HYPERSONIC AIRBREATHING VEHICLES/ TECHNOLOGIES

James L. Hunt
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by

James L. Hunt

INTRODUCTION

Hypersonic airbreathing horizontal takeoff and landing (HTOL) vehicles are highly integrated systems involving many advanced technologies. The design environment is variable rich, intricately networked, and sensitivity intensive; as such, it represents a tremendous challenge. Creating a viable design requires addressing three main elements: (1) an understanding of the "figures of merit" and their relationship, (2) the development of sophisticated configuration discipline prediction methods and a synthesis procedure, and (3) the synergistic integration of advanced technologies across the discipline spectrum. This paper will focus on the vision for hypersonic airbreathing vehicles and the advanced technologies that forge the designs.

Airbreathing hypersonics encompass endoatmospheric (airplanes...missiles are a part of the matrix but will not be included in this paper since they are an air force focus) and space access vehicles with speed from Mach 4 up to Mach 25 (orbital). These vehicles can be divided into two classes...cruisers and accelerators. The cruiser designs reflect high lift-to-drag whereas the accelerators reflect low drag per unit inlet capture; thus, the cross section of the accelerator attributes a much larger percentage to propulsion. One of the more design influencing items is fuel. The hydrogen fueled vehicles must be very volumetric efficient to contain the low density fuel and thus tend to be a bit bulgy (more conducive to lifting bodies or wing bodies) whereas with hydrocarbon fueled vehicles, the concern is loading because of the high density fuel; thus, they may tend to be more towards waveriders which are not usually very volumetric efficient. Hydrocarbon fuels (endothermic) are limited in their engine cooling capacity to below Mach 8.

HYPERSONIC AIRBREATHING VEHICLES/ TECHNOLOGIES

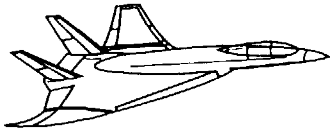
Scope: A perspective for hypersonic airbreathing vehicles and the advanced technologies that forge the designs

Outline:

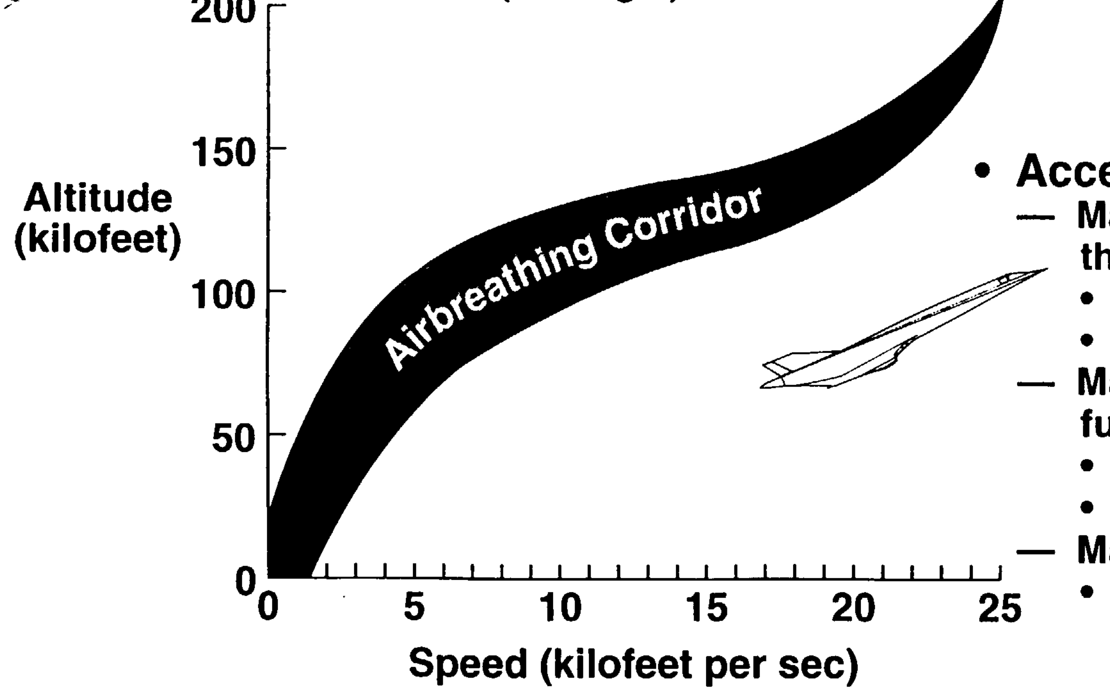
- Design Space
  - Space Access
    - Baseline design/technology } *The Synergy*
    - Matrix
  - Endoatmospherics
    - Matrix
- Global access from CONUS base
- Enhancing, cutting-edge technologies

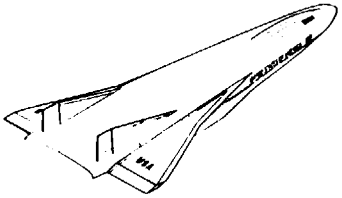
The hypersonic airbreathing vehicles matrix being explored in Langley's Hypersonic Vehicles Office, Systems Analysis Office (HVO/SAO), is presented in the first figure along with the airbreathing corridor in which they operate. It includes endothermically fueled theater defense and transport aircraft below Mach 8 as well as cruise missiles. Above Mach 8, the focus is on dual fuel and/or hydrogen fueled vehicles for long range cruise, first or second stage launch platforms and/or single-stage-to-orbit vehicles.

THE HYPERSONIC AIRBREATHING MATRIX... VEHICLES, APPLICATIONS, AND FLIGHT ENVELOPE



- Accelerators/Cruisers
  - — Mach 4-8 (endothermic fuel)
    - Theater aircraft and weapons
    - Missiles (tactical and strategic)
    - Transport aircraft
  - — Mach 8-18 (LH_2/SH_2 or dual fuel)
    - Global aircraft and weapons
    - Missiles (strategic)





- Accelerators (Space Access)
  - — Mach 4-8 (LH_2 or endothermic fuel)
    - 2STO 1st stage
    - 3STO 2nd stage
  - — Mach 8-18 (LH_2/SH_2 or dual fuel)
    - 2STO 1st stage
    - 3STO 2nd stage
  - — Mach 25 (SH_2 or dual fuel)
    - SSTO

A definitive design/performance study was performed on a single-stage-to-orbit (SSTO) airbreathing propelled orbital vehicle with rocket propulsion augmentation in the Access to Space activities (Ref. 1 and 2; Option III Team) during 1993. A credible reference design was established, but by no means an optimum. The results (Ref. 3) supported the viability of SSTO airbreathing/rocket vehicles for operational scenarios and indicated compelling reasons to continue to explore the design matrix. This airbreathing/rocket (A/R) SSTO and the technologies incorporated will be used as the baseline for the airbreathing space access vehicle/technology matrix.

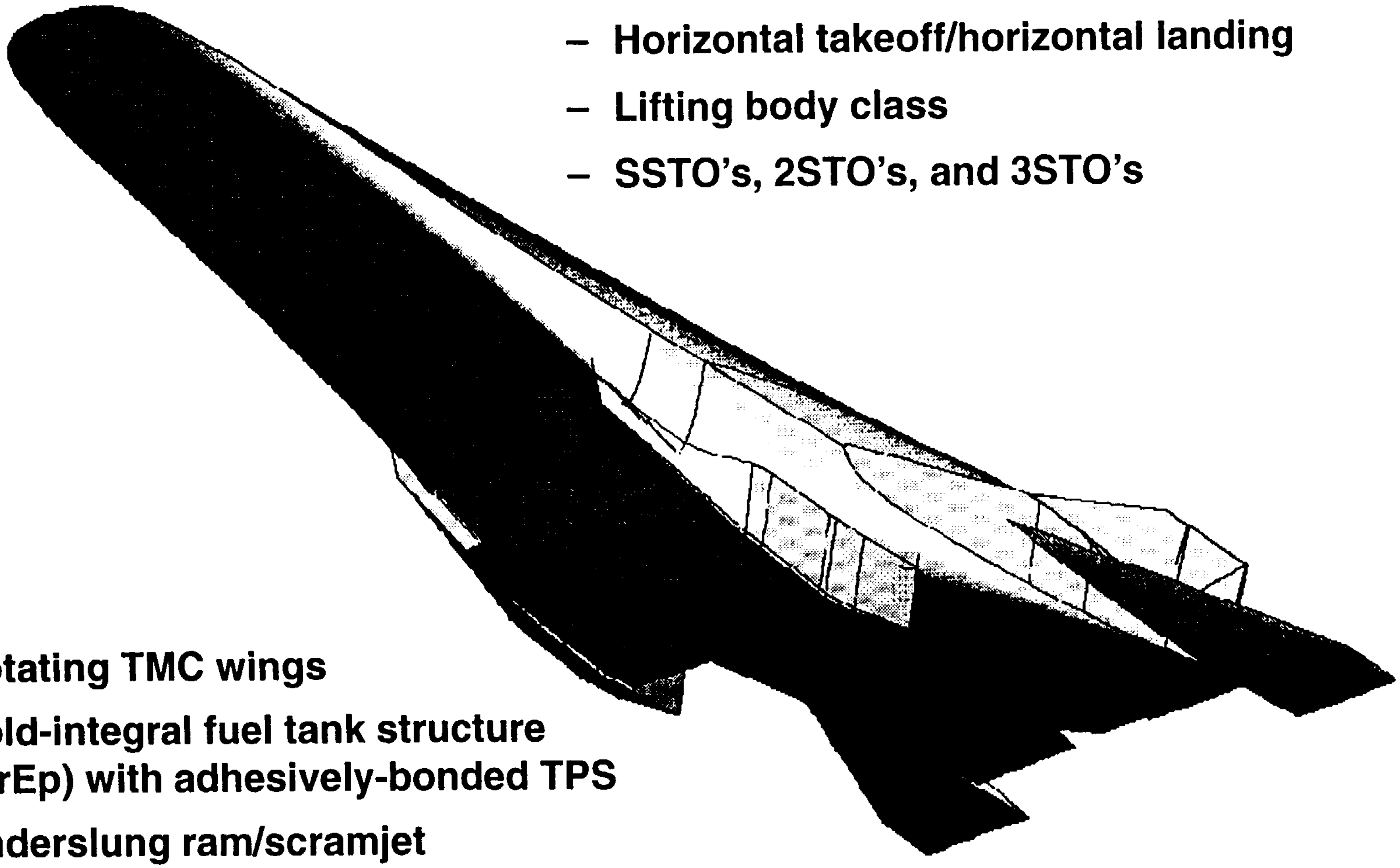
The A/R SSTO vehicle was designed to carry 25,000 lbs. of payload in a 15'x15'x30' rectangular payload bay to an orbit of 220 nm, 51.6° inclination, then dock with a hypothetical space station for delivery of the payload. The vehicle was designed with a 15% weight growth margin, a 5-minute launch window, and an ascent delta velocity margin of 1%. The wedge-shaped forebody, spatula-shaped planform, lifting body baseline configuration with salient features is shown in the accompanying figure.

Ref 1. Access to Space Study: Summary Report; Office of Space Systems Development, NASA Headquarters, January 1994.

Ref. 2 Beckey, I.; Powell, R.; and Austin, R.: NASA Studies Access to Space. Aerospace America, May 1994.

Ref. 3 Hunt, J. L.: Airbreathing/Rocket Single-Stage-to-Orbit Design Matrix. AIAA Paper 95-6011 presented at the Sixth International Aerospace Planes and Hypersonics Technologies Conference, Chattanooga, TN, April 3-7, 1995.

