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Highly Reusable Space Transportation: Approaches for Reducing ETO Launch Costs to $100-$200 per Pound of Payload

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The Commercial Space Transportation Study (CSTS) suggests that considerable market expansion in earth-to-orbit transportation would take place if current launch prices could be reduced to around $400 per pound of payload. If these low prices can be achieved, annual payload delivered to Low Earth Orbit (LEO) is predicted to reach 6.7 million pounds. The primary market growth will occur in communications, government missions, and civil transportation[1]. By establishing a cost target of $100 - $200 per pound of payload for a new launch system, the HRST program has clearly set its sights on removing the current restriction on market growth imposed by today's high launch costs.

To capture a significant portion of the expanded market, a new launch system in the 20,000 pounds of payload class would need to fly over 200 flights to LEO per year. Under HRST program guidelines, the launch costs should not exceed $4 million per flight — an order of magnitude lower than the current target being used by NASA's reusable launch vehicle (RLV) program[2]. To meet this challenge, "design for life cycle cost" must replace "design for performance." Focus must shift to cost and operability, and each design decision made must fully consider life cycle cost impacts. Advanced technologies should be used where cost effective. System reliability and robustness will be critical to achieving the aircraft-like operations often associated with a low-cost, mature transportation system. But perhaps most importantly, the vehicle designer must expand the design space to include disciplines normally associated with the business world — marketing strategies, customer imposed design requirements, funding limitations, and innovative operating strategies.

In particular, achieving the goal of $100 - $200 per pound of payload will require significant coordinated efforts in 1) marketing strategy development, 2) business planning, 3) system operational strategy, 4) vehicle technical design, and 5) vehicle maintenance strategy.

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Many concepts for achieving HRST's aggressive cost goals will be proposed and evaluated during the course of the program. In fact, there is almost certainly more than one "right answer" — that is, more than one launch system concept capable of achieving the desired goals. While individual concept definition and evaluation remains to be performed, it is appropriate to establish a rough set of hypotheses and ideas to guide the selection of potential candidates for additional concept definition work. The following sections outline proposed cost savings strategies in each of the five disciplinary areas listed above.

Marketing Strategy Development

The CSTS study predicts an elastic ETO market that will expand by nearly a factor of ten over today's market if prices can be significantly reduced. However, a new system must be appropriately positioned to capture payloads in many or all of the individual traffic segments. A vehicle designed to deliver humans to orbit might look significantly different than one designed to dispose of nuclear waste or one designed for multiple mission use. Well defined mission requirements (e.g. target orbit, payload weight, payload volume, life support requirements) are necessary in each marketing segment, and the vehicle concept must be designed around these requirements.

Since the mission requirements are likely to be dissimilar in many marketing of the segments, it is likely that a new vehicle concept will actually be a small *family of vehicles*, rather than a single vehicle. Each member of the family will be based on common technologies and similar design guidelines, but will be optimized to capture a particular market segment.

Although the expanded ETO market is attractive, a *vehicle system designed to capture even larger markets* could have increased flight rates, easier amortization of development and infrastructure costs, and therefore improved rate of return to private investors. Potential supplementary markets include small payload ETO missions, direct GTO missions, large military ETO missions, military transatmospheric missions (e.g. reconnaissance and global force projection), suborbital flight test experiments, and commercial high-speed endoatmospheric flight missions (e.g. VIP and high priority package delivery). A HRST system should target as many of these additional markets as feasible.

Business Plan

While it is the tendency of engineers to concentrate on vehicle design and vehicle performance, it is the business plan for a new launch system that will ultimately determine the financial success of the system. The U.S. government can probably be expected to continue its practice of sharing the development cost of new space systems with the aerospace industry. The government can also be expected to pay for much of the technological development and provide anchor tenancy for new systems, but 50% or more of the development cost will likely come from private sources/investors. Therefore the rate of *return on investment becomes a paramount concern* for a new system.

Upfront development costs for manufacturers cannot be excessive (under $4 - $5 billion of private investment) and system operations must produce a positive return (a profit) within a relative short timeframe (perhaps 4 to 6 years). Infrastructure and ground facilities costs must be limited, and long development times from time of initial capitol investment must be avoided. Given the development risks, price/cost margins must be sufficient to produce returns to investors on the order of 30% - 40%.

In addition to the cost per pound of payload goal, business plan-derived financial requirements and restrictions must be properly accounted for in a successful concept design. In many cases, financial restrictions will directly impact technical decisions made on the vehicle concept design.

System Operational Strategies

With the exception of amortizing investment cost, ground and flight operations are the two largest contributors to per flight launch costs in a highly reusable launch system. The standing army of technicians required to maintain, refurbish, checkout, and ready the Space Shuttle for flight must be significantly reduced on a new launch system in order to meet HRST cost goals.

To obtain aircraft-like operations, a paradigm shift from the government as designer-developer-operator-customer to a scenario more like the airframer-air carrier relationship will be required. A single manufacturer/multiple operator system has *potential to exert significant downward pressure on launch operations cost.*

Use of a single manufacturer maximizes vehicle production runs, maximizes learning effects, reduces tooling startup costs, and reduces duplication of design effort. Because of the high degree of commonality between members of the overall family of vehicles, a single manufacturer would be used to produce all vehicles. Prime contractor - subcontractor arrangements of airframe manufacturers and design partnerships with the government might be considered as alternatives.

Multiple vehicle operators — perhaps even competing in certain market segments — would have a strong profit-motive to reduce operations cost. They would exert pressure on the manufacturer to keep hardware and infrastructure investment costs low and operability high. Commercial carriers would operate individual vehicles from the family in many of the new markets (e.g. space tourism, high speed package delivery) as well as the expanded ETO market (analogous to the newly formed OSC/Rockwell Spacelines). The government would assume a role as an anchor tenant for the civil ETO payload carrier and would only serve as operator for military missions.

The choice of operational strategy has a significant effect on the vehicle technical design. The family of vehicles must be designed to meet the requirements of several different market segments and operators while maintaining a small overall number of vehicle designs and a high degree of commonality. Launch infrastructure costs must be keep low in order to reduce carrier investment costs, and the vehicle must be capable of operating from several launch sites established by the different carriers.

Vehicle Technical Design

Feasible concept designs are one of the expected products of the HRST project. Proposed designs are expected to represent a broad spectrum of shapes and ideas, and it would be premature to pick a particular preferred design concept at this stage of the project. However, consistent will the establishment of broad guidelines and strategic arguments in the sections above, certain vehicle/family design characteristics can be inferred from the HRST cost goals.

Most mature, low cost transportation systems are highly reusable — railroads, automobiles, airplanes. It is reasonable to expect that a space transportation system capable of meeting HRST cost requirements will also consist of highly reusable hardware. Vehicle designers must be cognizant of the need to recover and reuse hardware for many flights. Fleet sizes are expected to be small, and therefore the number of flights per vehicle will be high.

It will be the vehicle designer's challenge to design a small family of vehicles capable of meeting all of the missions targeted in the marketing plan in a cost effective manner. Single-stage, multi-stage, and launch assisted vehicles are all potential candidates. If multiple operators are to be used, then the infrastructure and facility costs must be kept low.

Because of high incremental costs, successful systems will likely avoid the use of a flight crew unless necessary to fulfill mission requirements. New technologies should be incorporated into the system only if they are cost effective. Advanced propulsion, actuators, avionics, materials, and heat shielding technologies all have the potential to improve vehicle performance, but their use must be weighed against financial investment limitations imposed by the business plan. Commonality of technology across a family of vehicles will be necessary to distribute development cost.

Vehicle Maintenance Strategy

An important subset of the vehicle technical design is the vehicle maintenance strategy. In fact, given the high cost of maintenance and refurbishment on the Space Shuttle, it is appropriate to address maintenance strategy as an individual discipline.

Routine maintenance and major refurbishment must be easy to accomplish and be cost-effective. Designers must make use of concurrent engineering techniques to maximize the maintainability of the system. Input from maintenance engineers and technicians should be solicited early in the concept design process. Access panels to subsystems, built-in test equipment, line replaceable units, simplified inspection and checkout procedures, increased mean time between maintenance (MTBM) for components, increased component reliability, and robust system operation (e.g. engine out) are all parts of a low maintenance cost system.

A key difference between current space transportation systems and operational aircraft systems is the level of ***margin*** built into the vehicle. Current space vehicles have been designed for maximum performance and have unacceptably low margins on most components (e.g. engine turbopumps and landing gear structure on the Space Shuttle). The result has been a high performing system with very high maintenance and post-flight inspection costs. A family of vehicles capable of meeting HRST cost goals should require an order of magnitude less inspection after each flight and have an increased number of flights between normally scheduled maintenance activities (around every 20 - 25 flights). However, this increased system robustness should not come at the expense of decreased reliability and system safety.

Summary and Approach to System Design

Each of the sections above has offered suggestions for designing an advanced launch system capable of meeting the $100 - $200 per pound of payload cost target established by the HRST program. In addition, it has been argued that the design of a successful system involves more than just the technical engineering disciplines. It depends just as heavily on business and financial planning disciplines as well. The HRST design space is *highly multidisciplinary* — involving skills in vehicle performance and sizing, technology assessment, market planning, business strategy planning, cost estimation, operations modeling, and maintenance modeling. The designer must recognize and solve the true multidisciplinary problem in order to produce a successful HRST concept.

Multidisciplinary design optimization (MDO) is an emerging field in aerospace engineering capable of searching vast design spaces with inputs from a variety disciplines[3]. To date, these MDO methods (ranging from complex optimization procedures to simple multi-variable response surface techniques) have only been used on problems with traditional engineering disciplines. However, it is highly likely that MDO can be extended for use in the HRST program. MDO methods will provide a sound approach to system design and concept selection. However, a significant effort will be required to produce design-oriented analysis models for each of the five critical areas discussed above.

Parametric analysis models in each of the appropriate disciplines will be required. Care should be taken to avoid "point designs" in the search for suitable design candidates. Trends and effects of various design and planning decisions should be coupled with designer intuition and experience to identify promising vehicle/family concepts. Standard assumptions and groundrules will also be required in order to produce fair comparisons between different concepts.

By considering the true multidisciplinary problem presented by the HRST program, the chances of producing a successful design will be improved. In addition, engineers must recognize the importance of business and financial planning disciplines on their designs. The author hopes that some of the ideas presented in this paper will help the HRST program reach its goals.

