascent includes
  - Turbine + rocket powered (booster & cross-fed orbiter) takeoff and transonic push-through
  - Supersonic turbine only operation (with scramjet flowpath open for reduced drag)
  - Transition to scramjet operation, and powered pullup to staging
- Flyback includes:
  - Complicated maneuver to recover from staging and head back to launch site
  - Scramjet powered cruise back (specific range of scramjet preferable over turbojet)
- Extensive aero and propulsion databases required to accurately model flight profile; complex trajectory to optimize; myriad of structural and thermal load cases

Aerodynamic Database

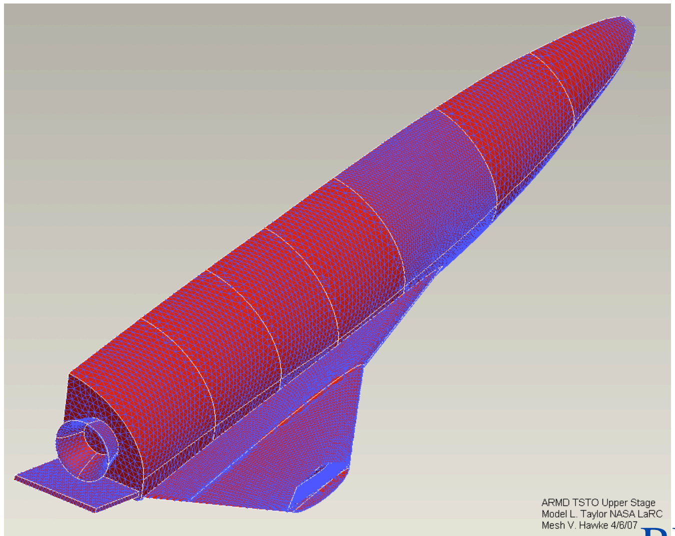
- Complicated, extensive aerodynamic database developed for HRRLS-1A
- Three separate vehicles operating with multiple propulsion cycles and variable geometries, incorporating multiple force accounting systems
- Aero database assembled through a mix of engineering (APAS, SHABP & CBAERO) and CFD codes (USM3D, CART3D, Vulcan)
- Part of effort also focused on code comparison, so some overlap in cases / conditions







CBAero Runs for Orbiter (Aero & Aerothermal)



Run Matrix

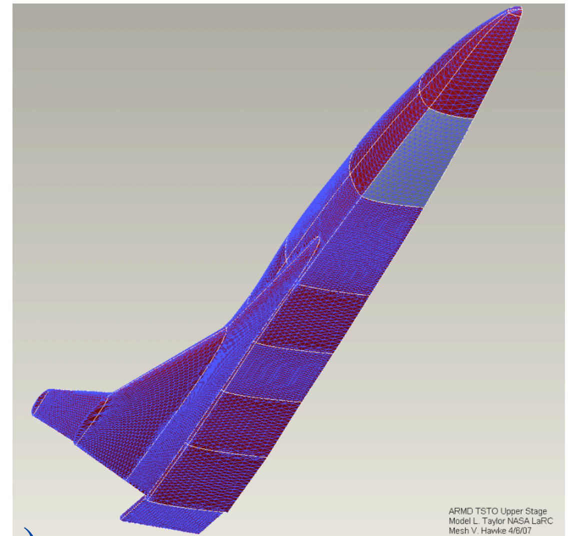
Mach: 1.5, 3, 6, 9, 12, 16, 20, 28

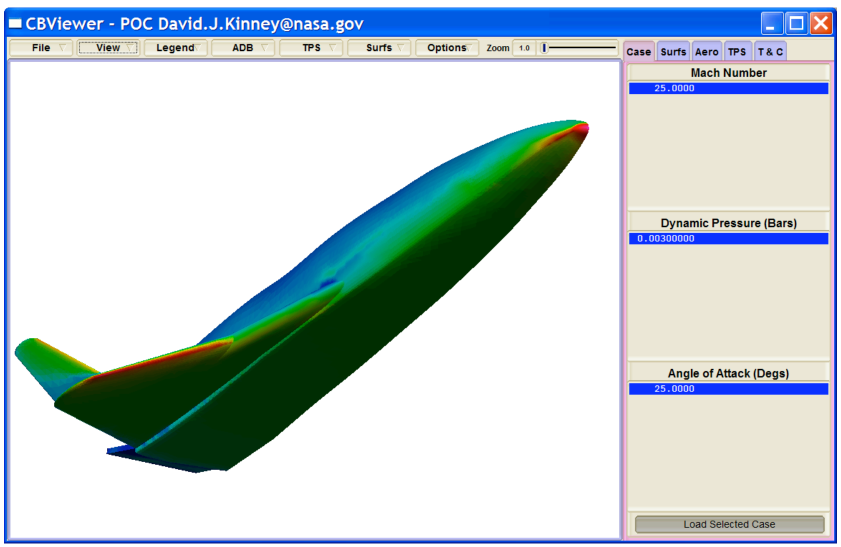
Alpha (deg): -2, 0, 2, 10, 15, 20, 30, 40