AIRBREATHING SPACE ACCESS CONFIGURATION MATRIX EXAMINED

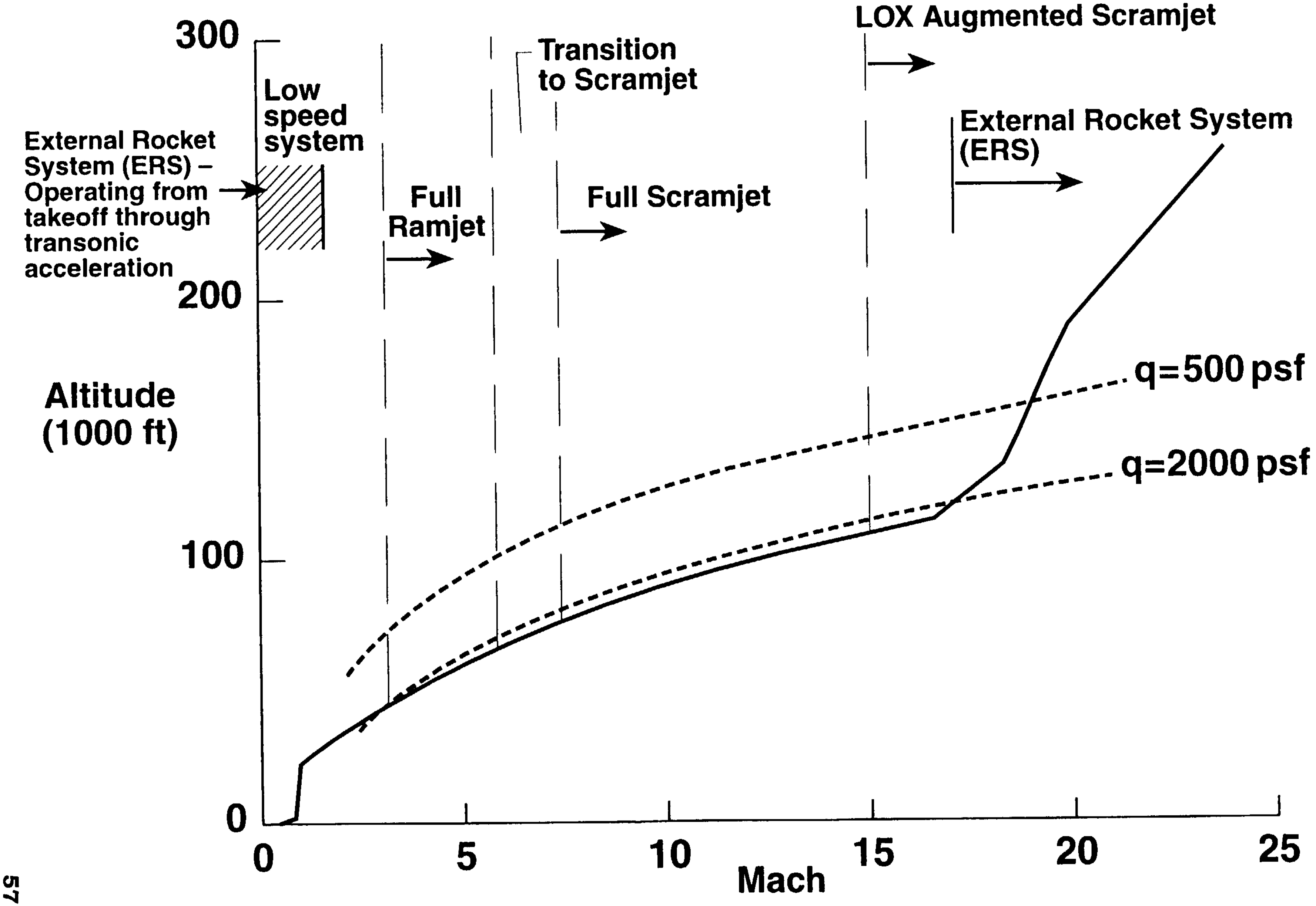


- Horizontal takeoff/horizontal landing
- Lifting body class
- SSTO's, 2STO's, and 3STO's

- Rotating TMC wings
- Cold-integral fuel tank structure (GrEp) with adhesively-bonded TPS
- Underslung ram/scramjet
- Trailing-edge mounted rocket (augmented expander with linear nozzle)

The airbreathing corridor to Mach 25 and the engine mode changes experienced in this acceleration process also characterize this aerospace plane. A representative ascent trajectory for the A/R SSTO vehicle is presented in the accompanying figure including indicators for propulsion mode events. Most of the airbreathing propelled ascent is along a high dynamic pressure isobar (2150 psf). Takeoff and transonic ascension are accomplished with the low-speed system and external rocket system performing simultaneously. The rocket is switched off at about Mach 1.8; the ramjet mode is initiated at Mach 3. Transition to the scramjet begins at Mach 6 with the full scramjet mode in operation by Mach 7.5. Departure from the isobar above Mach 15 signals the onset of LOX augmentation through the scramjet and the activation of the external rocket system. Scramjet main engine cutoff (MECO) is at Mach 24. Even though the external rocket system has essentially the same thrust at takeoff as the airbreathing engines, the airbreathing flowpath provides 80% of the total ascent energy. Within this 80%, the scramjet provides 27% and the LOX augmented scramjet provides 24% of the total ascent energy. With more optimization and an expanded database, the LOX augmented scramjet will become even more significant.

ASCENT TRAJECTORY FOR SSTO

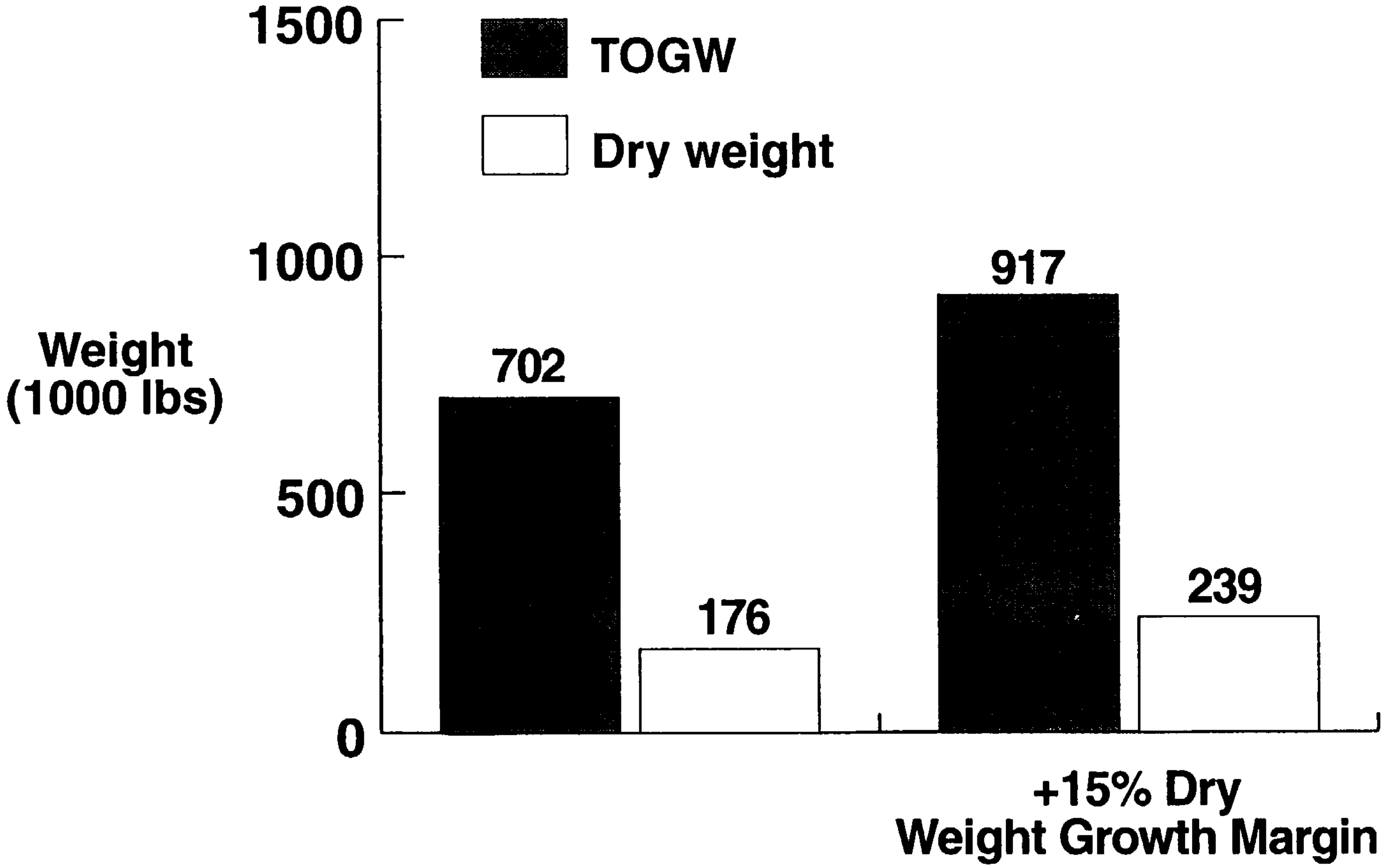


The baseline A/R SSTO vehicle closure weights for the previously described mission are presented. The takeoff gross weight (TOGW) is 702,000 lbs.; the dry weight (DW) is 176,000 lbs. Adding a 15% dry weight growth margin, as specified in the Access to Space Study, increased the TOGW to 917,000 lbs. and the DW to 239,000 lbs. (Ref. 1 and 2). The length of the closed vehicle with 15% dry weight growth is 200 ft.

CLOSURE WEIGHTS FOR A/R SSTO REFERENCE VEHICLE

Graphite/epoxy integral tank structure with Rohacell insulation

(FRCI-12 TPS on windward surfaces and TABI TPS on upper surface)