References

1. Anon. "Commercial Space Transportation Study (CSTS) - Executive Summary." NASA - Langley Research Center, Hampton, VA, April, 1994.

2. Anon. "Access to Space Study - Summary Report." NASA - Headquarters, Washington, DC, January, 1994.

3. Sobieszczanski-Sobieski, Jaroslaw. "Multidisciplinary Design Optimization: An Emerging New Engineering Discipline." World Congress on Optimal Design of Structural Systems, Rio de Janeiro, Brazil, August, 1993.

Achieving Low Cost Space Transportation

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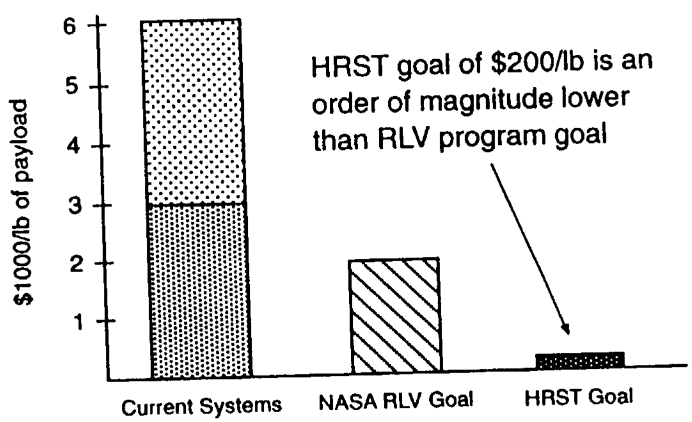
Outline

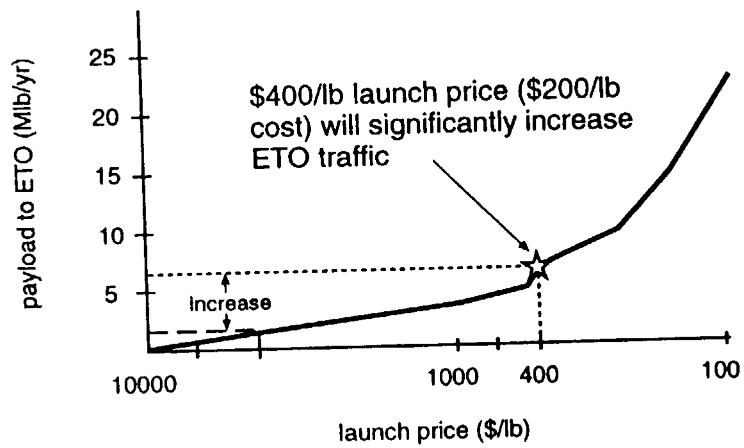
- HRST program introduction
  - » a *multidisciplinary* problem
  - » vehicle technical design guidelines
- Candidate propulsion system
  - » combined-cycle propulsion (rocket *plus* airbreather)
- Thought starters — selected vehicle concepts
  - » SSTO rocket references
  - » SERJ RBCC with Maglifter
  - » Mach 12 RBCC SSTO

HRST Program Cost Goals

ETO Launch Costs



ETO Market Elasticity (CSTS Study)



Decreasing launch costs will ...

» open additional ETO markets

» remove current growth limits on existing markets

» expand ETO traffic to over 200 flts/yr @ 20 klb/flt

Keys to Achieving HRST Goals

A successful HRST concept must solve a *multidisciplinary* problem (financial, business, and technical)*

1) Marketing Strategy
   - address all available markets, use a family of vehicles

2) Business Plan
   - design for return on investment within funding constraints

3) System Operational Strategy
   - paradigm shift from government as single designer/operator

4) Vehicle Technical Design ← this presentation

5) Vehicle Maintenance Strategy
   - design for operational margin, reliability, and maintainability

* see Olds' white paper "Highly Reusable Space Transportation: Approaches for Reducing ETO Launch Costs to $100 - $200 per Pound of Payload."

Vehicle Technical Design

In addition to addressing business and financial constraints, a HRST vehicle technical designer must...

Design reusable hardware
- eliminate many recurring costs
- design for maintenance over life-cycle

Make it robust and reliable
- include favorable launch and abort modes
- include go-around, self-ferry, etc.

Maintain mission flexibility
- use a family of vehicles for multiple markets
- use crew only if required

Design for operability
- design for cost rather than performance
- increase design margins

→ Successful Design

A Candidate Propulsion System for HRST Vehicles

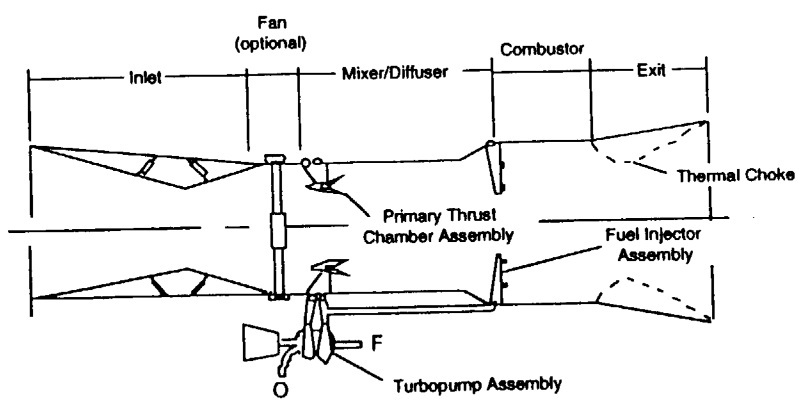
Rocket-Based Combined-Cycle (RBCC)

Combined-Cycle Propulsion

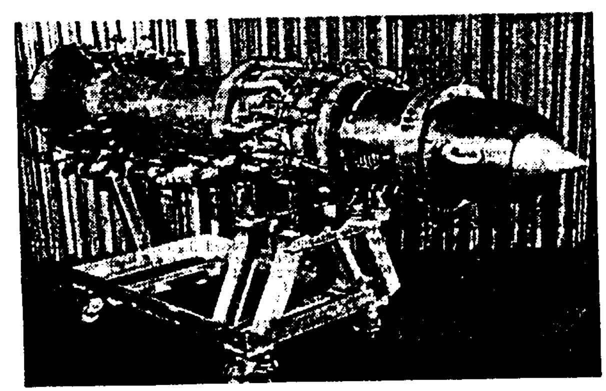
Propulsion systems combining elements of rockets *and* airbreathers may be able to meet HRST goals

Rocket-Based Combined-Cycle (RBCC) Propulsion

Engine Schematic



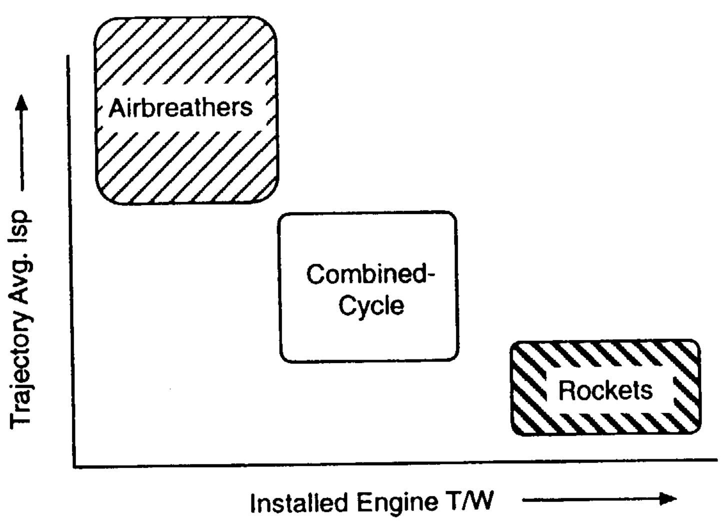
Historical Development



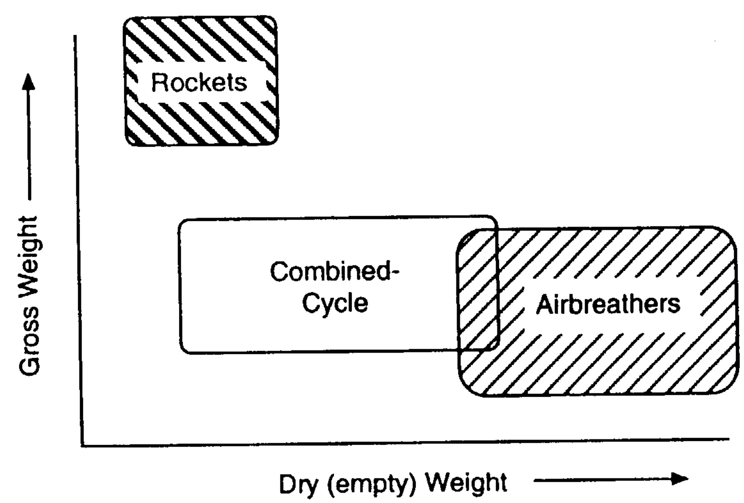
Marquardt Subscale Test Engine (1960's)

Combined-Cycle Benefits

Engine Parameters



Vehicle Impacts



Combined-cycle propulsion merges the best attributes of rockets and airbreathers

Thought Starters –
Selected Vehicle Concepts

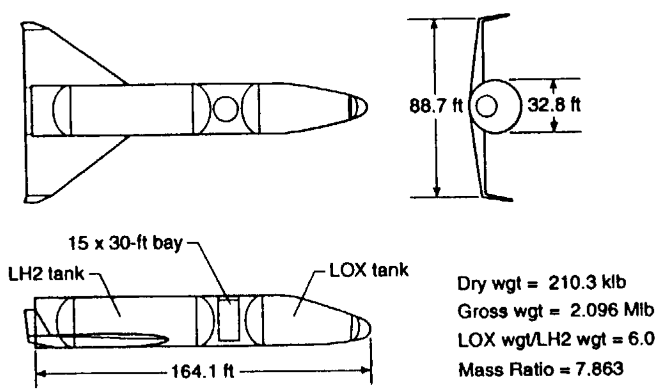
Design Groundrules

The following HRST vehicle concepts are designed for...