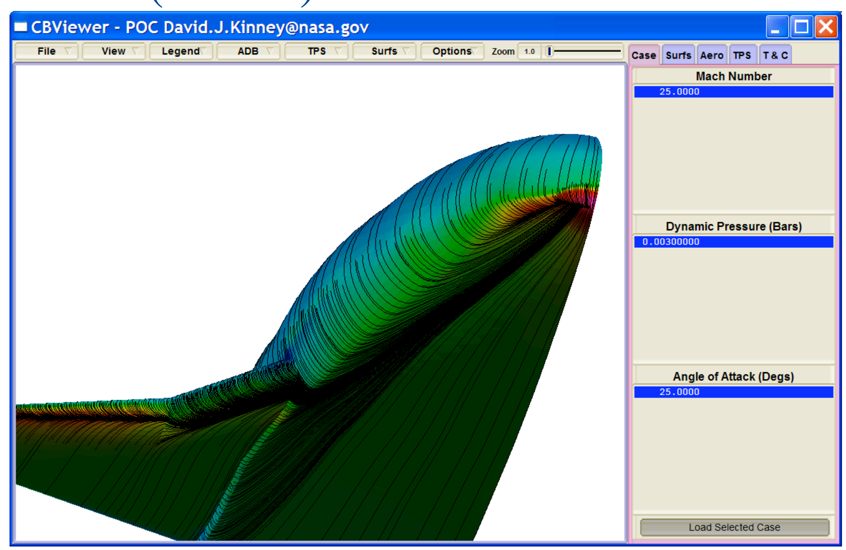
Dynamic Pressure (psf): 0.01, 0.1, 1, 10, 25, 50, 100, 200, 500

$Re_{\Theta}/M_e = 325$

BL transition criteria (Shuttle)