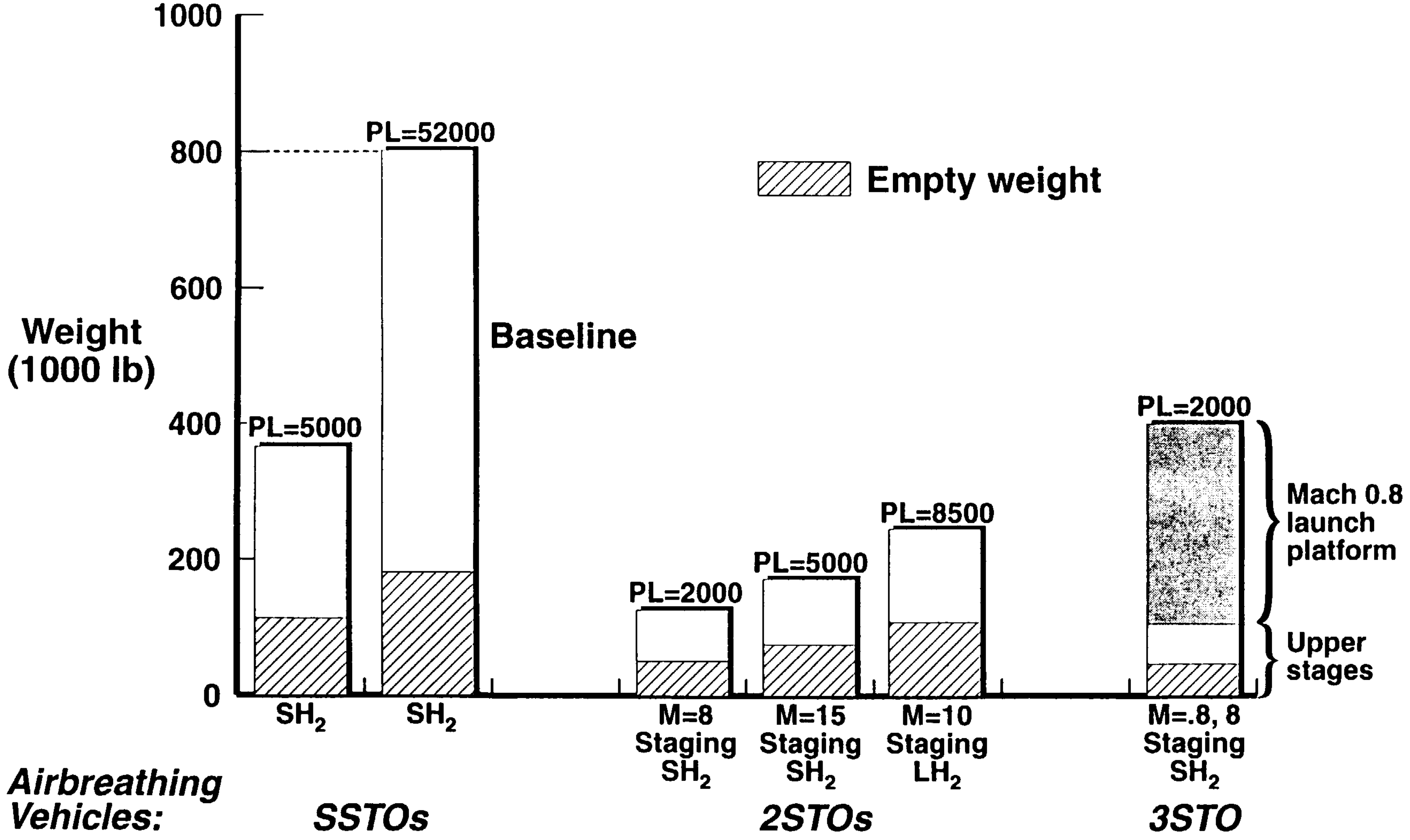
The horizontal takeoff/horizontal landing airbreathing space-access performance potential pursuant to the baseline configuration space and technologies is presented in the accompanying figure for SSTO's, 2STO's, and 3STO's flying to a low earth, easterly orbit. All payloads and/or upper stages are mounted internally and the vehicle weights include 7.5% dry weight growth margin. Note that for a low earth, easterly orbit, as compared to 51.6° and 220 nm, the baseline payload increased from 25,000 lbs. to 52,000 lbs.; the takeoff gross weight (TOGW) decreased from 917,000 lbs. to 800,000 lbs. due to reducing the dry weight growth margin from 15% to 7.5%. Dropping the payload to 5,000 lbs. decreased the TOGW of an SSTO to 371,000 lbs.

Two-stage systems (2STO) are shown for staging Mach numbers of 8, 10, and 15 with payloads of 2,000 lbs., 8,500 lbs., and 5,000 lbs., respectively. The upper stage of these launch systems is a rocket with hydrogen/LOX propellant. Slush hydrogen was used as fuel in the first stage of the Mach 8 and Mach 15 staging systems and indicated that the staging Mach number tends to increase with increasing payload weight. The Mach 10 staging system is fueled with liquid hydrogen (not slush) and thus it does not fit the payload staging Mach correlation.

The three-stage-to-orbit (3STO) system used a Mach 0.8 launch platform for the first stage (Antonov 225, for example) and stages a hydrogen fuel upper stage at Mach 8 carrying a 2,000 lb. payload.

SPACE-ACCESS PERFORMANCE POTENTIAL

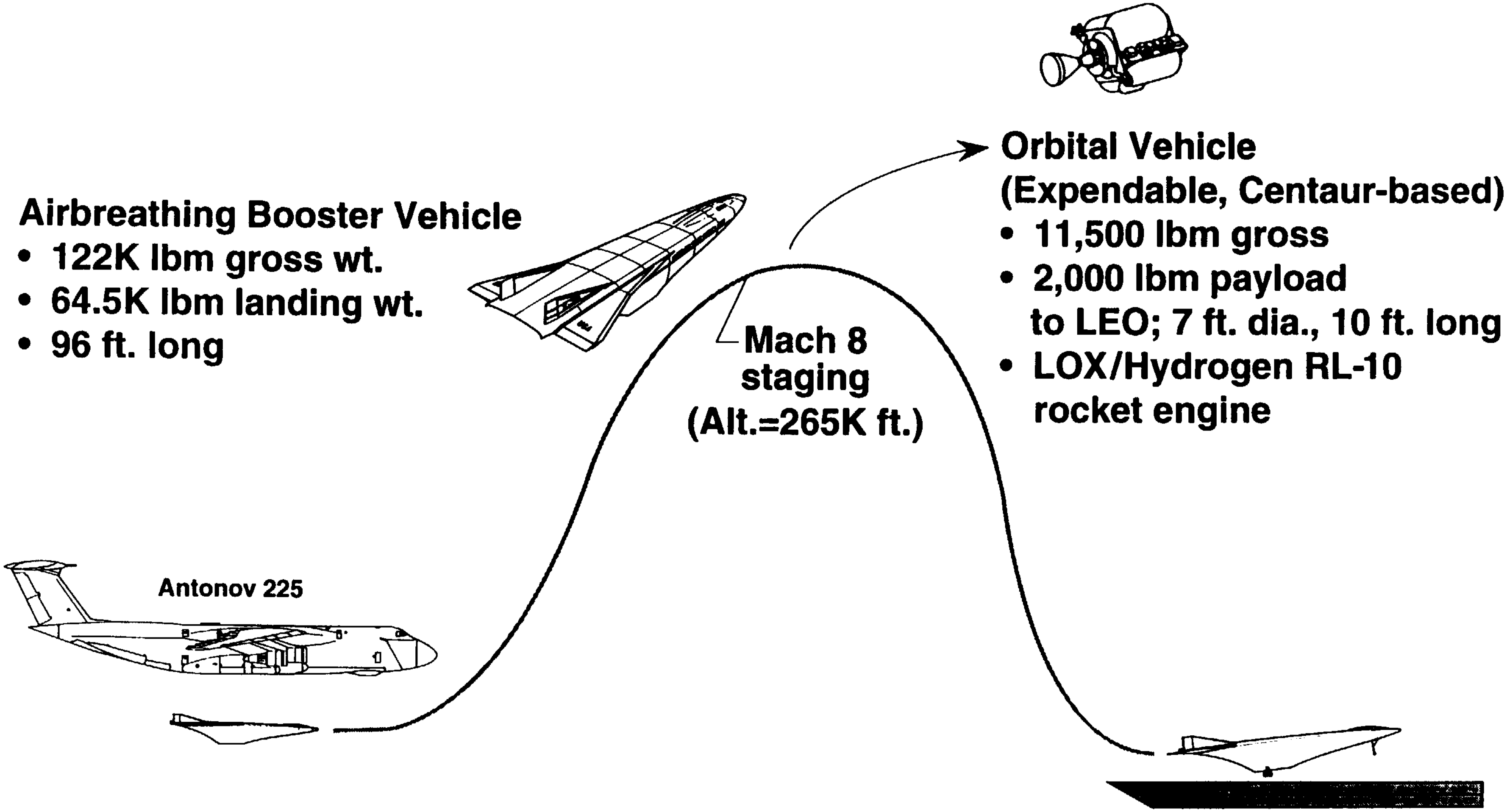
(Horizontal Takeoff/Horizontal Landing; Payload or Upper Stage Mounted Internally)
(Low Earth, Easterly Orbit)



Note: Vehicle weights include 7.5% dry weight growth margin

AIRBREATHING REUSABLE SMALL LAUNCH SYSTEM

(ARSLS For X-34 Type Missions)



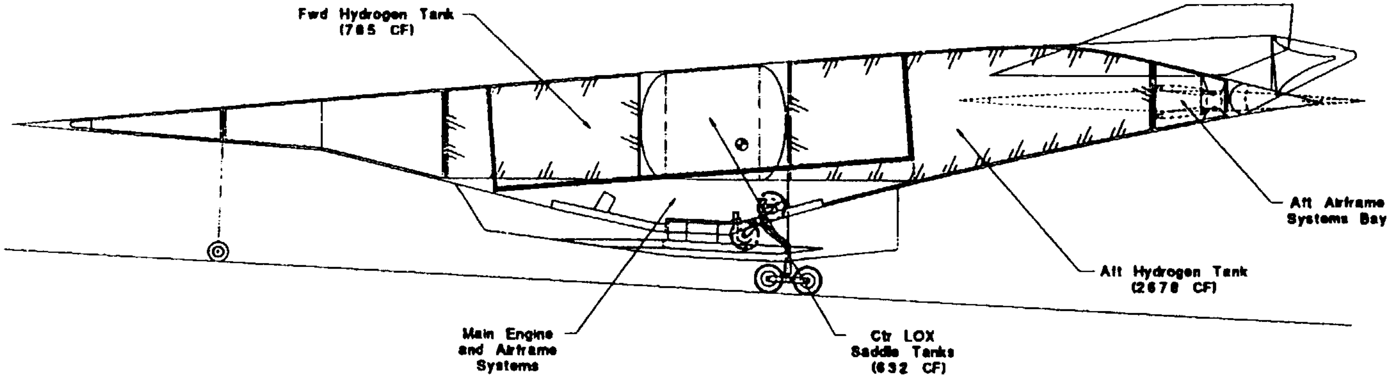
Airbreathing Booster Vehicle
- 122K lbm gross wt.
- 64.5K lbm landing wt.
- 96 ft. long

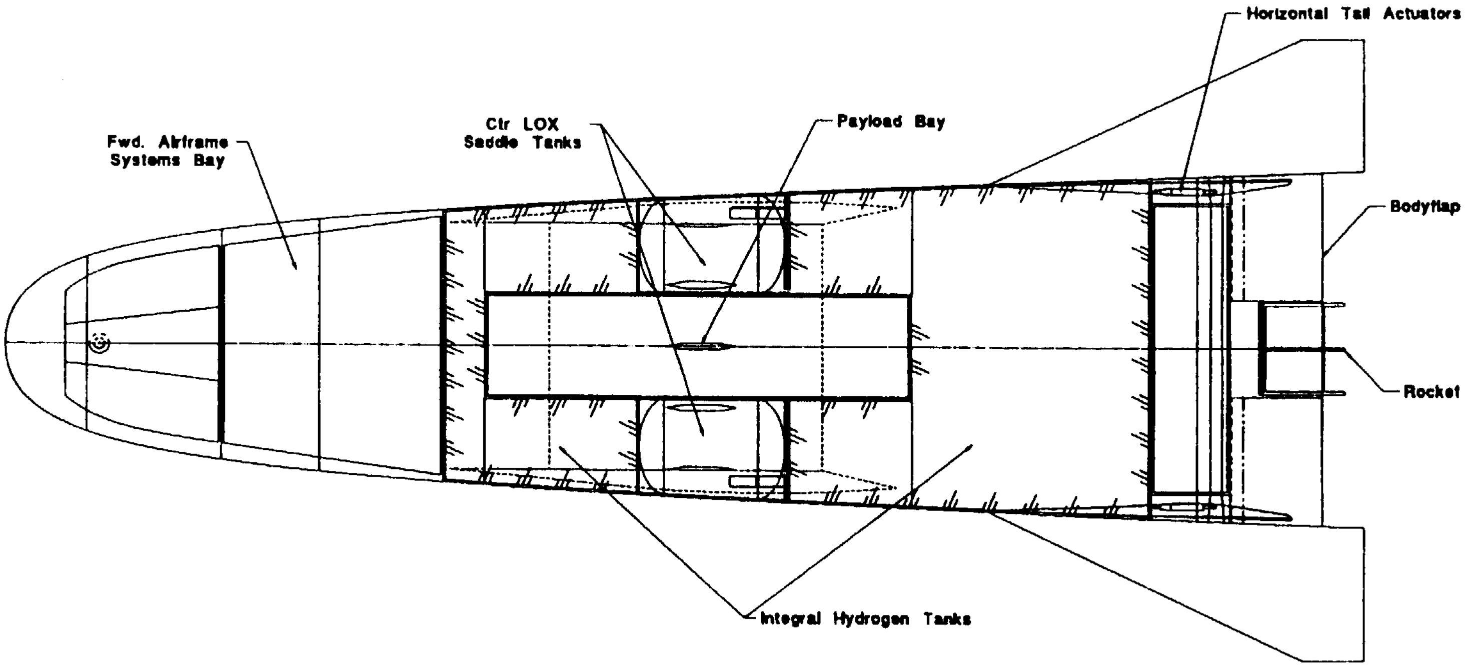
Mach 8
staging
(Alt.=265K ft.)