- mission requirements
  - » 20,000 lb payload to 100 nmi circ. 28.5° orbit
  - » 2,500 ft^3 payload volume
- 15% dry weight margin
- unmanned operation
  - » no separate crew cabin
  - » passengers ride in cargo bay (if required)

Reference All-Rocket Concepts

LH2/LOX SSTO

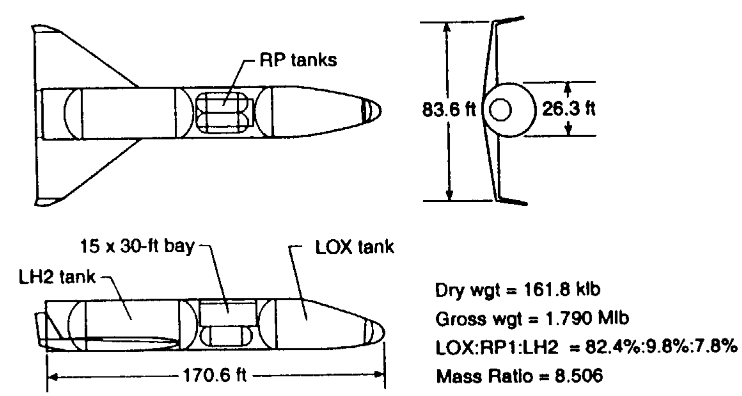


Main Propulsion:
- LOX/LH2 SSME-derivative engines
- Isp vac = 447.3 sec
- thrust vac = 482.5 klb/ea.
- engine T/W = 71.2

Trajectory/Operational Modes:
- vertical takeoff, horizontal landing

Vehicle Technologies:
- Al-Li propellant tanks
- Graphite/epoxy structure
- ACC/TABI/AFRSI TPS
- cryogenic OMS

Dual-Fuel SSTO

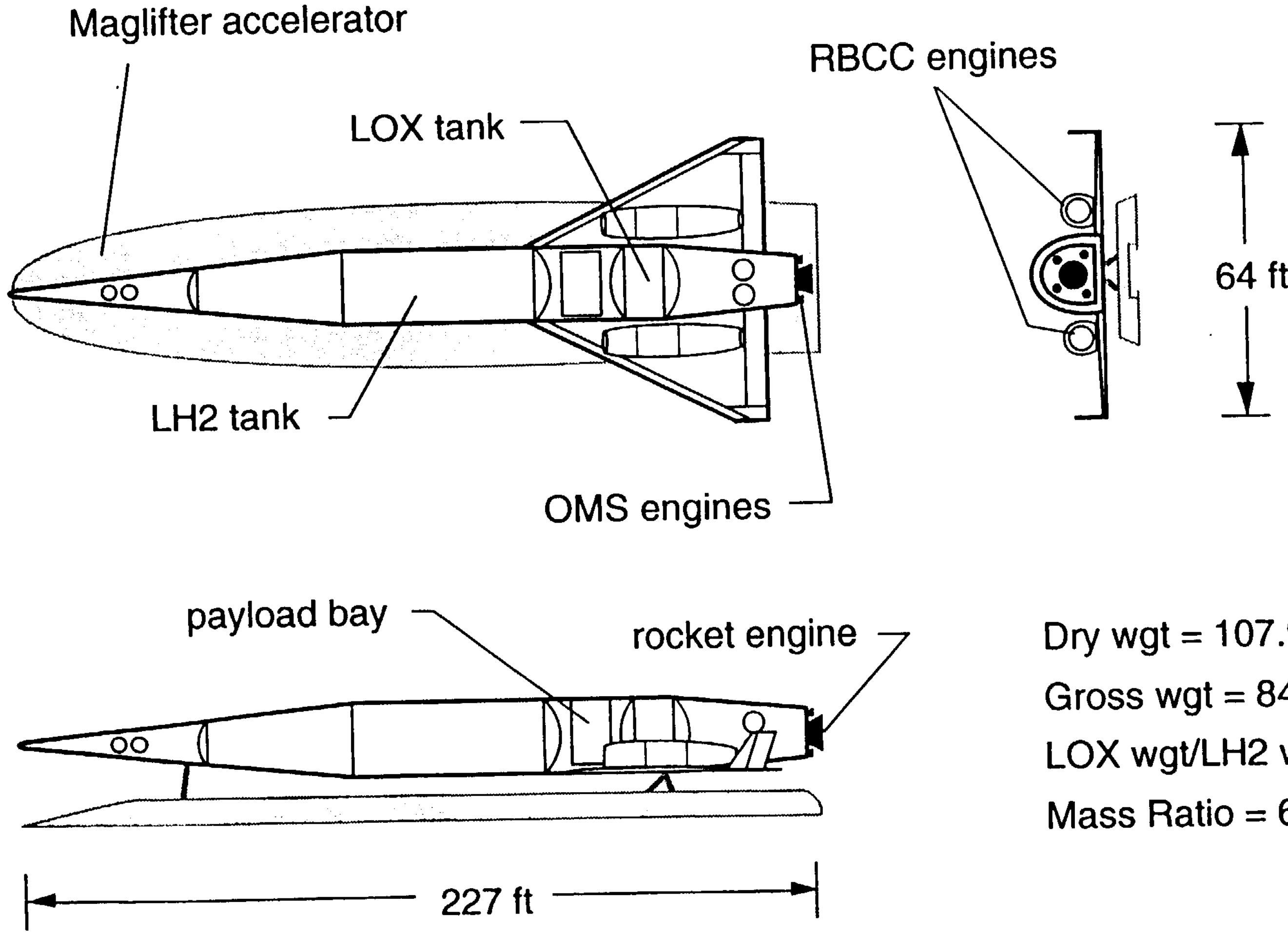


Main Propulsion:
- RD-701 dual-fuel engines (LOX/RP1/LH2)
- Isp vac = 407/452 sec (mode 1/2)
- thrust vac = 441.4/175.5 klb/ea. (mode 1/2)
- engine T/W = 70.2

Trajectory/Operational Modes:
- LOX/RP1 mode to Mach 10.7 then LOX/LH2
- vertical take-off, horizontal landing

Vehicle Technologies:
- Al-Li propellant tanks
- Graphite/epoxy structure
- ACC/TABI/AFRSI TPS, cryogenic OMS

SERJ RBCC with Maglifter



Dry wgt = 107.9 klb

Gross wgt = 849 klb

LOX wgt/LH2 wgt = 4.05

Mass Ratio = 6.125

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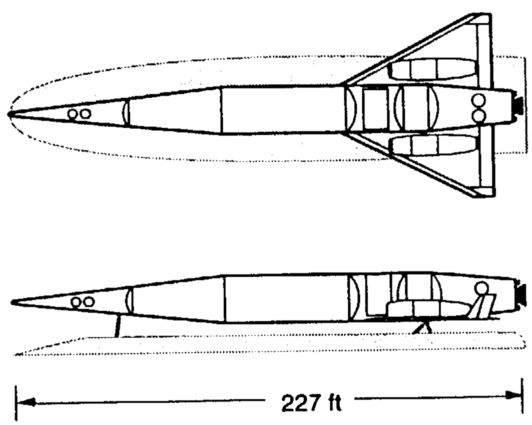
SERJ RBCC w/Maglifter Summary



Vehicle:
payload = 20 klb to 100 nmi. circular orbit @ 28.5°
dry weight = 107.9 klb
gross weight = 849 klb

Propulsion:
2 Supercharged Ejector Ramjet (SERJ) RBCC engines
Isp @ sea level = 460 sec. (LOX/LH2)
thrust @ sea level = 223.4 klb/ea.
engine installed T/W = 23.5
1 STME-class LOX/LH2 rocket
Isp vac = 455 sec
thrust vac = 655 klb
engine installed T/W = 70.0

Vehicle Technologies:
filament-wound Graphite/PEEK LH2 tank
Al-Li LOX tank
Titanium-aluminide hot structure (wings, etc.)
ACC/TUFI/TABI passive TPS
cryogenic OMS/RCS
electro-mechanical surface actuators

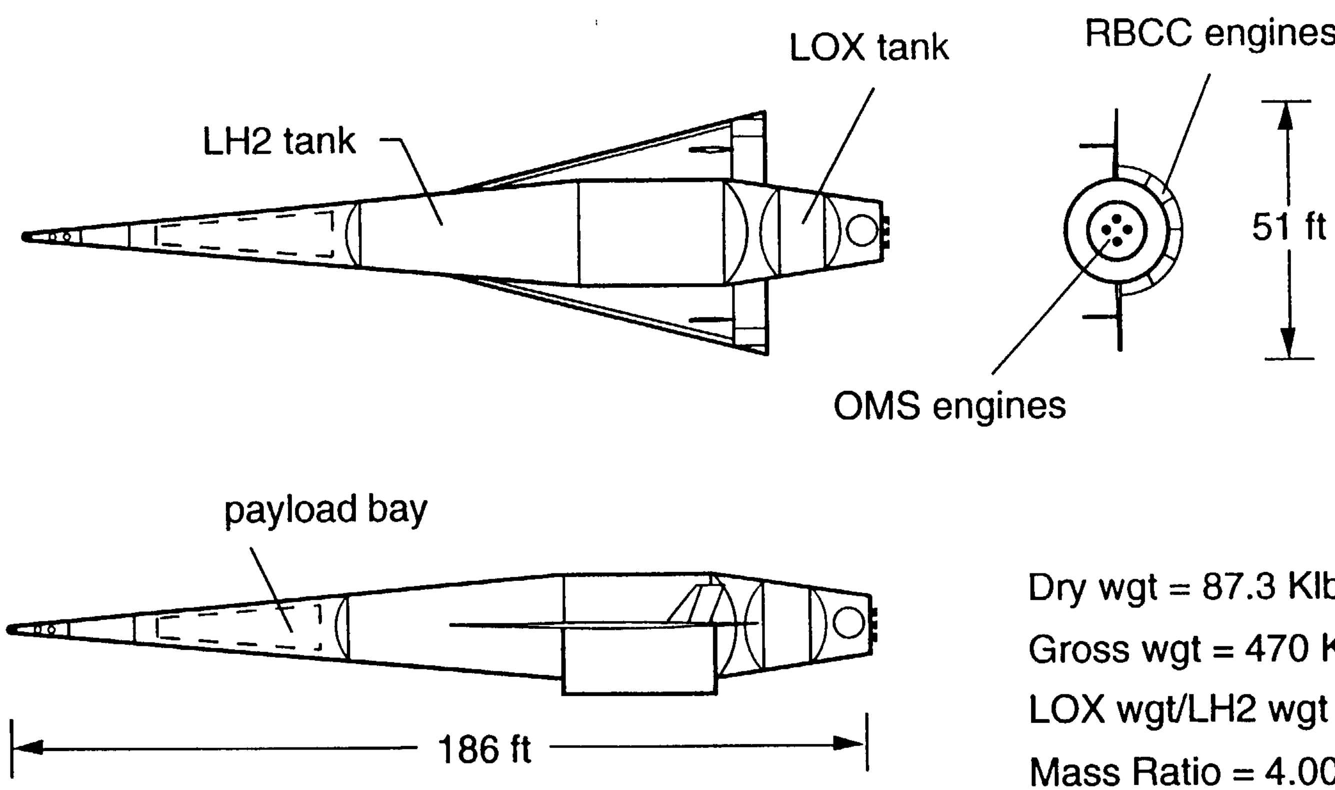
Trajectory/Operational Modes:
Maglifter horizontal acceleration to 800 fps @ sea level
ejector Mode to Mach 2
fan-ramjet mode to Mach 3
ramjet mode to Mach 6 (const. dyn. press. = 2000 psf)
(tail) rocket to orbit
horizontal landing