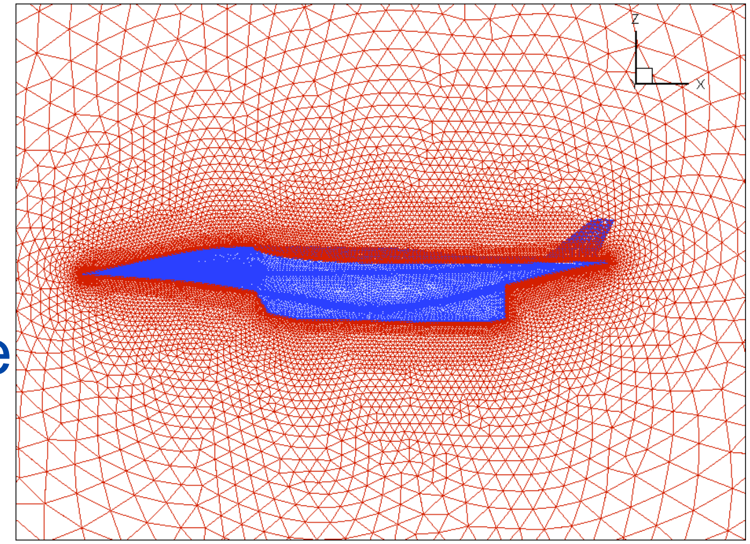


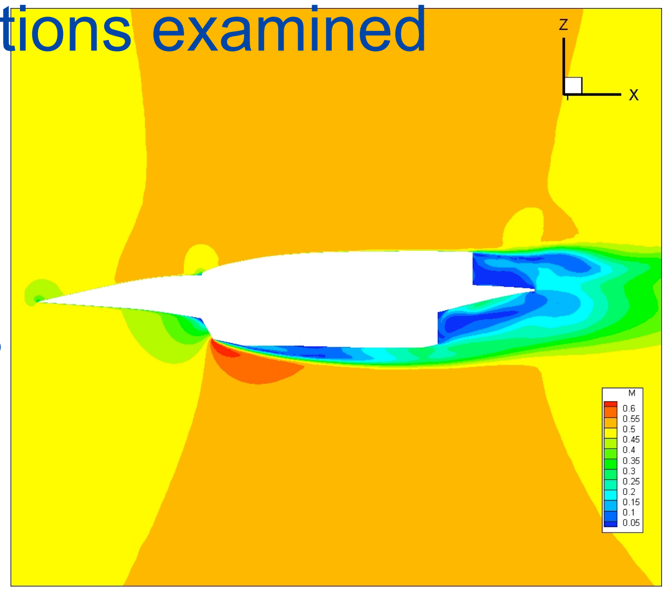


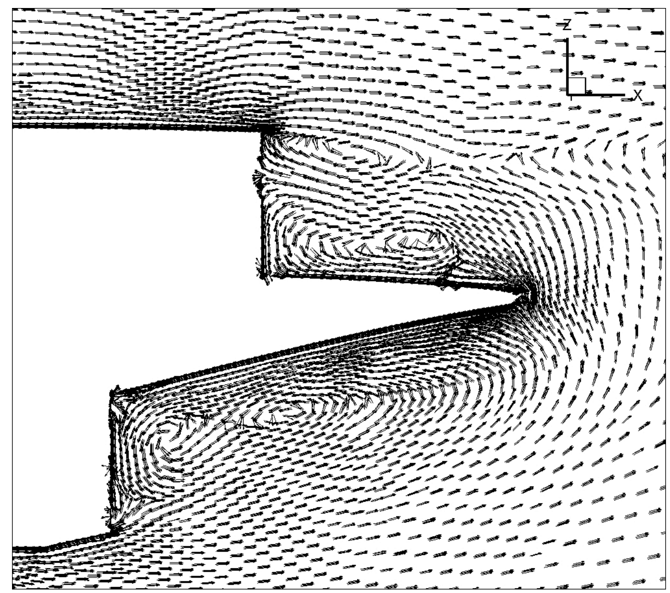


USM3D for Mated and Booster Alone

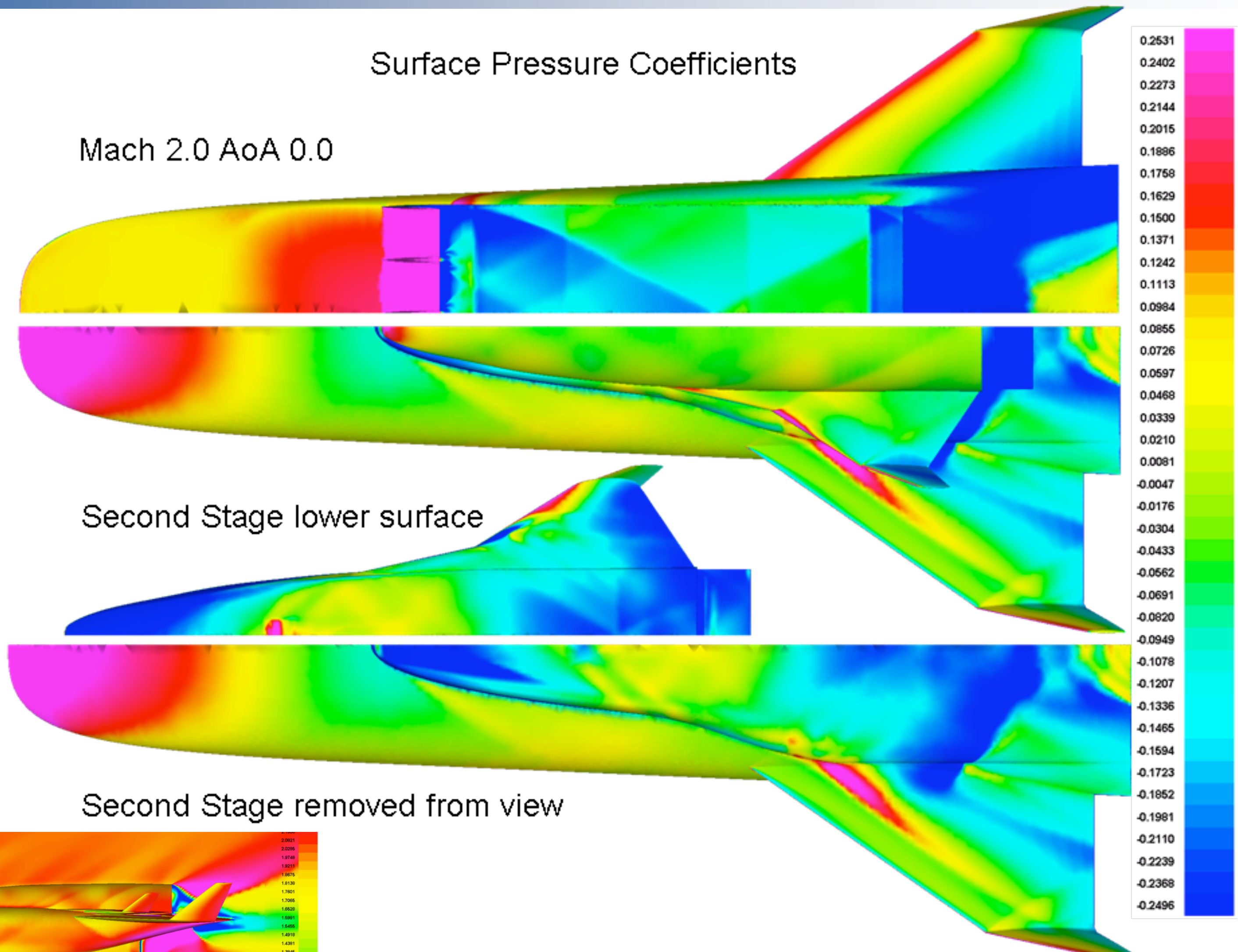
- USM3D used to examine low speed (Mach 0-4) operation of mated and booster alone configurations
- Initially examined cowl closed; currently working “simulated” turbine
- Significant circulation in base may require bleed or fairing for orbiter
- ~50 flight conditions examined
- Grid sensitivity performed at multiple Machs & grid densities (from 10 to 25 million cells)