Orbital Vehicle
(Expendable, Centaur-based)
- 11,500 lbm gross
- 2,000 lbm payload to LEO; 7 ft. dia., 10 ft. long
- LOX/Hydrogen RL-10 rocket engine

The top view and side view layouts of the airbreathing booster for the ARSLS is presented. The configuration is a low fineness ratio lifting body with an underslung, Mach 7 shock-on-lip airbreathing engine flowpath. The airbreathing engine is a LOX ejector ramjet to Mach 3, dual-mode ramjet to Mach 7 and scramjet to Mach 8 staging. External burning provides base drag reduction through the transonic pinch and the trailing edge mounted rocket (augmented expander cycle with linear aero-spike nozzle) is used for pull-up approaching staging. The fuel is liquid hydrogen. The structural architecture is that of a cold integral fuel tank (GrEp) with adhesively-bonded TPS.

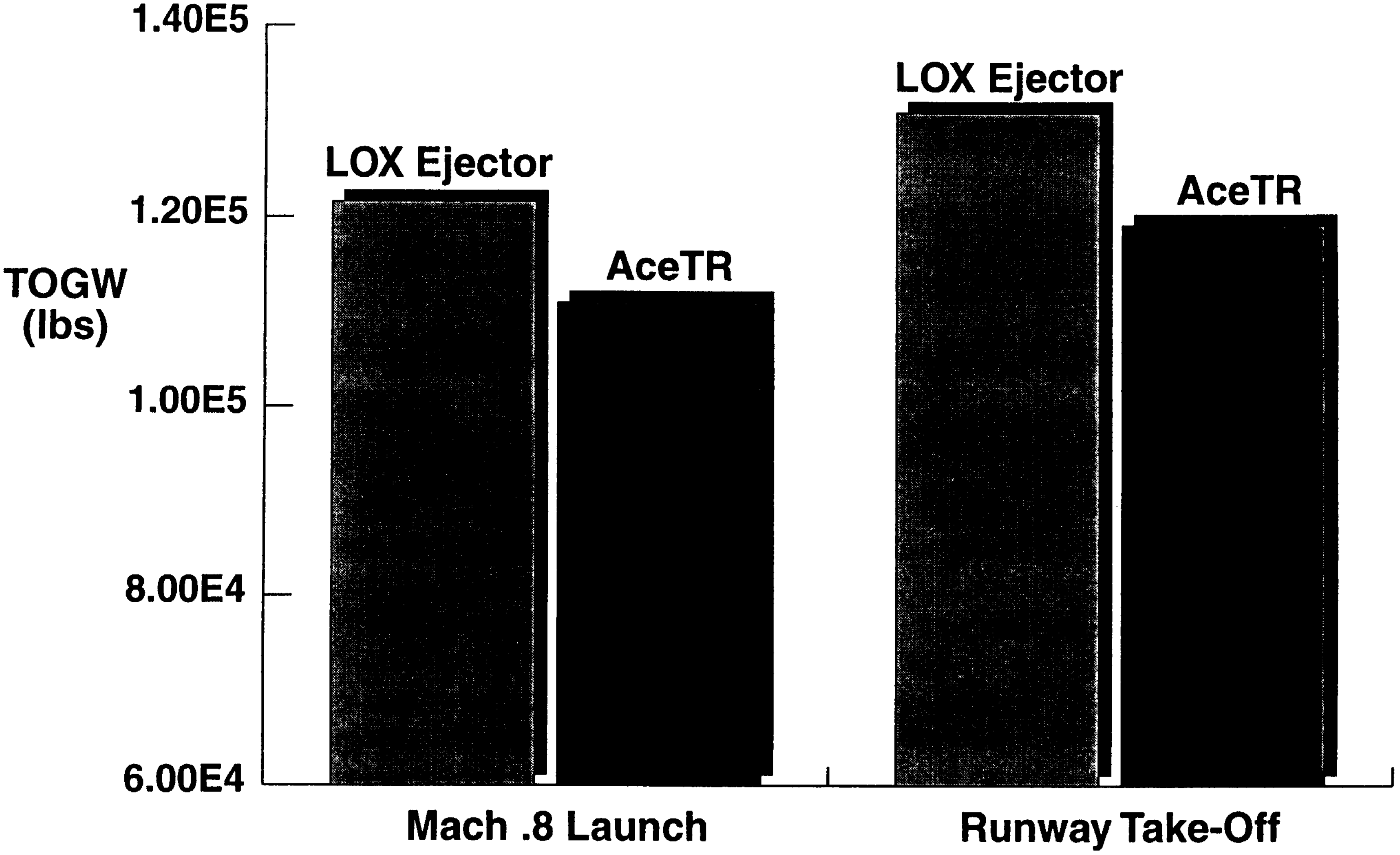
ARSLS, AIRBREATHING BOOSTER VEHICLE
(Mach 8 Staging)
Vehicle Layout





Two design trades were made on the Airbreathing Reusable Small Launch System (ARSLS). The LOX ejector ramjet mode was replaced with an integration of an Air Core Enhanced Turboramjet (AceTR) in an “over” position with the dual mode scramjet in the “under” position. Runway takeoff was also examined as opposed to the Mach 0.8 launch from an Antonov 225. The results are shown in the accompanying figure. Using an AceTR as the low speed system from Mach 0 to 3 rather than the LOX ejector reduced the gross weight of the airbreathing launch vehicle from 122K lbs. to 109K lbs. when launching from a Mach 0.8 platform. Designing the airbreathing launch vehicle to takeoff horizontally from a runway rather than being launched from an Antonov 225 at Mach 0.8 increased the gross weight by only about 7% for the LOX ejector version and 8% for the AceTR version.

ARSLS DESIGN TRADES



Note: AceTR is Air Core Enhanced Turboramjet

The Airbreather/Rocket (A/R) SSTO has many favorable characteristics. It can takeoff horizontally and climb with any one of its engines (two airbreathing systems, two rocket systems) out. It can abort from Mach 12 with one engine out and return to home base with a 20% propellant load (vehicle is designed to land with 50% of propellant load of which 50% is LOX). The A/R SSTO has a large launch window since it requires a low delta-V to chase the orbit's ascending node due to its high ascent cross range...attributed to high lift and specific impulse. This vehicle also has a significant self-ferry capability both subsonically and supersonically. Having high efficiency at high speeds provides very good hypersonic cruise capability, giving the A/R SSTO vehicle the synergistic capability of rapid long range endoatmospheric flight, applicable to future high performance and transport aircraft.

The characteristics of the A/R SSTO discussed above offer compelling reasons for the United States to pursue hydrogen-fueled hypersonic airbreathing technology. These reasons are categorized in the accompanying figure.

COMPELLING REASONS FOR AIRBREATHING SSTO AND 2STO (LH_2/SH_2) VEHICLES

Performance
- Large potential in terms of payload weight, range/orbit, and delivery times
- Endoatmospheric operations/hypersonic cruise and space access with same vehicle
- Subsonic and/or supersonic self ferry capability

Mission Flexibility
- Large launch window potential
- Launch offset capability
- Orbital plane change through endoatmosphere lifting/powered maneuvers
- Large cross range capability

Risk Reduction
- Gradual step and check engine start-up and shutdown
- Horizontal takeoff/abort capability
- Endoatmospheric abort during ascent with powered flyback

Environmental
- Relatively low noise levels
- Water vapor exhaust

Operations
- Conventional aircraft operations and logistics (horizontal takeoff/horizontal landing)
- Quick turn-around times

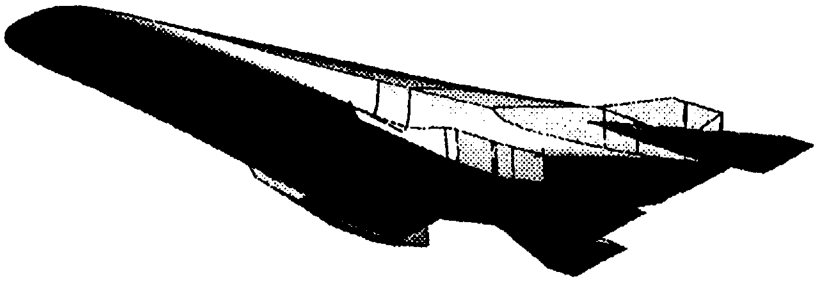
Switching from Space Access to Endoatmospherics, the configuration matrix examined is shown in the accompanying figure...lifting bodies and waveriders. (The lifting body class is the same as examined in the space access matrix.)

For endoatmospheric vehicles (principally airplanes), range for a given payload at a given cruise Mach number is a good figure of merit. How is this figure of merit impacted for hydrocarbon fueled airplanes and liquid hydrogen fueled airplanes? The hydrocarbon fuel cruise Mach limit is about 8 because preliminary calculations indicate that Mach 8 is the cruise speed extent to which a dual-mode ramjet/scramjet can be cooled with endothermic fuels (depends on contraction ratio). On the other hand, liquid hydrogen has much more cooling capacity and provides considerably more range than hydrocarbons for the same Mach. The range for hydrogen fueled vehicles maximizes at about Mach 10, beyond the cooling limits of the hydrocarbons.

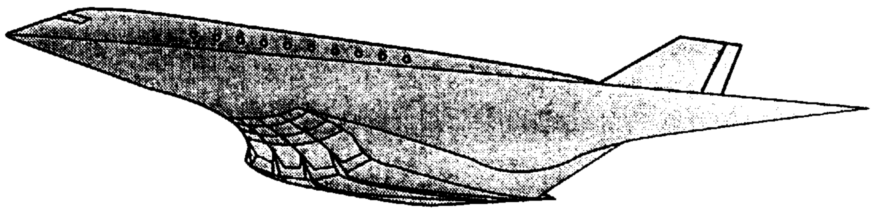
The takeoff gross weight (TOGW) of the hydrocarbon fueled airplanes are much greater for the same cruise Mach number than that for hydrogen fueled airplanes. Although, the dry weight of hydrocarbon vs. hydrogen airplanes for the same cruise Mach number and for the same payload is a much tougher call, it still tends to break favorably for the hydrogen fueled airplanes.