Notes and Issues:
- concept avoids use of scramjet airbreathing mode (and associated development costs)
- Mach 6 transition to rocket avoids severe aeroheating problems
- SERJ RBCC engine builds on historical development
- Maglifter development and infrastructure costs remain to be determined
- elimination of redundant rocket capabilities (tail rocket and ejector) could improve performance

SERJ RBCC w/Maglifter Weights

Name	Weight (lbs)
Wing and Tail Group	14,100
Body Group (incls. tanks)	24,600
Thermal Protection	7,900
Main Propulsion	31,800
OMS/RCS Propulsion	2,300
Subsystems and Other Dry Weights	13,200
Dry Weight Margin (15%)	14,000
Dry Weight	107,900
Payload	20,000
Other Inert Weights (residuals, etc.)	10,700
Insertion Weight	138,600
Ascent Propellants	710,200
Gross Lift-off Weight	848,800

Mach 12 RBCC SSTO



Dry wgt = 87.3 Klb

Gross wgt = 470 Klb

LOX wgt/LH2 wgt = 2.80

Mass Ratio = 4.002

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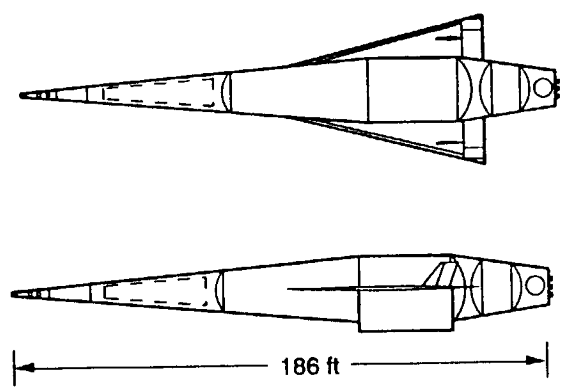
Mach 12 RBCC SSTO Summary



Vehicle:
- payload = 20 klb to 100 nmi. circular orbit @ 28.5°
- dry weight = 87.3 klb
- gross weight = 470 klb

Propulsion:
- 9 Ejector Ramjet/Scramjet RBCC engines
- 180° cowl wraparound angle, integrated flow path
- Isp @ sea level = 421 sec. (LOX/LH2 ejector mode)
- thrust @ sea level = 62.6 klb/ea.
- Isp in scramjet mode = 1600 - 3000 sec. (typ.)
- thrust in scramjet mode = 20 - 30 klb/ea. (typ.)
- maximum capture area = 20 sq. ft./ea.
- engine installed T/W = 23.5

Vehicle Technologies:
- filament-wound Graphite/PEEK LH2 tank
- Al-Li LOX tank
- Titanium-aluminide hot structure (wings, etc.)
- ACC/TUFI/TABI passive TPS plus advanced active TPS
- cryogenic OMS/RCS
- electro-mechanical surface actuators

Trajectory/Operational Modes:
- vertical take-off, horizontal landing
- ejector Mode to Mach 3
- ramjet mode to Mach 6 (const. dyn. press. = 2000 psf)
- scramjet mode to Mach 12 (dyn. press. = 2000 psf)
- rocket mode (RBCC built-in) to orbit

Notes and Issues:
- no scramjet airbreathing mode operation above Mach 12 (minimum dry weight transition for tested range)
- no engine supercharger fan (saves engine weight but hinders go-around and self-ferry capability)
- active cooling on wing leading edges, nose, and engine will be required
- vertical take-off control/thrust-vectoring requirements remain to be determined
- infrastructure and technology development costs remain to be determined

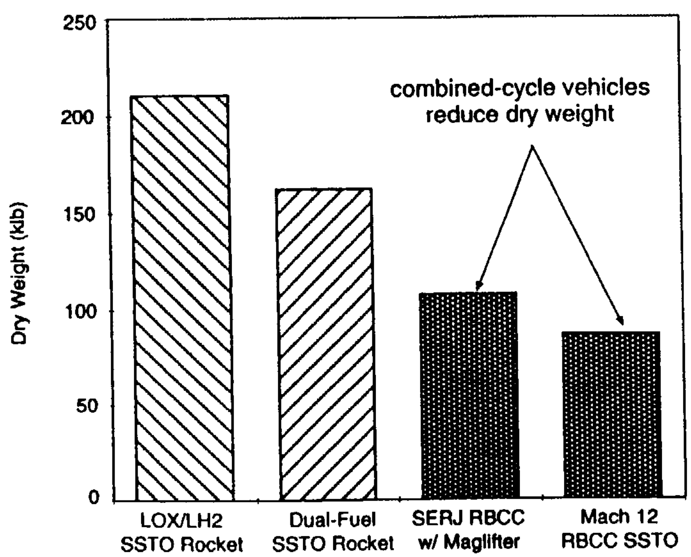
Mach 12 RBCC SSTO Weights

Name	Weight (lbs)
Wing and Tail Group	4,700
Body Group (incls. tanks)	28,300
Thermal Protection	11,000
Main Propulsion (less cowl)	18,600
OMS/RCS Propulsion	2,200
Subsystems and Other Dry Weights	11,100
Dry Weight Margin (15%)	11,400
Dry Weight	87,300
Payload	20,000
Other Inert Weights (residuals, etc.)	10,100
Insertion Weight	117,400
Ascent Propellants	352,300
Gross Lift-off Weight	469,700

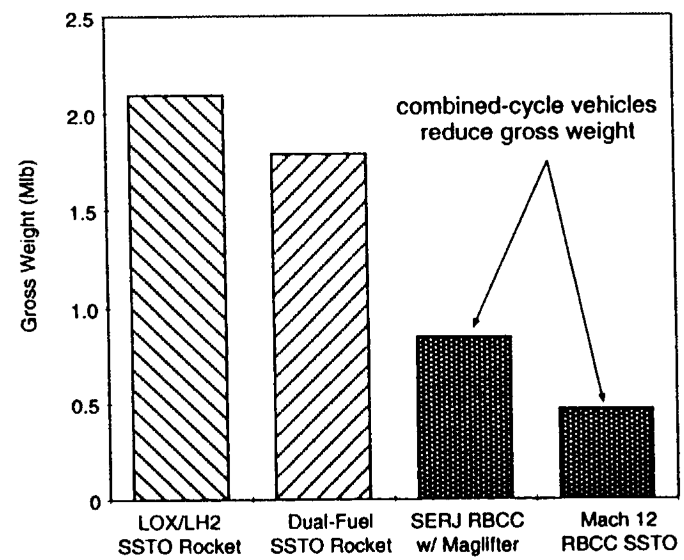
Vehicle Comparisons

Based on *performance* characteristics, combined-cycle propulsion appears to be an attractive option

Dry Weight Comparison



Gross Weight Comparison



Can it be used to meet HRST *cost* goals?

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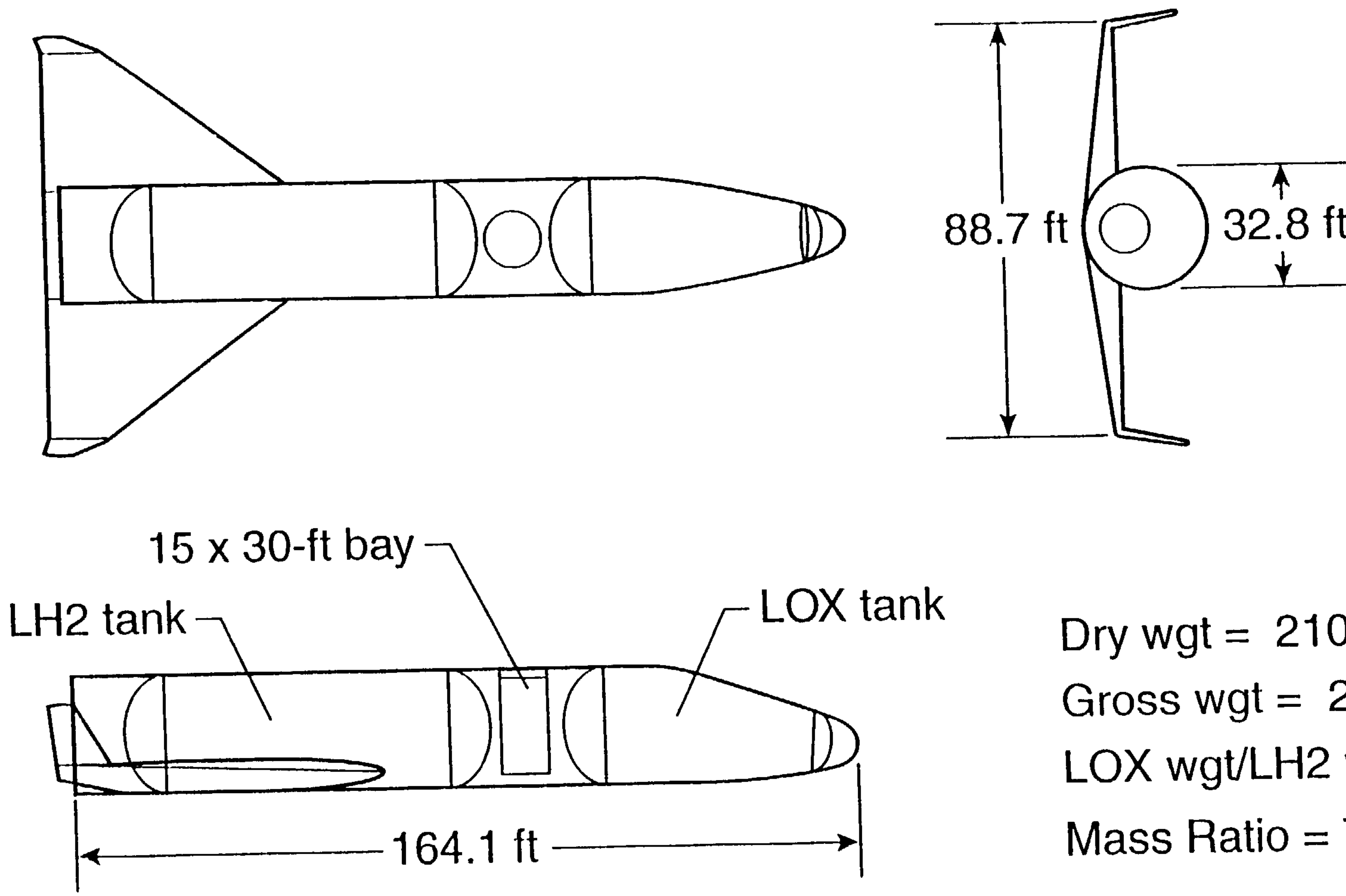
Summary