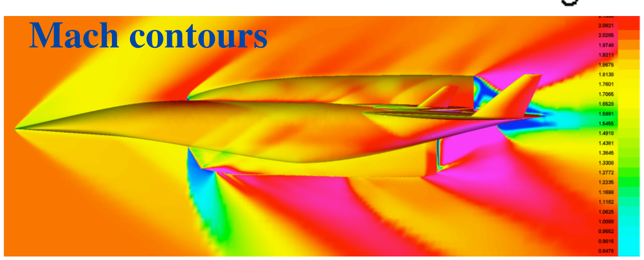






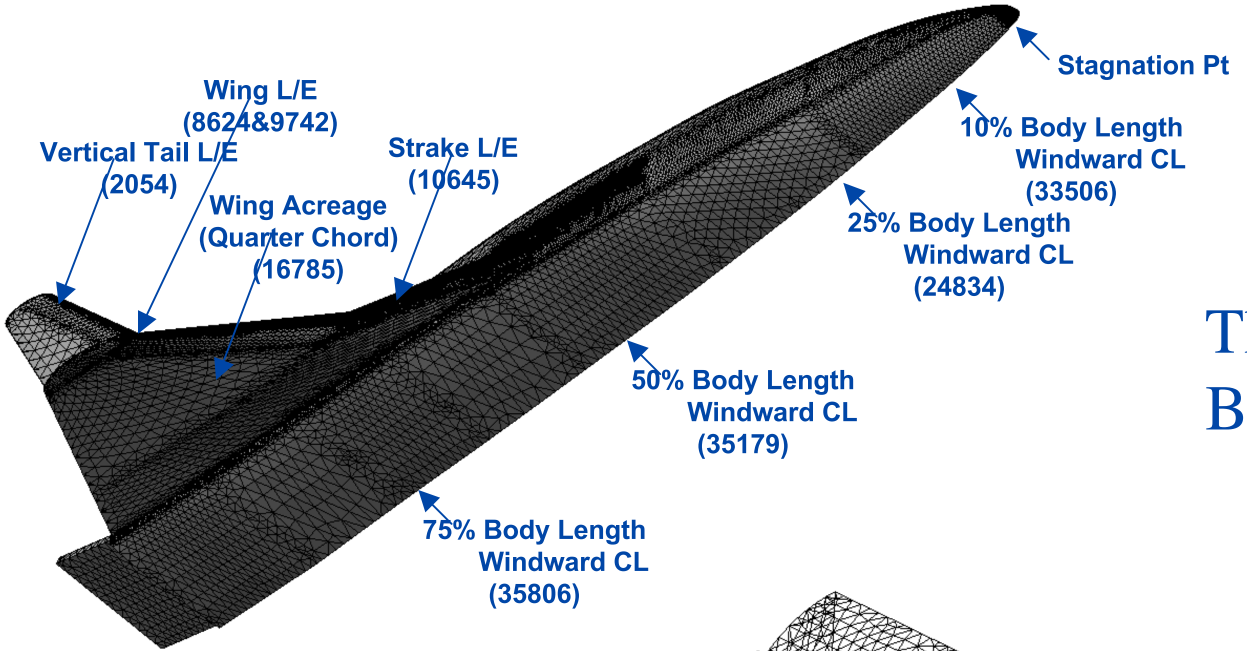
CART3D (Euler) Flowthru CFD



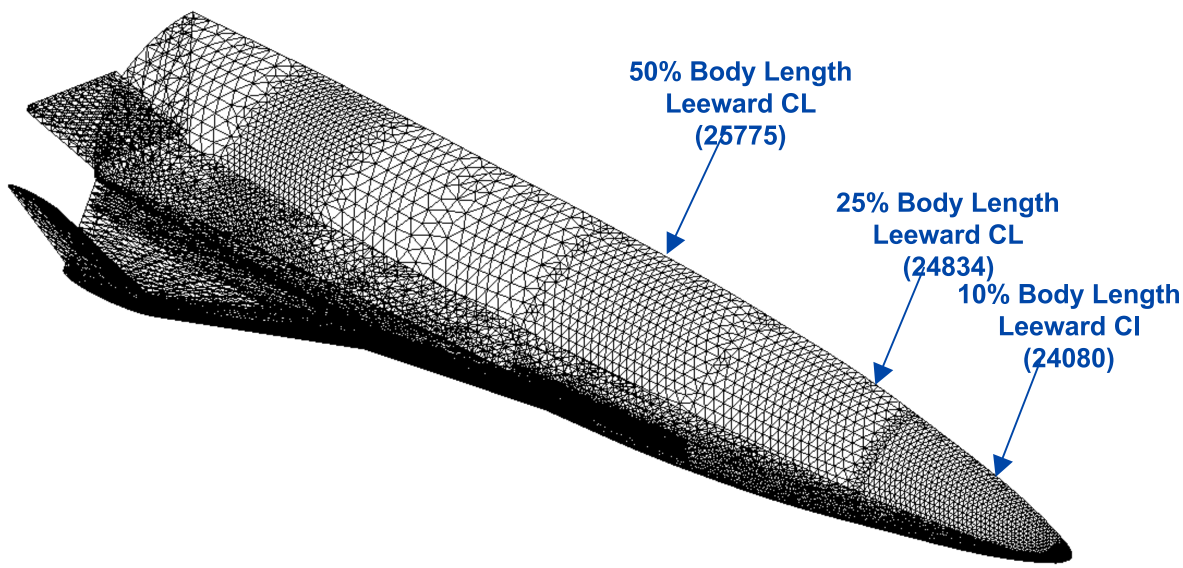


CART3D also run on orbiter

Orbiter Aerothermal Database

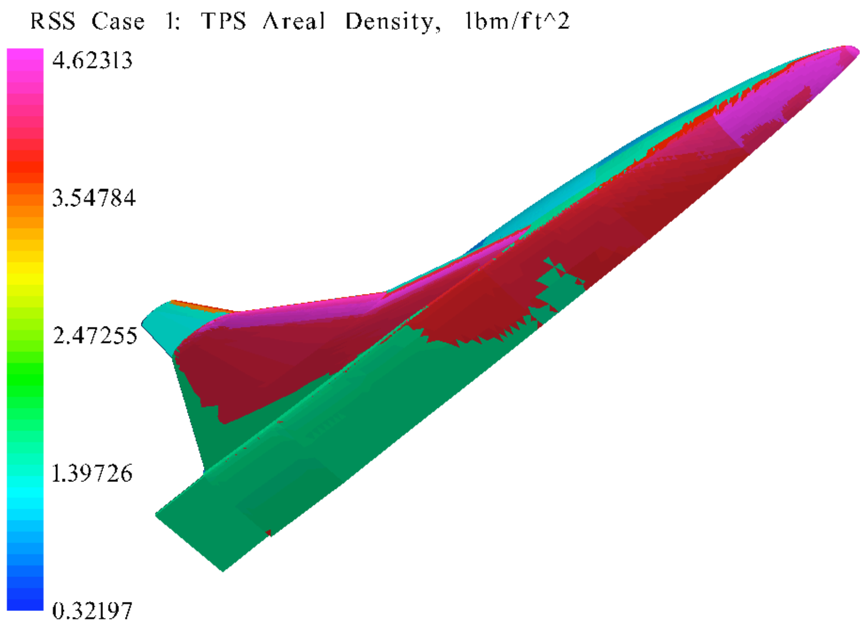