ENDOATMOSPHERIC CONFIGURATION MATRIX EXAMINED

- Lifting-body, Space Access class



- Waverider, airplane class



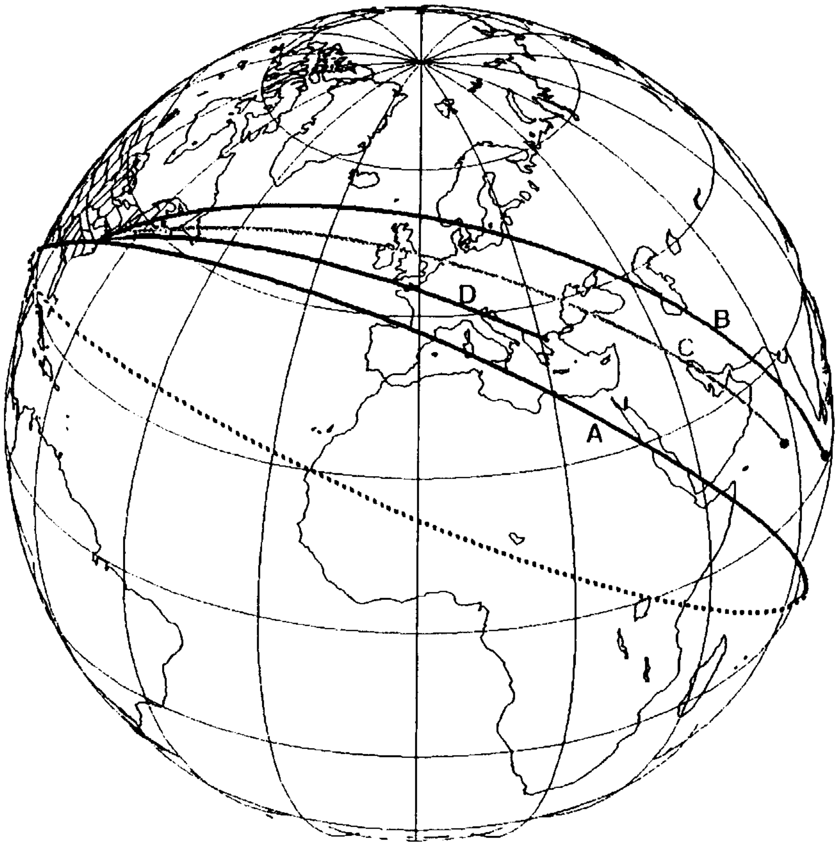
Performance for endoatmospheric operations are given in the accompanying figure for three vehicles with space access capability...SSTO, 1st stage of Mach 10 2STO launch system and 1st stage of Mach 15 2STO launch system...and a Mach 5 waverider, hydrocarbon fueled aircraft. The figure indicates that hydrogen and/or slush hydrogen fueled, hypersonic airbreathing launch systems with enclosed payload bays have considerable endoatmospheric capability. The 1st stage of a 2STO that stages at Mach 10 when performing as a cruise airplane can cover a range of 10K nm (ground-to-ground) with a payload of 10K lbs. for under 300K lbs. of gross weight. Essentially the same vehicle could deliver more than 8K lbs. to orbit with a hydrogen fueled 2nd stage...it would have to perform a pull-up at Mach 10.

The hydrocarbon fueled waverider comes up short comparatively; its ground-to-ground range with 10K payload is less than 6,000 nm for a 550K lb. gross weight.

The global coverage potential of hypersonic airplanes with 10K nm range over-point from Langley and Vandenberg air bases presents an interesting perspective. Less than 10% of the earths surface is not accessible from these two CONUS bases and this inaccessible area is essentially over the Indian Ocean...where there is nothing to access. With Mach 10 cruise capability, 10K nm can be covered in 90 minutes...long range, quick response.

CONUS-BASED GLOBAL DELIVERY POTENTIAL FOR AIRBREATHERS

(Endoatmospheric Operations, Ground-To-Ground)



A. SSTO Vehicles
(once around or less, suborbital)
- Access-to-Space, GW=917K, PL=52K
- Medium Payload Vehicle, GW=371K, PL=5K

B. Mach 10 Cruise Airplane (1st stage of 2STO)
GW=275K, PL=10K

C. Mach 15 Cruise Airplane (1st stage of 2STO)
GW=188K, PL=5K

D. Mach 5 Cruise Airplane (HC)
GW=550K, PL=10K

From the previous discussions herein, consider the overall synergistic perspective in the adjoining figure. For global reach from a CONUS base, a Mach 10 cruise vehicle has many favorable characteristics...quick response, hydrogen fuel to cool and provide long range in a reasonably low takeoff gross weight vehicle, and an AceTR low-speed propulsion system with high installed thrust-to-weight that operates on hydrocarbon fuel (endothermic). The dual fuel feature of this vehicle would provide a logistically manageable, synergistic system capable of in-air refueling for a return leg below Mach 4. An integrated rocket system at the trailing edge of the vehicle would allow the aircraft to perform a pull-up for staging of an upper stage from an enclosed payload bay to provide orbital access...use of advanced technologies for multiple purposes makes such a system easier to justify (cost).

OVERALL PERSPECTIVE—
SPACE ACCESS AND ENDOATMOSPHERIC

For global access/space access in a logistically manageable, synergistic system with in-air refueling capability, consider:

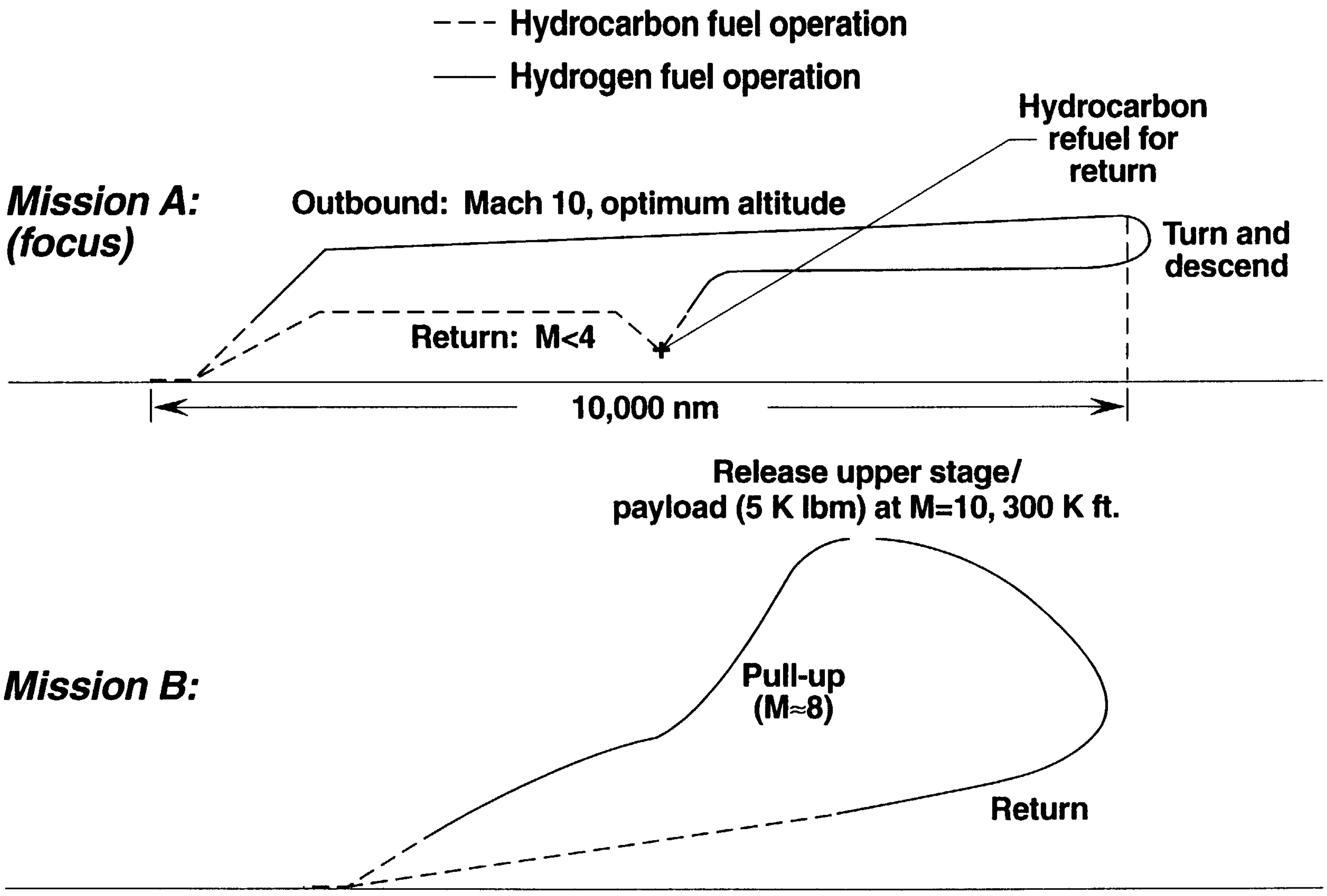
- **Mach 10 cruise/stage***
- **AceTR low-speed system**
- **Dual fuel...endothermic/liquid hydrogen**

* *This staging capability would require a rocket in the tail end of the aircraft to perform a pull-up maneuver to reach low dynamic pressures for staging.*

Quick response, global coverage from CONUS bases is a vision that emanates from the top echelons of the U.S. government/Air Force. In this regard, officials at NASA Langley's Hypersonic Vehicles Office, have recently awarded a contract to McDonnell Douglas Aerospace (MDA) to explore designs for vehicles capable of flying at ten times the speed of sound (Mach 10).

The contract, entitled "Dual-Fuel Airbreathing Hypersonic Vehicle Design Study," has been planned for 30 months and has a total value of almost $3 million. The first phase of the study, lasting six months, will concentrate on developing conceptual designs for a CONUS-based, Mach 10 reconnaissance aircraft (Mission A in the figure). A lesser task will be to examine the possibility of using such a vehicle in a space access role (Mission B in the figure). The work will be performed in St. Louis by MDA's Advanced Systems Technology - Phantom Works. Pratt & Whitney of West Palm Beach, Florida, will provide propulsion/propulsion integration support, and the University of Maryland in College Park, Maryland, and Astrox of Rockville, Maryland, will provide assistance in assessing high lift-to-drag (L/D) vehicle concepts.

MISSION SCENARIOS



- - - Hydrocarbon fuel operation

—— Hydrogen fuel operation

Mission A:
(focus)

Outbound: Mach 10, optimum altitude

Hydrocarbon refuel for return

Turn and descend

Return: M<4

10,000 nm

Mission B:

Release upper stage/ payload (5 K lbm) at M=10, 300 K ft.

Pull-up ($M \approx 8$)

Return

Note: Vehicles for Missions A and B will be designed in Phase I (using similar architectures) and merged into one design in Phase II if feasible

Note: The number of in-air refuelings for Mission A are to be optimized

The baseline technologies on which a lot of the space access and endoatmospheric vehicle's performance potential depends evolved during the National Aero-Space Plane (NASP) Program, and the community is indebted to that program for their maturation level. But, there is tremendous performance gains to be made by advancing beyond the baseline technologies. These enhancing, cutting-edge technologies for airbreathing vehicles are categorized in the accompanying figure.

ENHANCING, CUTTING-EDGE TECHNOLOGIES FOR AIRBREATHING VEHICLES

(Focus on SSTO...Beyond Baseline)

Airbreathing Propulsion

- Low Speed
  - Ejector Ramjets (M=0 to 3)
    ...Super strut ejector ramjet (Rocket-Based Combined Cycle, RBCC)
  - Air Core Enhanced Turboramjet (AceTR...M=0 to 4, 5)
  - Pulse Detonation Wave Engine (PDE...M=0 to 4)
- Mid Speed—dual mode scramjet...optimized baseline (M=3, 5 to 8)
- High Speed
  - Super strut scramjet (M=8 to 15) and super-strut LOX augmented scramjet (M=12 to 23)
  - PM/SIC (M=8 to 23) and LOX augmented PM/SIC (M=12 to 23)
    ...see John Weidner's paper

Rocket Propulsion

- Staged combustion cycle incorporating LOX-driven LOX pump ("Hot LOX") with linear, aero-spike nozzle
- Tripropellant-staged combustion cycle with linear, aero-spike nozzle
- Pulse Detonation Wave Rocket (PDR)

ENHANCING, CUTTING-EDGE TECHNOLOGIES FOR AIRBREATHING VEHICLES *(Continued)*

Structures

- Fully engineered/optimized composite architectures
  - Filament, laminate
  - Structural components...treat TPS as part of primary structure, etc.