- HRST cost goals present a *multidisciplinary* challenge
  - » must solve business, financial, *and* technical problems
  - » vehicle design must emphasize cost, flexibility, and operability
- Combined-cycle propulsion is an attractive candidate
  - » combines best of rockets and airbreathers
  - » builds on historical development work
  - » preliminary vehicle concepts look attractive
- Integrated system/cost assessment remains TBD
  - » can RBCC be integrated into a successful system concept?
  - » additional concept exploration work will be required

Appendices

Vehicle Weight Statements



Dry wgt = 210.3 klb

Gross wgt = 2.096 Mlb

LOX wgt/LH2 wgt = 6.0

Mass Ratio = 7.863

WEIGHT STATEMENT - LEVEL I (lb)

unmanned ssv, ssme-50 der. - 20 klb p/l, 28.5 deg incl.

1.0 Wing	9977.
2.0 Tail	1462.
3.0 Body	66312.
4.0 Induced environment protection	18896.
5.0 Undercarriage and aux. systems	7099.
6.0 Propulsion, main	58561.
7.0 Propulsion, reaction control (RCS)	3623.
8.0 Propulsion, orbital maneuver (OMS)	1363.
9.0 Prime power	2339.
10.0 Electric conversion and distr.	8438.
11.0 Hydraulic conversion and distr.	0.
12.0 Control surface actuation	1272.
13.0 Avionics	1314.
14.0 Environmental control	2219.
15.0 Personnel provisions	0.
18.0 Payload provisions	0.
19.0 Margin	27431.
EMPTY	210305.
20.0 Personnel	0.
21.0 Payload accomodations	0.
22.0 Payload	20000.
23.0 Residual and unusable fluids	11688.
25.0 Reserve fluids	7273.
26.0 Inflight losses	5650.
27.0 Propellant, main	1855335.
28.0 Propellant, reaction control	2861.
29.0 Propellant, orbital maneuver	8815.
PRELAUNCH GROSS	2121927.
	0.
Prelaunch gross	2121927.
Start-up losses	-25771.
Gross lift-off	2096155.
Ascent propellant	-1829564.
Insertion	266591.
Ascent reserves	-5862.
Ascent residuals	-9582.
Inflight losses	-5650.
Aux. propulsion propellant	-10966.
Payload delivered	-20000.
Payload accepted	20000.
Entry	234532.
RCS prop. (entry)	-710.
Landed	233822.
Payload (returned)	-20000.
Landed (p/l out)	213822.
Payload accomodations	0.
Personnel	0.
Subsystem residuals	-605.
Aux. propulsion residuals	-1501.
Aux. propulsion reserves	-1410.
Empty	210305.

unmanned ssv, ssme-50 der. - 20 klb p/l, 28.5 deg incl.

DESIGN DATA

payload volume (cu. ft.)	2500.0000
payload weight (lb)	20000.0000
oms delta v req. (ft./sec.)	500.0000
mass ratio	7.8628
rocket reduction factor	0.0000
body_length_______________ft_	164.1086
body_width_______________ft_	32.7748
exp_wing_span_______________ft_	61.7037
exp_wing_root_chord_______ft_	56.0225

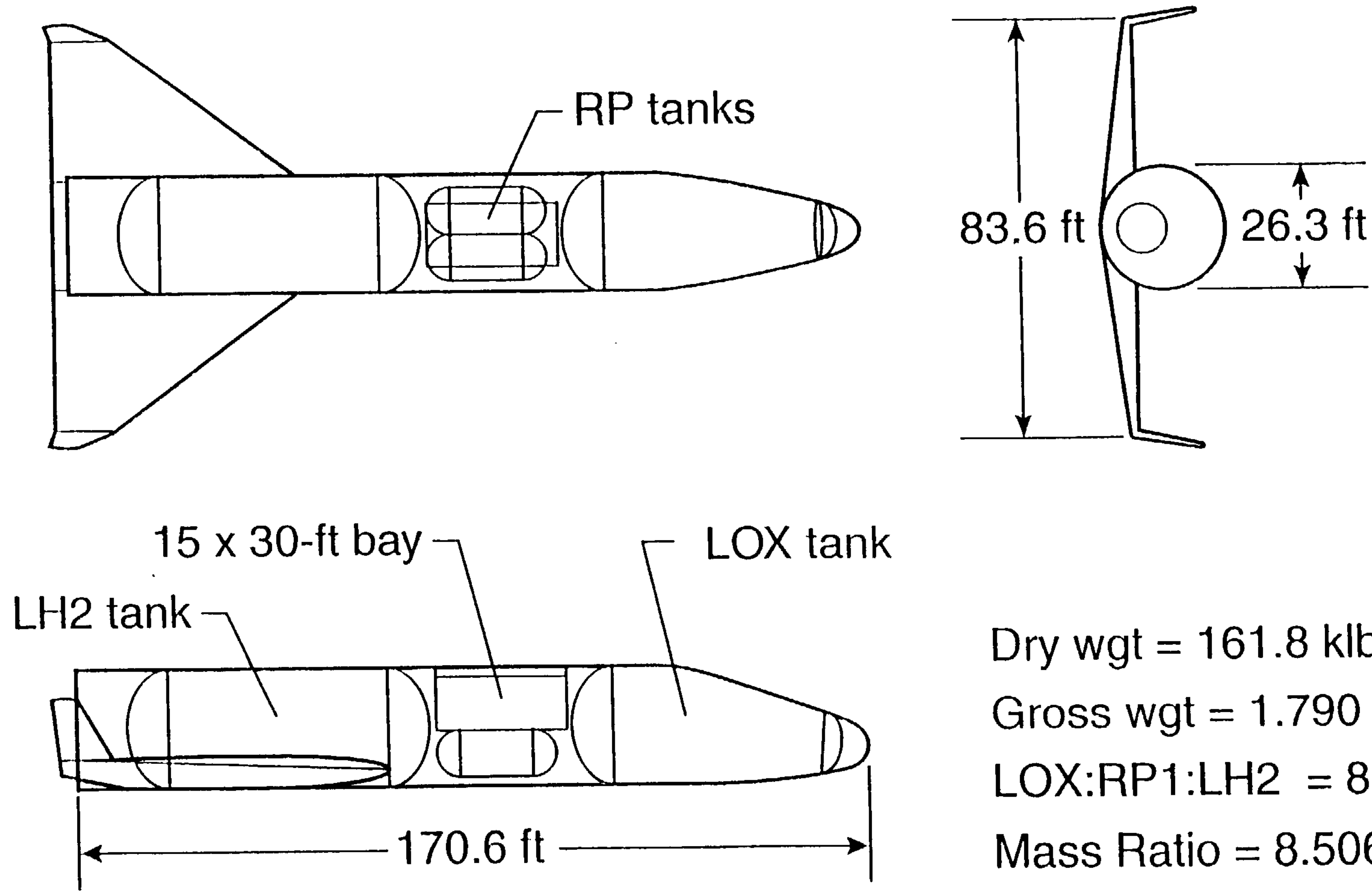
nose_section_area_____sq_ft_	282.0456
intertank_area________sq_ft_	4079.4360
aft_skirt_area________sq_ft_	1164.8359
engine_bay_area_______sq_ft_	1221.7495
body_tps_wetted_area__sq_ft_	15910.3421
wing_tps_wetted_area__sq_ft_	4405.7115
exposed_wing_planform_sq_ft_	2134.6666
theo_wing_planform____sq_ft_	3923.7254
body_volume____________cu_ft__	123640.5167
carry_through_width_ft________	26.9737
exposed_wing_taper_ratio______	0.2359
exposed_wing_aspect_ratio_____	1.7836

SIZING PARAMETERS

Mass ratio	7.8628
Propellant mass fraction	0.8728
Body length (ft.)	164.1
Wing span (ft.)	88.7
Theoretical wing area (sq. ft.)	3897.0
Wing loading at design wt (psf)	60.0
Wing planform ratio, sexp/sref	0.55
Sensitivity of volume to burnout wt (cu. ft./klb.)	457.3
Burnout weight growth factor (lb/lb)	4.58

	BODY	WING
Total volume (cu. ft.)	123641.	12623.
Tank volume (cu. ft.)	84883.	0.
Fixed volume (cu. ft.)	0.	0.
Tank efficiency factor	0.6865	0.0000
Ullage volume fraction	0.0300	0.0300

PROPELLANT	FRACTION	DENSITY (lb/cu. ft.)	FLUID VOLUME (cu. ft.)	TANK VOLUME (cu. ft.)
lh2	0.1429	4.42	59150.	61838.
lox	0.8571	71.14	22043.	23045.
lox (Wing)	0.0000	71.14	0.	0.