Thermal Control Body Points



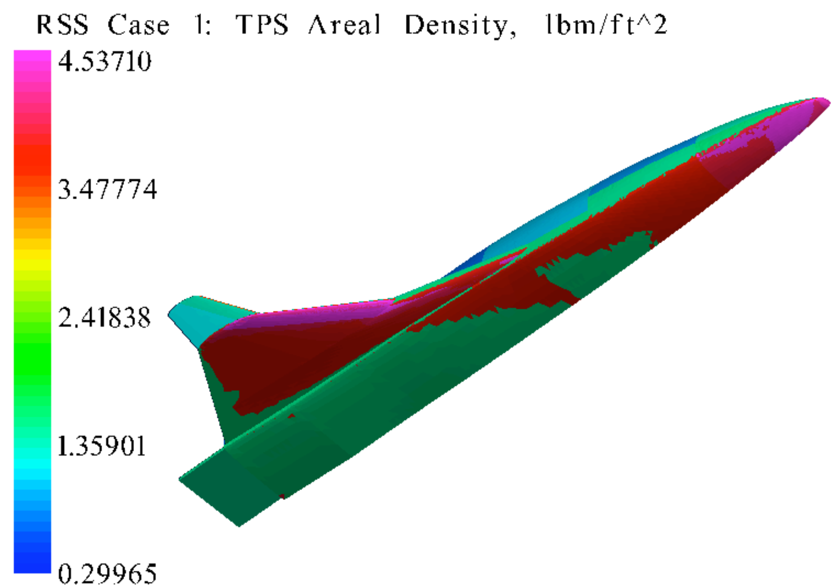
TPS Sizing and Trajectory Optimization

Initial trajectory



Total TPS System Wt. = 8180 lbs
(25% Trajectory Dispersion &
No Aero Heating Uncertainty Margin)