Thermal Management/Power Generation

- Compact catalytic heat exchangers/reactors (CHER)
- Cooling with LOX as well as LH_2 ("Hot LOX")
- "Hot LOX" for power generation

Controls (Airframe and Engine)

- Neural networks

Fuel Systems

- Dual fuel systems

Configurations

- Upside-down lifting-body (engine on top)
- High fineness ratio winged-body

...Incorporate wave-rider characteristics in both

Take-Off Assist

- Mag-Lev rail launch
- In-air refueling

At present, ejector ramjet with constant area sections (Ref. 4--see figure) are operated with the ejector rocket running stoichimetric (LH_2/LOX) and the ramjet fuel is injected downstream of the constant-area-section choke-point at the beginning of the expanding subsonic combustor. More thrust can be obtained by operating the ejector rocket fuel rich (Ref 5). This reduces the static temperature of the stream, increasing the density, and thus allows more mass to be passed through the choke point.

The only problem is that in a constant area mixer, the fuel will mix and burn and thus choke in the mixer. The solution is to provide some small expansion in the mixing region so that as the flow mixes and burns, it has an area ratio to accommodate the heat release.

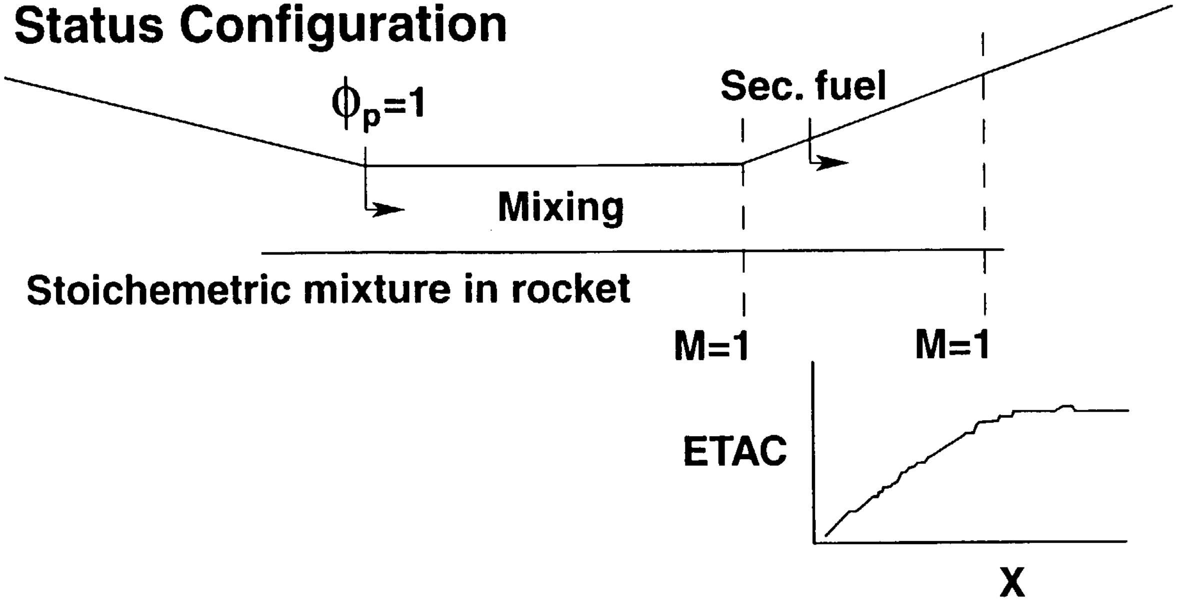
Also, super struts that can accommodate both the ejector action at low speed and fuel injection for the scramjet at high speeds would be a tremendous asset in a dual-mode propulsion system.

Ref. 4 Escher, W. J. D. and Florner, B. J.: Study of Composite Propulsion Systems for Advanced Launch Vehicle Applications. NAS7-377, 1967.

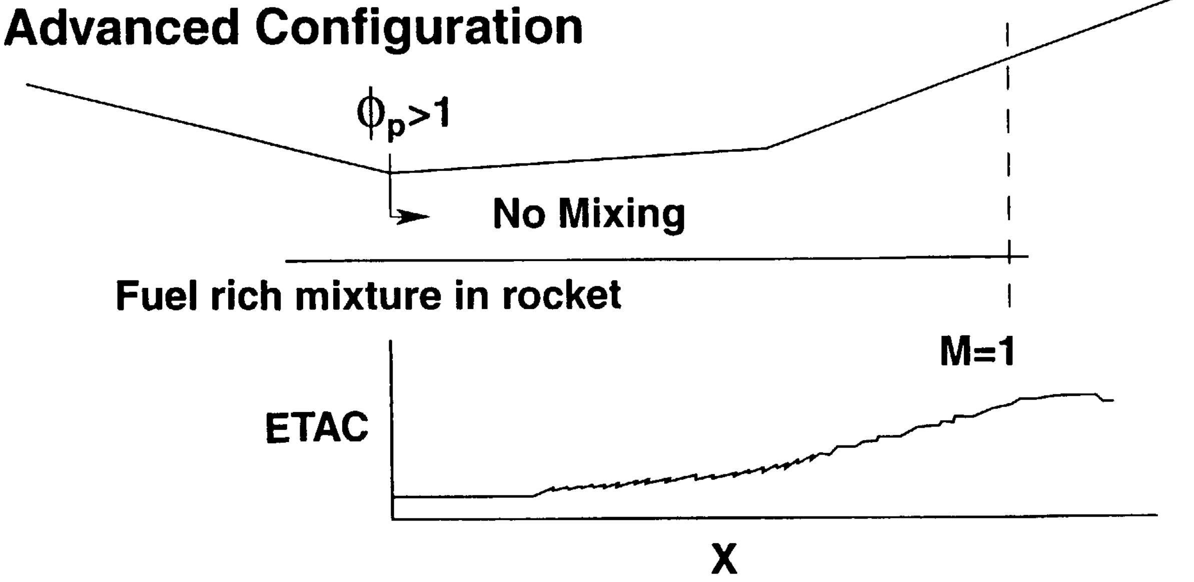
Ref. 5 Bulman, M. and Siebenhaur, A.: A Strutjet Engine: Exploding the Myths Surrounding High Speed Airbreathing Propulsion. AIAA 95-2475, July 1995.

EJECTOR RAMJET PERFORMANCE ENHANCEMENT

- Status Configuration



- Advanced Configuration



The Air Core Enhanced Turboramjet is a hybrid cross between an air turboramjet and a turbojet. It is a regeneratively cooled system that utilizes the momentum of the fuel injection for thrust augmentation. Its advantage is a large projected thrust-to-weight ratio as given in the accompanying figure. This large thrust-to-weight ratio comes at the expense of only a slight decrease in specific impulse from Mach 0 to 2 relative to that projected for twin spool turbojet technology.

TURBINE TECHNOLOGY EVOLUTION

	IHPTET Phase I	IHPTET Phase II	IHPTET Phase III
Technology Avail. Date	1994	1997	2003*
Initial Operational Capability	2001	2005	2010+*
AceTR Cycle T/W Goals	20:1	24:1	30:1*
Characteristics	– Superalloy compressor blades	– TiAl compressor blades – Fuel-cooled, superalloy turbine blades – Hollow turbine disk	– Composite “blisk” (carbon silicon carbide)

**Materials availability concerns*

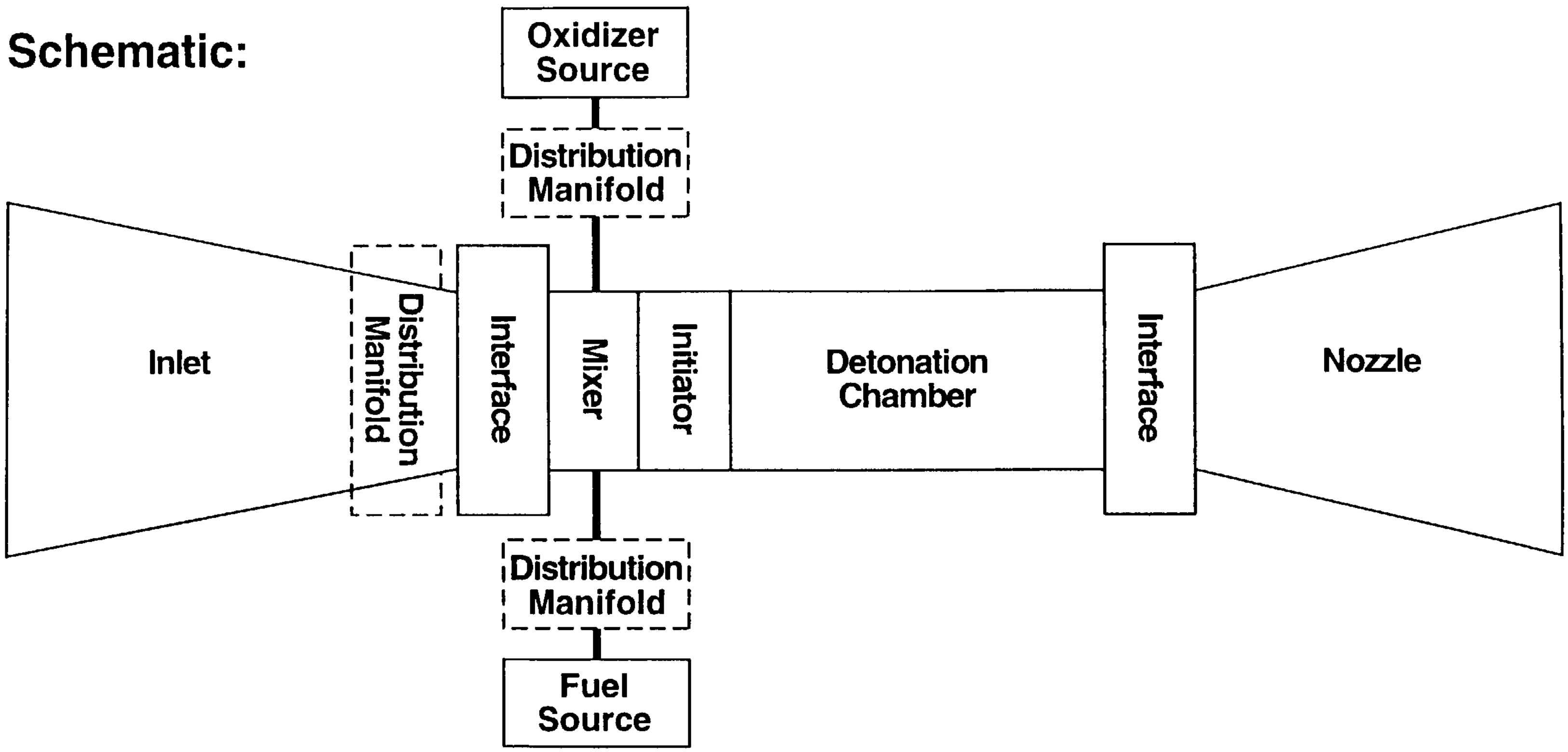
Airbreathing propulsion systems which currently operate in the low subsonic through high supersonic regimes are expensive and complex. An innovative propulsion system, based on a Pulse Detonation Engine (PDE), is being developed to overcome these limitations.

PDEs use detonation waves (shock wave triggered combustion) propagating through a premixed fuel-air mixture to produce large chamber pressures and thereby thrust. Detonation waves typically propagate at speeds of the order of 2000 meters per second in hydrogen-air mixtures. PDEs offer the potential for very favorable performance because the rapid detonation process allows very high cycle rates and combustion chamber pressures to be achieved. PDEs are predicted to be very efficient and offer good thrust characteristics. PDEs also have the potential to operate at very high energy densities, allowing the use of small and compact combustors.