Dry wgt = 161.8 klb

Gross wgt = 1.790 Mlb

LOX:RP1:LH2 = 82.4%:9.8%:7.8%

Mass Ratio = 8.506

M_{tr} = 10.7

WEIGHT STATEMENT - LEVEL I (lb)

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 20klb p/l - 28.5 inc., *

1.0 Wing	8325.
2.0 Tail	1481.
3.0 Body	51009.
4.0 Induced environment protection	16524.
5.0 Undercarriage and aux. systems	5843.
6.0 Propulsion, main	39745.
7.0 Propulsion, reaction control (RCS)	3362.
8.0 Propulsion, orbital maneuver (OMS)	1191.
9.0 Prime power	2339.
10.0 Electric conversion and distr.	6246.
11.0 Hydraulic conversion and distr.	0.
12.0 Control surface actuation	1050.
13.0 Avionics	1314.
14.0 Environmental control	2292.
15.0 Personnel provisions	0.
18.0 Payload provisions	0.
19.0 Margin	21108.
EMPTY	161827.
20.0 Personnel	0.
21.0 Payload accomodations	0.
22.0 Payload	20000.
23.0 Residual and unusable fluids	9894.
25.0 Reserve fluids	5691.
26.0 Inflight losses	3777.
27.0 Propellant, main	1603438.
28.0 Propellant, reaction control	2258.
29.0 Propellant, orbital maneuver	6957.
PRELAUNCH GROSS	1813842.
	0.
Prelaunch gross	1813842.
Start-up losses	-24124.
Gross lift-off	1789717.
Ascent propellant	-1579313.
Insertion	210404.
Ascent reserves	-4577.
Ascent residuals	-8231.
Inflight losses	-3777.
Aux. propulsion propellant	-8655.
Payload delivered	-20000.
Payload accepted	20000.
Entry	185164.
RCS prop. (entry)	-561.
Landed	184604.
Payload (returned)	-20000.
Landed (p/l out)	164604.
Personnel	0.
Payload accomodations	0.
Subsystem residuals	-478.
Aux. propulsion residuals	-1185.
Aux. propulsion reserves	-1113.
Empty	161827.

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 20klb p/l - 28.5 inc.,

DESIGN DATA

payload volume (cu. ft.)	2500.0000
payload weight (lb)	20000.0000
oms delta v req. (ft./sec.)	500.0000
lift-off t/w ratio	1.2000
mass ratio	8.5061
rocket reduction factor	0.0000
body_length________________ft_	170.5762
body_width_________________ft_	26.2636
body_volume______________cu_ft_	82008.9934

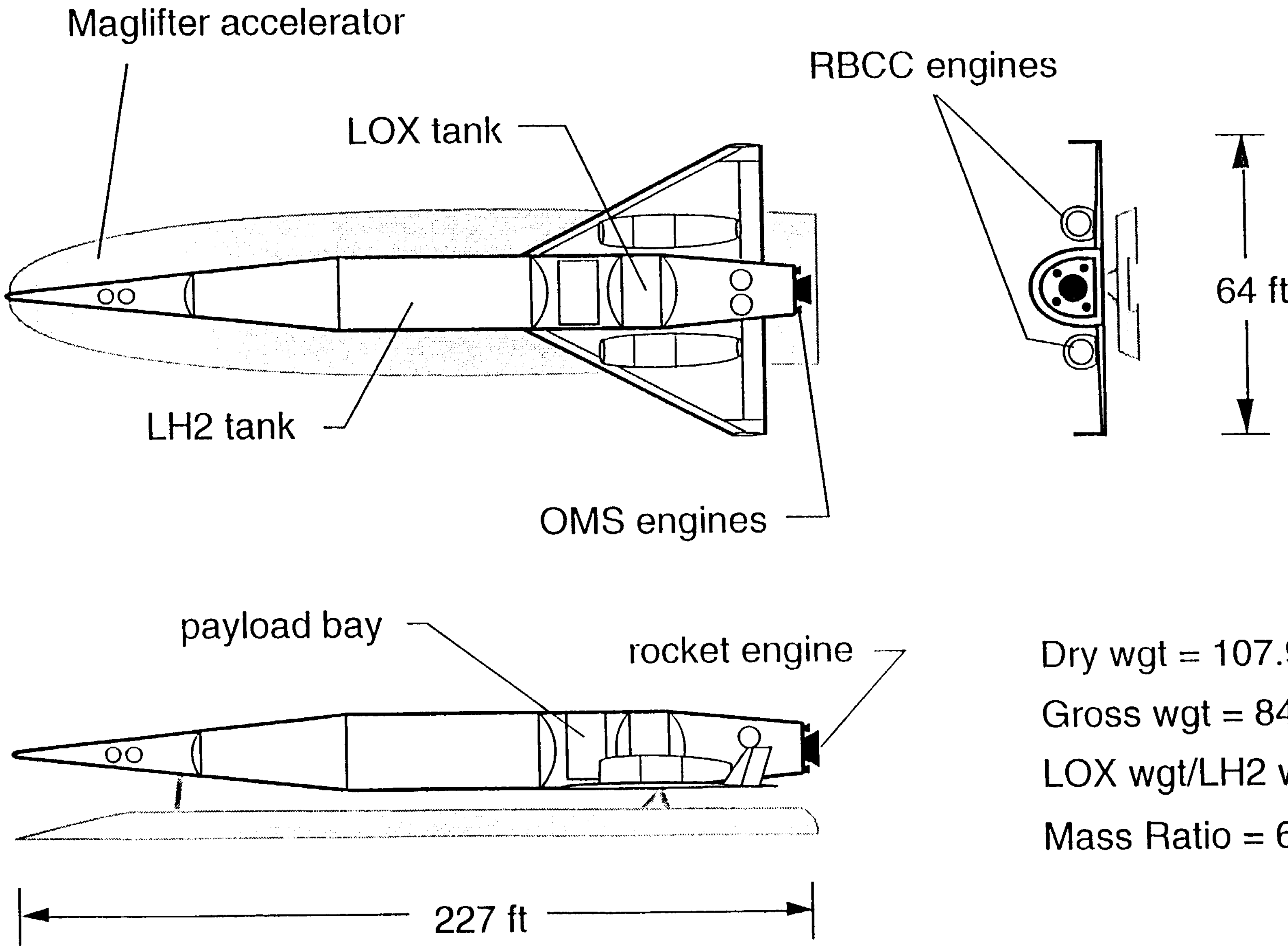
body_tps_wetted_area___sq_ft_	13140.4064
nose_section_area______sq_ft_	350.7522
intertank_area________sq_ft_	4029.3243
aft_body_area_________sq_ft_	766.1485
engine_bay_area_______sq_ft_	908.0100
lox_tank_wetted_area___sq_ft_	4079.4898
lox_tank_volume________cu_ft_	20090.5600
lh2_tank_wetted_area___sq_ft_	5483.4919
lh2_tank_volume________cu_ft_	30581.6126
ker_tank_volume________cu_ft_	3383.7165
wing_tps_wetted_area___sq_ft_	4028.8602
carry_through_width_______ft_	23.7076
exposed_wing_span_________ft_	59.9081
exposed_wing_root_chord___ft_	53.0740
exposed_wing_planform__sq_ft_	1943.5810
exposed_wing_taper_ratio_____	0.2324
exposed_wing_aspect_ratio____	1.8472
body flap length (ft)	7.4742
tip fins (2) planform area (ft2)	215.9368

SIZING PARAMETERS

Mass ratio	8.5061
Propellant mass fraction	0.8824
Body length (ft.)	170.6
Wing span (ft.)	83.6
Theoretical wing area (sq. ft.)	3381.0
Wing loading at design wt (psf)	54.6
Wing planform ratio, sexp/sref	0.57
Sensitivity of volume to burnout wt (cu. ft./klb.)	384.6
Burnout weight growth factor (lb/lb)	3.73

	BODY	WING
Total volume (cu. ft.)	82009.	9480.
Tank volume (cu. ft.)	51522.	0.
Fixed volume (cu. ft.)	0.	0.
Tank efficiency factor	0.6283	0.0000
Ullage volume fraction	0.0300	0.0300

PROPELLANT	FRACTION	DENSITY (lb/cu. ft.)	FLUID VOLUME (cu. ft.)	TANK VOLUME (cu. ft.)
lh2	0.0782	4.42	27959.	29161.
hc	0.0983	50.50	3073.	3230.
lox	0.8235	71.14	18282.	19132.
lox (Wing)	0.0000	71.14	0.	0.



Dry wgt = 107.9 klb

Gross wgt = 849 klb

LOX wgt/LH2 wgt = 4.05

Mass Ratio = 6.125

HRST Vehicle w/RBCC Weights and Sizing

HTO sled launch RBCC with engine #11
V launch = 800 fps, q = 2000 psf, Mtr = 6

Directions:
Variables that can be changed are marked with bold underline.
Boxed variables are inputs that are products of other analyses
Adjust ascent propellant until actual mass ratio matches required mass ratio

Vehicle Overall Parameters

Ascent Propellant (iterate)	710,200 lb	
Vehicle diameter (max.)	19.76 ft	
Mass Ratio (required)	6.125	
LH2 ascent/total ascent prop	0.198	
Payload (round-trip)	20,000 lb	
Mass Ratio (actual)	6.125	
Total vehicle length	227.26 ft	
Fineness ratio (targ 11.5)	11.50	
Gross Weight (actual)	848,778 lb	
Dry Weight (actual)	107,904 lb	
Landing c.g. (P/L in)	171.57 ft	75.50%
Landing c.g. (P/L out)	171.07 ft	75.27%
Gross Weight c.g. (P/L in)	176.57 ft	

Nosecone Data

Nosecap radius	0.75 ft
Structural unit weight	2.21 lb/ft2
Nosecone angle	6.50 deg
Total forebody length	80.88 ft
Nosecone length	20.22 ft
Nosecone aft diameter	6.11 ft
Nosecone surface area	243.21 ft2
Nosecone volume	257.9 ft3

Crew Cabin Data

Number of crew	0
Mission duration	0.00 days
Cabin length	0.00 ft

Payload Bay/Intertank Data

PL bay volume	2500.0 ft3
PL bay struct. unit weight	2.21 lb/ft2
PL bay doors str. unit weight	3.50 lb/ft2
PL bay length	8.15 ft
Margin to domes	1.50 ft
Payload section length (total)	11.15 ft
PL bay doors surface area	200.00 ft2
PL bay area (exluding doors)	1346.89 ft2