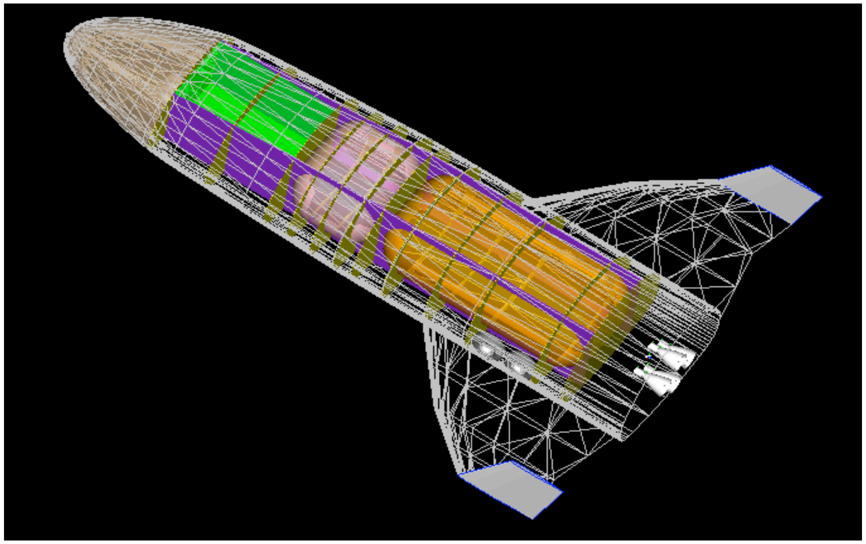
After Optimization

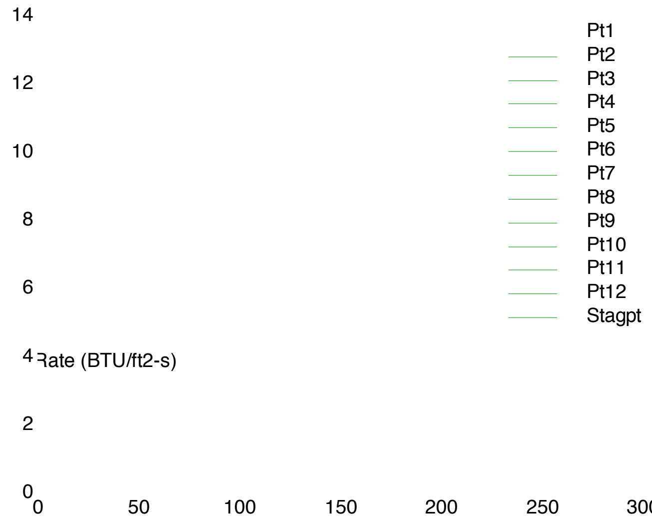


Total TPS System Wt. = 7359 lbs
(25% Trajectory Dispersion &
No Aero Heating Uncertainty Margin)

Orbiter Ascent Trajectory & Closure

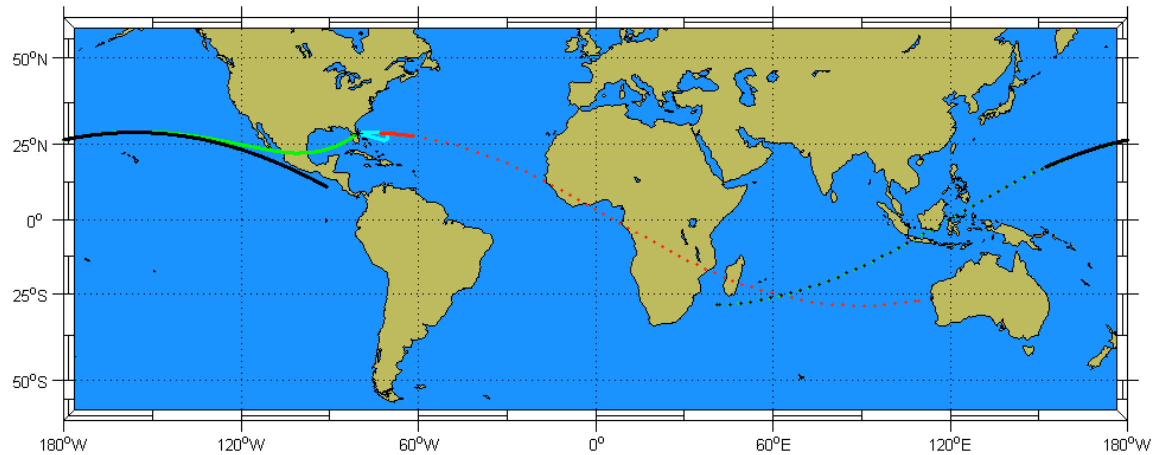
- Staging conditions Mach 7.5, 200 psf dynamic pressure, 5 degree flight path angle assumed (not-optimized)
- Ascent optimized for minimum fuel use; entry optimized to minimize heating / TPS weight
- Orbiter designed with "engine out" capability; nominal stage T/W = 1.2 with four engines at 90% throttle; one engine out provides T/W 1.0 with three engines operating at 100% (100 klb class engines)
- 3 g max acceleration limit



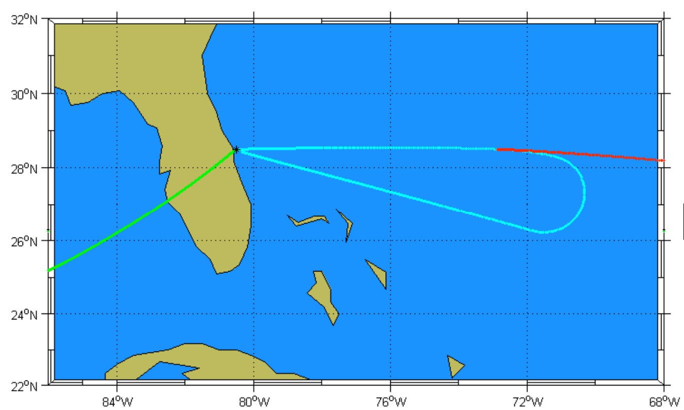


End-to-End Trajectory Simulation

- All phases of TSTO trajectory flown and optimized using POST2
  - Orbiter re-entry with 1200 nmi crossrange requirement; optimized for minimum entry heating
  - Booster & orbiter ascent and booster flyback optimized for minimum propellant use
- Closure performed using Examine (in-house sizing tool w/ empirical MERs)
- Converged to < 0.01%



cyan : mated ascent & booster flyback
red : orbiter ascent **green : orbiter entry**
black : 1200 nmi crossrange orbit pass