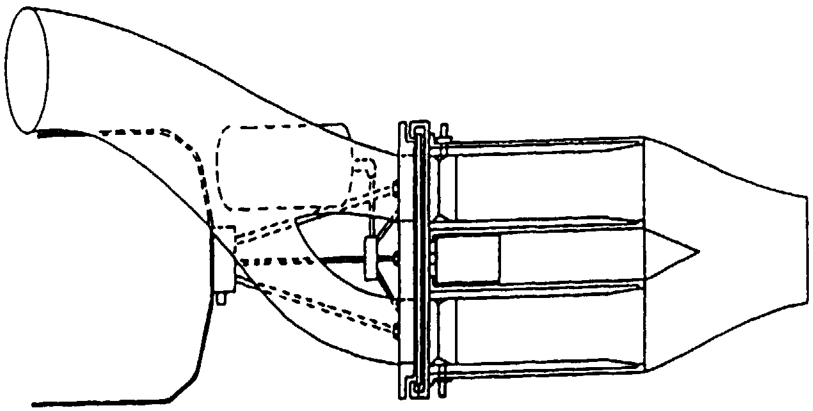
The pulse detonation wave concept can be evolved into a rocket engine (PDR). This PDR offers potentially higher performance than steady-combustion chemical rocket engines (roughly 7 to 10% more specific impulse) and is potentially lighter weight than conventional rocket engines...order of magnitude reduction in pump power and major reduction in turbopumps and ducting weight. The key to the realization of these engines is tube cycle frequency.

PULSE DETONATION ENGINE

Schematic:



Rotary Valve Multiple Pulse Detonation Engine:



Neural networks are biologically motivated, highly abstracted data driven computers. They are trained rather than programmed...rather than representing a process as an algorithm and programming the computer to implement the algorithm, a process is represented by observed (or experimentally generated) input/output data and the neural network is trained to approximate the observed I/O data. These networks are designed for massively parallel implementation and are adaptive, fault-tolerant, robust, and reprogrammable. These characteristics should be suited for the control system of hypersonic vehicles which have mixed mode control surfaces and flexible structure over wide range of Mach numbers.

A neural network control system (inner and outer loop) for a waverider configuration aircraft is being developed under an SBIR program. The system will be tested in a flight simulator and on two remotely piloted waverider vehicles...an 8.3’ long model and a 24’ long model...at subsonic speeds (see figure).

LOFLYTE
SUBSONIC NEURAL NET DEMONSTRATOR

<u>DATA:</u>

Airframe: Modified MQM-107 Target Drone

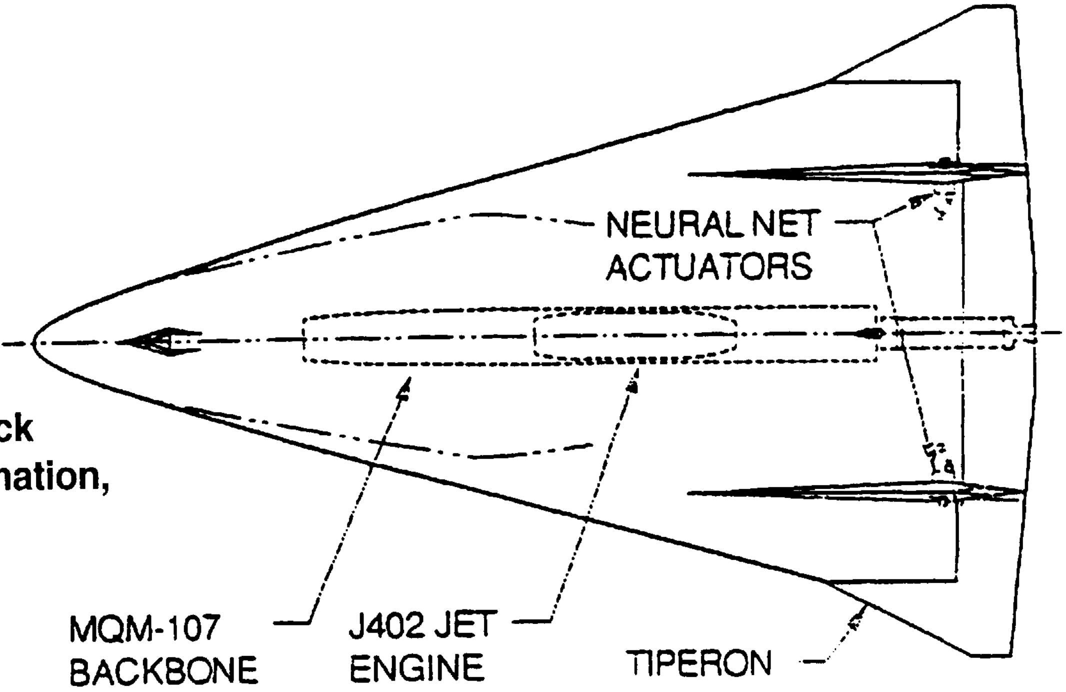
Shape: NASA Mach 5 Waverider

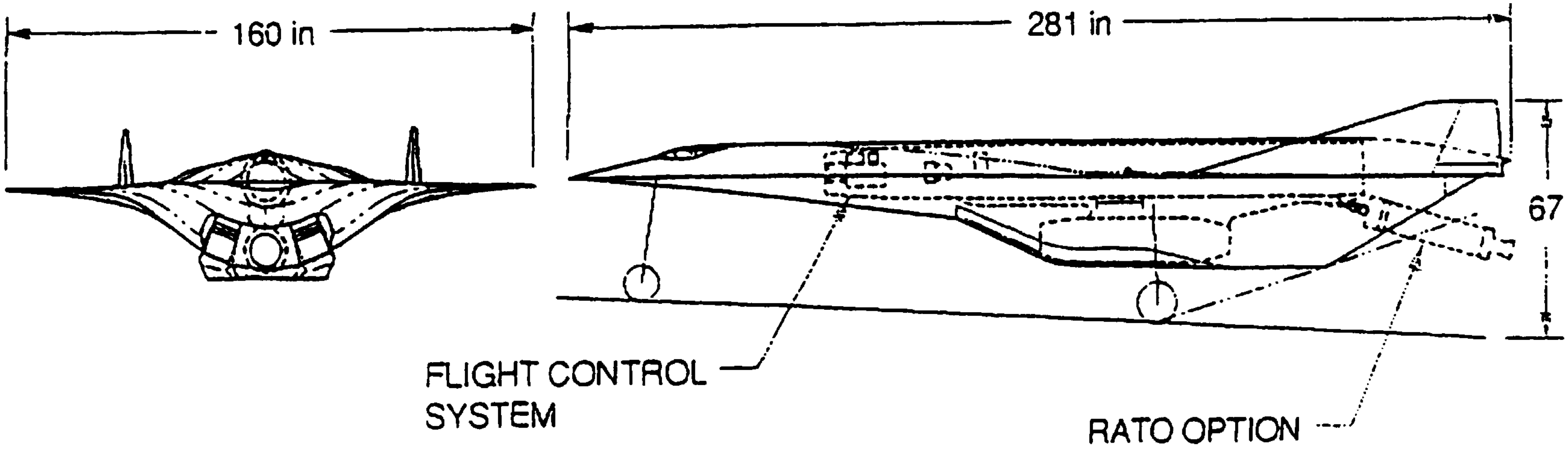
Controls: Neural Net Actuators

Engine: Teledyne J402 Jet

Structure: Fiberglass & Foam Over Alum. Strongback

Team Members: Accurate Automation, Mississippi State University, and Lockheed Fort Worth





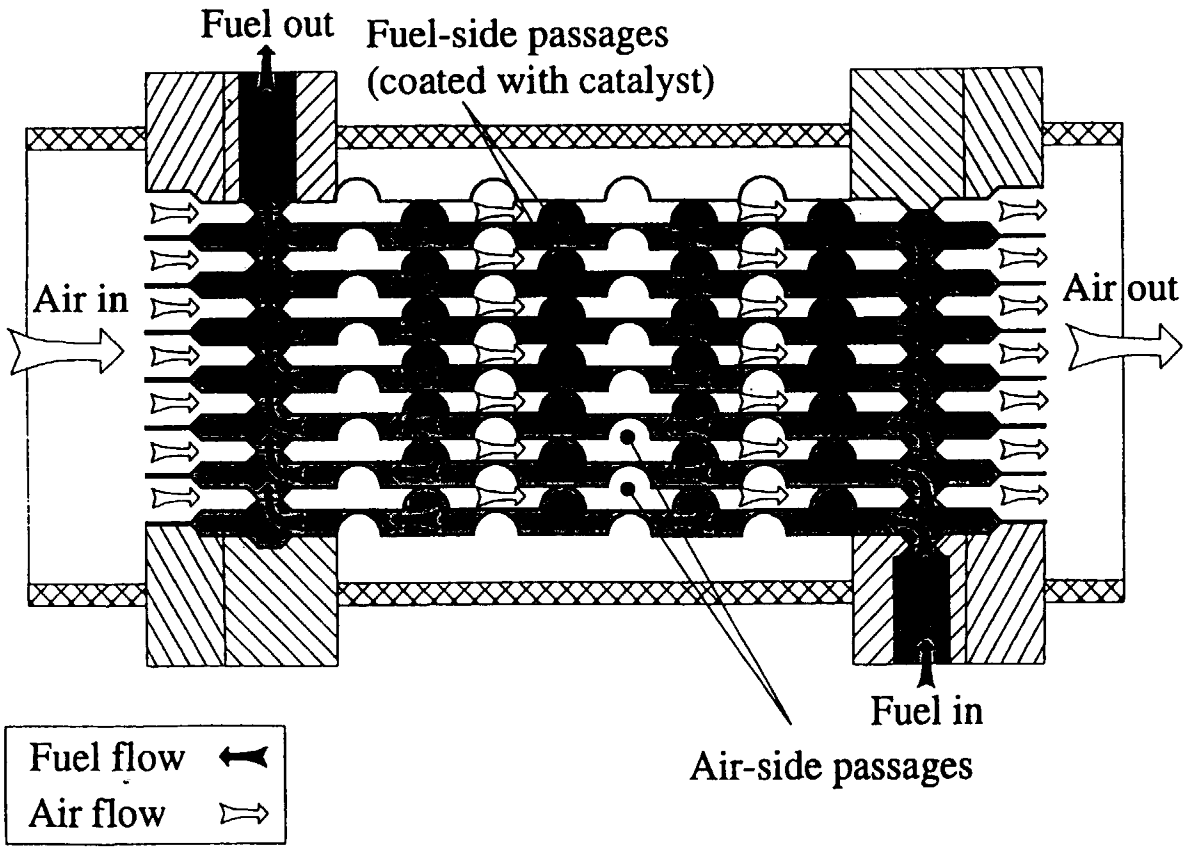
Heat exchangers could have a wide variety of uses on hypersonic airbreathing vehicles...from engine heat exchangers that operate on direct and/or indirect (secondary cooling loop that requires compact catalytic heat exchangers/reactors) cooling principles to low speed oxidizer systems. Also, the propellant on airbreathing/rocket single-stage-to-orbit (A/R SSTO) vehicles is approximately 50% hydrogen, 50% LOX, and thus far, only the cooling capacity of the hydrogen is being used. In fact, above Mach 12, the hydrogen flow rate is set by that required to cool the engine, not to fuel it, such that the equivalence ratio (Ø) is 1.5 at Mach 15 rather than the desired stoichimetric (Ø = 1) for near maximum efficiency. Since the Russians have been using "hot LOX" to drive their oxygen turbopumps on their staged combustion cycle rocket engines since the 1950's...thus material coating that allow the use of "hot LOX" exist...there is no reason that a heat exchanger should not be placed between the hydrogen and LOX to transfer some of the heat load to the LOX and keep the engine throttle at stoichimetric conditions for fueling the scramjet above Mach 12. The "hot LOX" could then be used for power generation (turbine expander) and LOX augmentation of the scramjet.