LH2 Main Tank Data

Tank structural unit weight	0.26 lb/ft3
Tank insulation unit weight	0.26 lb/ft2
Cryo insulation thickness	0.17 ft
Tank ullage volume/total vol.	0.0425
LH2 density	4.43 lb/ft3
Tank dome height/radius	0.707
Tank volume (total)	33441.1 ft3
LH2 tank length (cyl. sect.)	80.63 ft
LH2 tank length (cone sect.)	57.69 ft
Fore dome diameter	6.28 ft
Fore dome height	2.22 ft
Aft dome diameter	19.43 ft
Aft dome height	6.87 ft
Total tank length	147.41 ft
Tank surface area (total)	7797.0 ft2

LOX Main Tank Data

Tank structural unit weight	0.33 lb/ft3
Tank insulation unit weight	0.20 lb/ft2
Cryo insulation thickness	0.13 ft
Tank ullage volume/total vol.	0.0425
LOX density	71.2 lb/ft3
Tank dome height/radius	0.707
Tank volume (total)	8436.1 ft3
LOX tank length (cyl. section)	19.02 ft
Fore dome height	6.90 ft
Aft dome height	6.90 ft
Total tank length	32.82 ft
Tank surface area (total)	2136.42 ft2

Tailcone/Base Data

Aftbody cone half angle	10.00 deg
Base diam/fuselage diam	0.7
Tailcone struct. unit weight	2.21 lb/ft2
Base structural unit weight	1.99 lb/ft2
Tailcone length (cyl. section)	5.00 ft
Tailcone length (total)	21.81 ft
Base diameter	13.83 ft
Base area	150.27 ft2
Tailcone surface area	1211.06 ft2
Aft compartment volume	3886.2 ft3

RBCC Engine Data

Vehicle T/W (SLS)	0.55
AB/Rocket Trans. Mach #	6.00
Engine T/W (instl, no marg)	23.50
Engine Isp (sea level)	460.0 sec
Liftoff mixture (LOX/LH2)	6.00
Engine length/diameter	5.0
Ejectors weight %	0.27
Fan/GG weight %	0.28
Req'd thrust (SLS, both)	466,828 lb
Inlet/capture area (both)	153.12 ft2
Engine diameter (ea.)	9.87 ft
Total engine length (ea.)	49.37 ft
Inlet section length (ea.)	29.62 ft

Rocket Engine Data

Transition Wgt/Gross Wgt.	0.735
Vehicle T/W @ transition	1.05
Engine T/W (instl, no marg)	70.00
Rocket thrust (vac.)	655,044 lb
Isp (vac)	455.0 sec
Mixture ratio (LOX/LH2)	6.00
Nozzle exit area	69.69 ft2

TPS Data

Nose cap active cooling weight	0.00 lb
Active cooling weight/length	0.00 lb/ft
Active cooling weight/area	0.00 lb/ft2
ACC area/body area	0.05
ACC area/wing&tail area	0.05
ACC unit weight	2.00 lb/ft2
TUFI area/body area	0.20
TUFI area/wing&tail area	0.55
TUFI unit weight	0.74 lb/ft2
TABI area/body area	0.75
TABI unit weight	0.25 lb/ft2
Approx. body passive TPS area	14107.9 ft2
Wing (top&btm) wetted area	3164.68 ft2
Tail wetted area (both)	307.26 ft2

Wing/Tail Data

Wing leading edge sweep	68.00 deg
Landing weight/Sref	42.000
Landing speed	200 knts
Tail area(ea.)/wing ref. area	0.025
Wing thickness ratio	0.05
Wing taper ratio	0.10
Cruise norm. force/gross wgt.	0.677
Wing Reference area	3072.6 ft2
Wing Aspect ratio	1.322
Wing exposed planform	1582.3 ft2
Tail planform area(each)	76.8 ft2
Wingspan	63.74 ft
Theoretical center chord	87.65 ft
Tip chord	8.76 ft
Exposed root chord	63.19 ft
Wing exp. leading edge (ea.)	58.70 ft
Span through half-chords	101.42 ft
Thickness of expos. root chord	3.16 ft
Design(max.) wing limit load	9.77E+05 lb
Required landing Cl	0.3721

Body Flap Data

Body flap length	8.00 ft
Body flap unit weight	2.21 lb/ft2
Body flap planform area	158.08 ft2
Body flap area (top&btm)	316.16 ft2

OMS Data

OMS on-orbit ΔV (deorbit)	250 ft/sec
OMS Isp	462.0 sec
OMS mixture ratio (O/F)	6
Total OMS LH2 prop.	359.96 lb
OMS LH2 tank vol.	85.3 ft3
OMS LH2 tank diam.	5.46 ft
Total OMS LOX prop.	2159.77 lb
OMS LOX tank vol.	31.9 ft3
OMS LOX tank diam.	3.93 ft
Aft He tank diameter	2.38 ft

RCS Data

Forward RCS on-orbit ΔV	15 ft/sec
Aft RCS on-orbit ΔV	35 ft/sec
RCS Isp	420.0 sec
RCS mixture ratio (O/F)	4

Forward RCS

Total forward RCS LH2 prop.	49.47 lb
Forward RCS LH2 tank vol.	11.7 ft3
Forward RCS LH2 tank diam.	2.82 ft
Total forward RCS LOX prop.	197.86 lb
Forward RCS LOX tank vol.	2.9 ft3
Forward RCS LOX tank diam.	1.77 ft
Forward He tank diameter	1.89 ft

Aft RCS

Total aft RCS LH2 prop.	115.49 lb
Aft RCS LH2 tank vol	27.4 ft3
Aft RCS LH2 tank diam.	3.74 ft
Total aft RCS LOX prop.	461.96 lb
Aft RCS LOX tank vol.	6 8 ft3
AFT RCS LOX tank diam.	2.35 ft
Aft He tank diameter	2.50 ft

SERT

No crew or ca

Vehicle Weight Statement **HTO sled launch RBCC with engine #11** V launch = 800 fps, q = 2000 psf, Mtr = 6

	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			13,086
2.0 Tail Group			1,022
3.0 Body Group			24,627
4.0 Thermal Protection			7,914
5.0 Landing Gear			3,871
6.0 Main Propulsion			31,785
7.0 RCS Propulsion			1,417
8.0 OMS Propulsion			930
9.0 Primary Power			617
10.0 Electrical Conversion & Dist.			3,616
11.0 Hydraulic Systems			0
12.0 Surface Control Actuation			853
13.0 Avionics			1,600
14.0 Environmental Control			2,491
15.0 Personnel Equipment			0
16.0 Dry Weight Margin (15%)			14,074
Dry Weight			**107,904**
17.0 Crew and Gear			0
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			856
21.0 OMS/RCS Reserve Propellants			291
Landed Weight			**129,050**
22.0 RCS Entry Propellants (ΔV = 25 fps)			239
Entry Weight			**129,289**
23.0 RCS/OMS Propellants (on-orbit)			2,670
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			5,327
26.0 Inflight Losses and Vents			1,293
Insertion Weight			**138,578**
27.0 Ascent Propellants			710,200
Gross Liftoff Weight			**848,778**
28.0 Startup Losses			2,030
Maximum Pre-launch Weight			**850,807**

Vehicle Weight Statement
HTO sled launch RBCC with engine #11
V launch = 800 fps, q = 2000 psf, Mtr = 6

	Level 3	Level 2	Level 1
1.0 Wing Group			13,086
Exposed wing		8,973	
Carry through		4,112	
2.0 Tail Group			1,022
3.0 Body Group			24,627
Nosecone		537	
Crew Cabin		0	
Payload Bay/Intertank Structure		6,677	
Structure	2,977		
P/L Bay Doors	700		
P/L Accommodations	3,000		
LH2 Tank		10,555	
Tank Structure	8,527		
Tank Insulation	2,027		
LOX Tank		3,184	
Tank Structure	2,767		
Tank Insulation	417		
Aft Body		2,975	
Tail cone	2,676		
Base	299		
Body Flap		699	
4.0 Thermal Protection			7,914
Active Cooling		0	
Nosecap	0		
Wing leading edges	0		
Advanced Carbon/Carbon		1,758	
Body/cowl	1,411		
Wing/tails	347		
TUFI (tiles)		3,511	
Body/cowl	2,094		
Wing/tails	1,417		
TABI (blankets)		2,645	
Body/cowl	2,645		
Wing/tails	0		
5.0 Landing Gear			3,871
Nosegear		581	
Main gear		3,291	
6.0 Main Propulsion			31,785
RBCC Engines (installed)		19,865	
Ejector rockets (incl. pumps)	5,291		
Diff./Comb./Noz. (w/ cooling)	8,930		
Fan/gas generator	5,644		
Main Rocket Engine		9,358	
Pressurization and feed systems		1,640	
Purge Systems		922	
7.0 RCS Propulsion			1,417
Foreward RCS		354	
Thrusters (15 pressure fed)	111		
Prop. tanks/empty(195 psia)	37		
He pressnt. tank(3000 psia)	113		
He pressurant	10		
Lines,manifolds,valves,etc.	82		
Aft RCS		1,064	
Thrusters (22 pressure fed)	397		
Prop. tanks/empty(195 psia)	86		
He pressnt. tank(3000 psia)	264		
He pressurant	23		
Lines,manifolds,valves,etc.	294		
8.0 OMS Propulsion			930
Engines (4 pump fed)		367	
Prop. tanks/empty(25 psia)		38	
He pressnt. tank(3000 psia)		226	
He pressurant (for low pressure tanks)		20	
Lines,manifolds,valves,etc.		279	
9.0 Primary Power			617
Fuel cells		396	
Reactant dewers		177	
Batteries		44	
10.0 Electrical Conversion & Dist.			3,616
Power conversion and distribution		1,406	
EMA controllers		276	
Circuitry & wiring		1,827	
EMA cabling		107	
11.0 Hydraulic Systems			0
12.0 Surface Control Actuation			853
Elevon EMAs		521	
Verticals EMAs		111	