Sizing & Mass Properties Summary

ELEMENT DRY MASS SUMMARY

Element Name		Airbreathing Launch Vehicle Booster	Airbreathing Launch Vehicle Orbiter
1.0 Structure	**lbm**	**87,615**	**24,085**
Primary Body Structure	lbm	51,315	11,634
Secondary Body Structure	lbm	13,679	2,249
Aerosurface Structure	lbm	10,954	5,194
Habitat Structure	lbm	0	1,213
Ascent Tank Structure	lbm	11,666	3,795
2.0 Protection	**lbm**	**22,225**	**5,593**
3.0 Propulsion	**lbm**	**115,830**	**8,362**
Ascent Engines & Installation	lbm	110,283	5,645
Fuel Feed & Pressurization	lbm	2,341	407
Oxidizer Feed & Pressurization	lbm	2,143	940
Space Engines & Installation	lbm	0	320
NTR Engine & Installation	lbm	0	0
RCS Engines & Installation	lbm	590	374
OMS Fuel Tanks & Feed/Fill/Drain System	lbm	0	339
OMS Oxidizer Tanks & Feed/Fill/Drain System	lbm	0	322
RCS Fuel Tanks & Feed/Fill/Drain System	lbm	202	0
RCS Oxidizer Tanks & Feed/Fill/Drain System	lbm	269	0
Pressurization System	lbm	1	14
4.0 Power	**lbm**	**9,193**	**2,693**
5.0 Control	**lbm**	**3,091**	**725**
6.0 Avionics	**lbm**	**575**	**757**
7.0 Environment	**lbm**	**18**	**2,268**
8.0 Other	**lbm**	**33,279**	**3,040**
9.0 Growth	**lbm**	**13,633**	**2,483**
Dry Mass w/ Growth	**lbm**	**285,458**	**50,005**

ELEMENT WET MASS SUMMARY

Element Name		Airbreathing Launch Vehicle Booster	Airbreathing Launch Vehicle Orbiter
Dry Mass w/ Growth	**lbm**	**285,458**	**50,005**
10.0 Non-Cargo	**lbm**	**6,985**	**5,164**
11.0 Cargo	**lbm**	**304,863**	**0**
Inert Mass	**lbm**	**597,306**	**55,169**
12.0 Non-Propellant	**lbm**	**724**	**827**
13.0 Propellant	**lbm**	**839,220**	**248,867**
Usable Ascent Fuel	lbm	527,115	67,781
Usable Ascent Oxidizer	lbm	308,143	176,231
Usable OMS Fuel	lbm	0	895
Usable OMS Oxidizer	lbm	0	3,133
Usable RCS Fuel	lbm	1,467	184
Usable RCS Oxidizer	lbm	2,495	643
Gross Mass	**lbm**	**1,437,250**	**304,863**

System Study Next Steps

- Continued refinement and analysis planned under joint NASA / Air Force system study
  - Reclose system for Air Force ORS mission and technology suite
  - Continue working structural layout and sizing
  - 2-D (axial & normal force + pitching moment) turbine data
  - TPS / thermal assessment of booster
  - Control surface sizing for both stages
  - Complete thermal and power balance
  - Detailed packaging and time dependent mass properties
  - Powered transonic and ground effects analysis
  - Takeoff analysis
  - Vehicle level trades & optimization
  - Eventually develop 6-DoF aero database and simulation (long term)

Additional

- Vehicle data, CAD models, databases, etc requested and distributed to nearly all HYP disciplines and numerous NRA partners
- Supporting analysis / improved models now expected from several disciplines
- Plans beyond AF / NASA joint system study include examining alternate fuel combinations (H2 / JP dual fuel, all H2, all methane) as well as other vehicle level trades and optimization
- Operations assessment to be performed by Spaceworks