Heat exchanger technology ideally suited for the purposes mentioned in the above paragraph is shown on the accompanying figure; it is dimpled foil heat exchanger architecture. Relative to conventional tube-bank, manifold heat exchanger architecture, the dimpled foil designs have the potential to be an order of magnitude less weight for the same heat transfer load. The dimpled foil heat exchanger technology, which lends itself to all types of heat exchanger configurations, is being developed in LaRC's SBIR program.

DIMPLED FOIL HEAT EXCHANGER TECHNOLOGY FOR HYPERSONIC VEHICLES

Advantages

- Light weight
- Small volume
- Low pressure drop
- High thermal efficiency
- Potentially low cost



Applications

- Catalytic Heat Exchanger Reactors
- H2 to LOX Heat Exchanger
- Cool air supply for APU
- Cryogenic Heat Exchangers
- Electronics Thermal Management

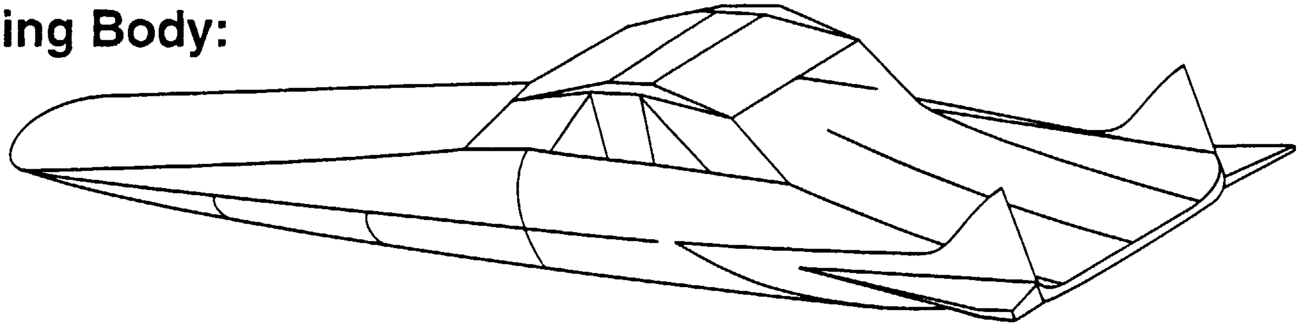
In enhancing the airbreathing/rocket SSTO and 2STO designs, the configuration is extremely important. The lifting body that serves as the baseline for this matrix would be a much better SSTO if it were designed upside down...inverted lifting body...as shown in the accompanying figure. It is simply a much better lifting shape inverted since its profile now looks more like a proper airfoil (positive rather than negative camber). Inverted, it would have much greater lift at takeoff (lower takeoff speeds) and through transonics when it would fly at much lower angles-of-attack and therefore lower drag. Also, lower angle-of-attack would mean less base drag and reduced need for external burning through the transonic pinch. Somewhere above Mach 5, the vehicle could roll 180° or continue to orbit in the inverted attitude.

As engine weights increase with design/technology maturation in the NASP program, it became apparent that it may be an advantage to switch configurations from a lifting body to a high fineness ratio wing body where engine weight could be traded for wing weight, since the high fineness ratio configuration would have lower drag per unit volume and thus require less engine size. This configuration approach is currently being pursued in the SAO/HVO at LaRC.

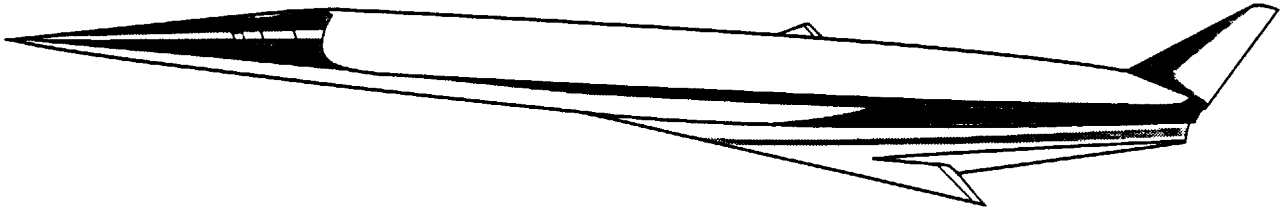
The ultimate SSTO configuration in terms of propulsion flowpath for a point design (nominally Mach 15) is the inward turning inlet (funnel) configuration as shown in the accompanying figure. Ideally, the funnel inlet configuration offers more air capture and more efficient compression to the inlet throat for less wetted area with an accompanying, more efficient expansion through the radial nozzle than does its two-dimensional, underslung engine/airframe integrated counterpart, thus resulting in potentially higher net thrust and specific impulse. This propulsion integration attribute is a substantial positive factor in favor of the funnel inlet configuration, but there are negative factors to be considered as well, such as: “on-design/off-design” spillage, volumetric efficiency, etc. The Systems Analysis Office (SAO) has been pursuing the evolution of the funnel class of configurations for several years through a contract with the Astrox Corporation of Rockville Maryland. Astrox has an inverse code that derives a continuous spectrum of flowfields/shapes ranging from maximum outward flows, through two-dimensional flows, to maximum inward turning flows.

EXTENDED/ADVANCED CONFIGURATION MATRIX

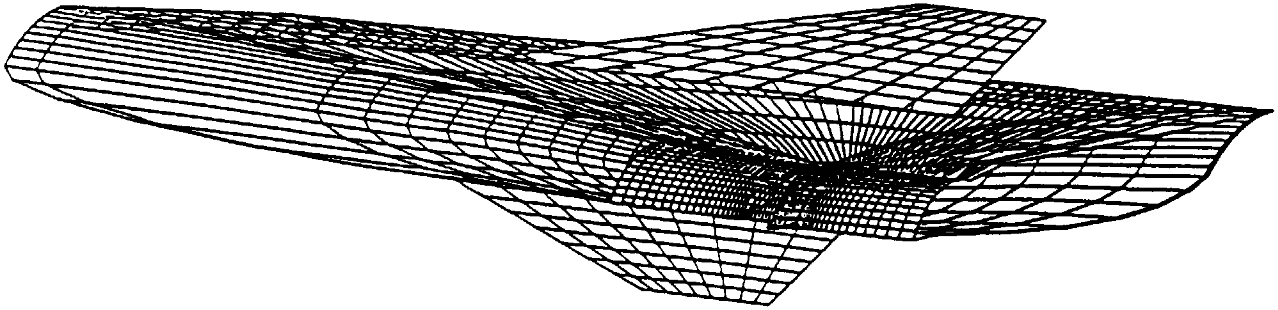
Inverted Lifting Body:



High Fineness Ratio Wing Body:

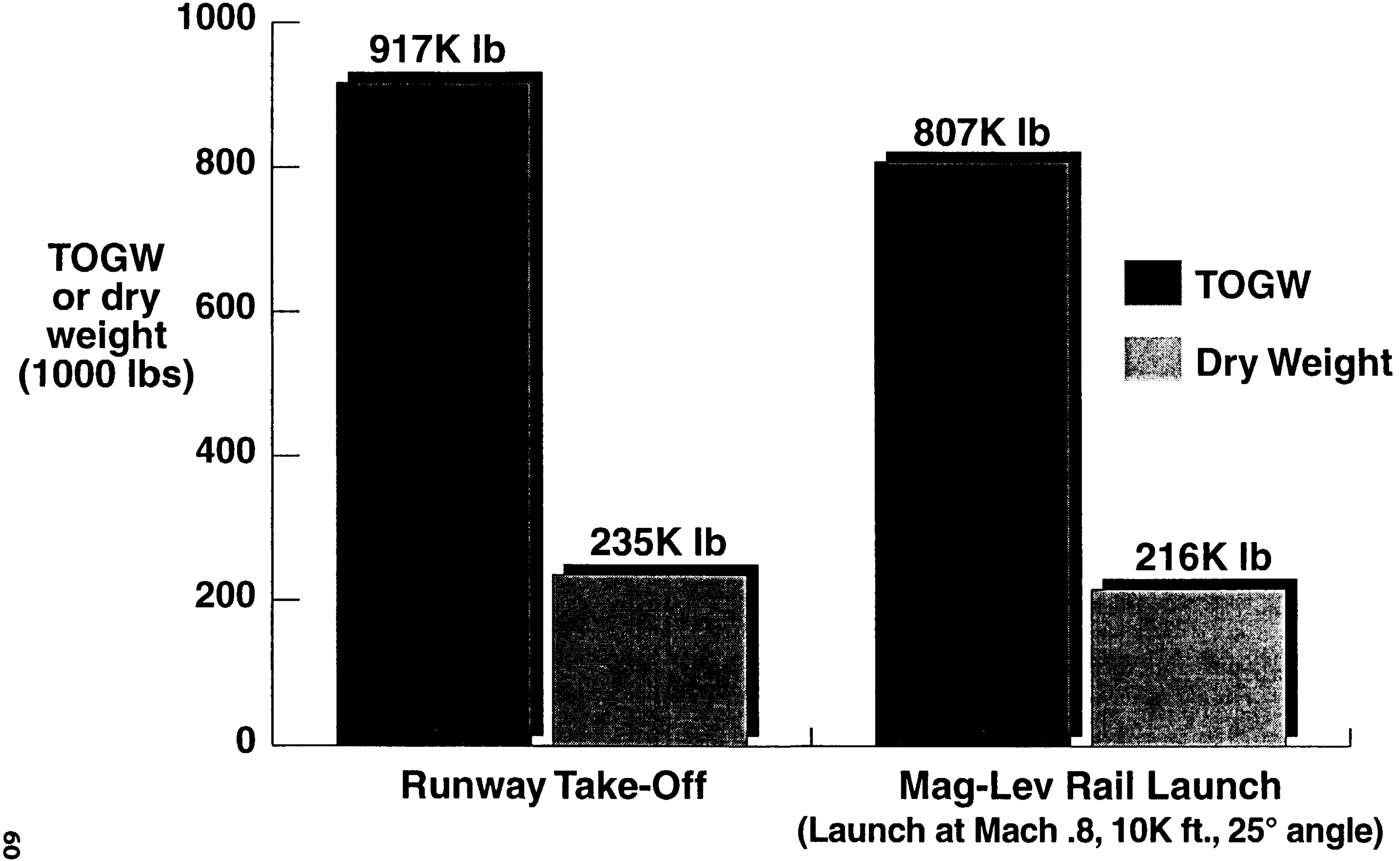


Inward Turning Inlet (Funnel) Configuration:



MagLifter technology is being examined for rail launch and/or takeoff assist technology under sponsorship of Code X in NASA Headquarters. Assuming that a MagLifter rail device could provide a launch velocity of mach 0.8 at a 25° inclination angle at 10K ft. altitude, the baseline A/R SSTO was resized for these launch conditions compared to a runway takeoff for the Access to Space Mission (an orbit at 51.6° inclination at 220 nm altitude with a payload of 25K lbs.). The results are shown in the accompanying figure. Relative to a runway takeoff, the Mag-Lev launched vehicle was 12% less in takeoff gross weight and 8% less in dry weight.

IMPACT OF MAG-LEV RAIL LAUNCH ON ACCESS-TO-SPACE A/R SSTO VEHICLE



CONCLUDING REMARKS

With the maturation of the advanced technologies mentioned herein such as AceTRs, PDEs, super-strut LOX augmented scramjets, dimpled foil heat exchangers, cold integral Gr/Ep fuel tanks with adhesive bonded TPS, neuro network controls, etc. and vehicle design/optimization methods, hypersonic airbreathing vehicles (endoatmospheric and space access) have enormous optimization potential.

The attractive characteristics of hypersonic airbreathing vehicles including payload delivery capability, either for space access or endoatmospheric cruise over long ranges, and operational flexibility, offer compelling reasons for the United States to pursue hypersonic airbreathing technology.

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