Body Flap EMAs		221	
13.0 Avionics			1,600
14.0 Environmental Control			2,491
Personnel systems		0	
Equipment cooling		729	
Heat transport loop		1,087	
Heat rejection system		675	
Radiators	512		
Flash evaporators	163		
15.0 Personnel Equipment			0
Food, water, waste manag.		0	
Seats, etc.		0	
16.0 Dry Weight Margin (15%)			14,074
Dry Weight			**107,904**
17.0 Crew and Gear			0
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			856
OMS/RCS residuals		145	
Fore LH2 RCS residuals	2		
Fore LOX RCS residuals	9		
Aft LH2 RCS residuals	5		
Aft LOX RCS residuals	20		
LH2 OMS residuals	16		
LOX OMS residuals	94		
Main Propellant residuals		710	
LH2 residuals	141		
LOX residuals	570		
21.0 OMS/RCS Reserve Propellants			291
RCS reserves		72	
Fore LH2 reserves	4		
Fore LOX reserves	17		
Aft LH2 reserves	10		
Aft LOX reserves	40		
OMS reserves		219	
LH2 reserves	31		
LOX reserves	188		
Landed Weight			**129,050**
22.0 RCS Entry Propellants (ΔV = 25 fps)			239
Forward RCS Propellants		72	
LH2	14		
LOX	57		
Aft RCS Propellants		167	
LH2	33		
LOX	134		
Entry Weight			**129,289**
23.0 RCS/OMS Propellants (on-orbit)			2,670
Forward RCS Propellants		143	
LH2	29		
LOX	115		
Aft RCS Propellants		335	
LH2	67		
LOX	268		
OMS Propellants		2,191	
LH2	313		
LOX	1,878		
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			5,327
LH2 reserves and unusables		1,055	
LOX reserves and unusables		4,272	
26.0 Inflight Losses and Vents			1,293
Insertion Weight			**138,578**
27.0 Ascent Propellants			710,200
LH2 ascent		140,620	
LOX ascent		569,580	
Gross Liftoff Weight			**848,778**
28.0 Startup Losses			2,030
LH2 startup		290	
LOX startup		1,740	
Maximum Pre-launch Weight			**850,807**

olds

SERJ No CCaSw

No crew

Gross = 848778

Sep = 3072.6

ejector = $\frac{466828}{169193}$ = 2.759 Lox = - * 312.89 = 863.31

A_c = $\frac{153.12}{207}$ = .7397

Rocket = 655044 (69.7)

MR = $\frac{848778}{138564}$ = 6.126

LH2% = 1 - $\frac{569456}{710214}$ = .198

Wing% = $\frac{574596}{848778}$ = .677

W_{900} = $\frac{623432}{848778}$ = .735

Gross = 849115

Sep = 3073.4

ejector = $\frac{467013}{169193}$ = 2.760 Lox = ____ * 312.89 = 863.65

A_c = $\frac{153.18}{207}$ = .740

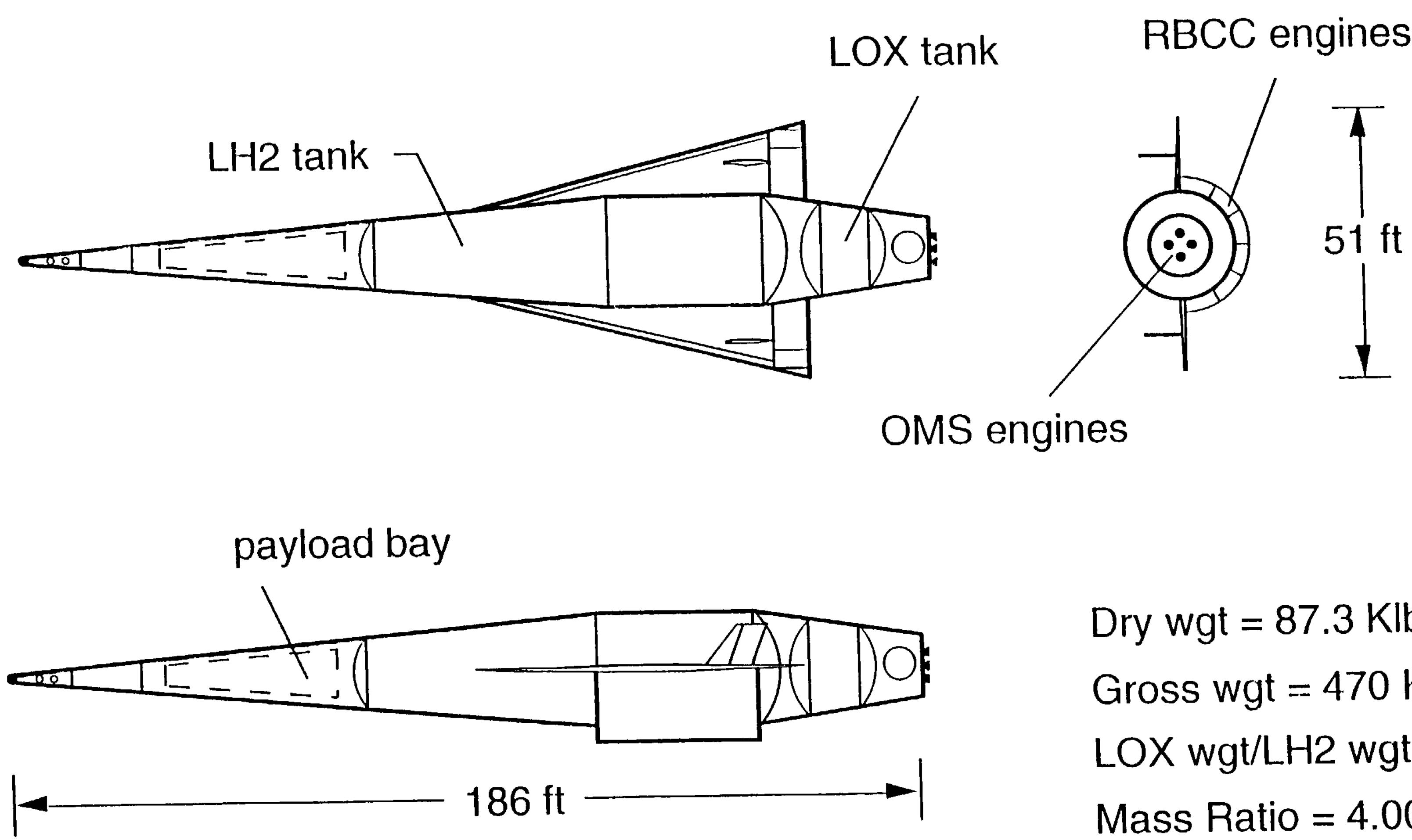
Rocket = 655304 (69.7)

MR = $\frac{849115}{138621.3}$ = 6.125

LH2% = 1 - $\frac{569687}{710494}$ = .198 ← Done

Wing% = $\frac{574978}{849115}$ = .677

W_{900} = $\frac{623687}{849115}$ = .735



Dry wgt = 87.3 Klb

Gross wgt = 470 Klb

LOX wgt/LH2 wgt = 2.80

Mass Ratio = 4.002

RBCC Single-stage-to-orbit Weights and Sizing
HRST Requirements Configuration
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf, Mtr =12, stag. heat rate = 350 BTU/sqft-sec

Directions:
Variables that can be changed are marked with bold underline.
Boxed variables are inputs that are products of other analyses
Adjust aft LH2 tank diameter until actual mass ratio matches required mass ratio

Vehicle Overall Parameters

Forebody cone half angle	5.00 deg
Aftbody cone half angle	7.50 deg
Mass Ratio (required)	4.002
LH2 ascent/total ascent prop	0.263
Payload (round trip)	20,000 lb
Forebody cone half angle	0.087 rads
Aftbody cone half angle	0.131 rads
Total vehicle length	186.04 ft
Mass Ratio (actual)	4.002
Gross Weight (actual)	469,726 lb
Dry Weight (actual)	87,254 lb
Landing c.g. (P/L in)	103.22 ft
Landing c.g. (P/L out)	116.33 ft
Gross Weight c.g. (P/L in)	145.74 ft

Eng. Thrust 62630

Nosecone Data

Nosecap Radius	0.50 ft
Structural unit weight	2.21 lb/ft2
Aft diameter	7.50 ft
Nosecone length	37.63 ft
Nosecone surface area	499.38 ft2
Nosecone volume	630.0 ft3

Crew Cabin Data

Crew cabin volume	0.0 ft3
Number of crew	0
Mission duration	0.00 days
Aft diameter	7.50 ft
Cabin length	0.00 ft

Payload Bay Data

PL bay volume	2500.0 ft3
PL bay struct. unit weight	2.21 lb/ft2
PL bay doors str. unit weight	3.50 lb/ft2
PL bay length	30.24 ft
PL bay doors surface area	483.74 ft2
PL bay area (exluding doors)	684.61 ft2

LH2 Main Tank Data

Eng. Exit 33.92

Aft diameter (incl. insulation)	20.75 ft
Tank structural unit weight	0.26 lb/ft3
Tank insulation unit weight	0.26 lb/ft2
Cryo insulation thickness	0.17 ft
Tank ullage volume/total vol.	0.0425
LH2 density	4.43 lb/ft3
Tank dome height/radius	0.707
Fore diameter	13.63 ft
Fore dome height	4.82 ft
Aft dome height	7.34 ft
Tank surface area (total)	4955.1 ft2
Tank volume (total)	22122.1 ft3
Tank length	86.11 ft

LOX Main Tank Data

Tank structural unit weight	0.33 lb/ft3
Tank insulation unit weight	0.20 lb/ft2
Cryo insulation thickness	0.13 ft
Tank ullage volume/total vol.	0.0425
LOX density	71.2 lb/ft3
Tank dome height/radius	0.707
Aft LH2 tank dome to LOX dist.	3.00 ft
Fore diameter	16.49 ft
Fore dome height	5.83 ft
Aft diameter	11.61 ft
Aft dome height	4.10 ft
Tank surface area (total)	1208.60 ft2
Tank volume (total)	3868.1 ft3
Tank length	28.48 ft

Tailcone/Base Data

Base diam/LH2 tank max diam	0.5
Tailcone struct. unit weight	2.21 lb/ft2
Base structural unit weight	1.99 lb/ft2
Base diameter	10.38 ft
Base area	84.54 ft2
Tailcone surface area	1943.08 ft2
Tailcone length	39.40 ft
Aft compartment volume	155.9 ft3

Engine Data

Vehicle liftoff T/W	1.20
Total Engine length	33.29 ft
Inlet section length	23.49 ft
AB/Rocket Trans. Mach #	12.00
Engine T/W (inst., no marg.)	23.50
Engine Isp (sea level)	420.8 sec
Liftoff mixture (LOX/LH2)	6.00
Ejectors weight %	0.37
Fan/GG/stowage weight %	0.00
Cowl wrap angle	180.00 deg
Cowl struts separation angle	20.00 deg
Cowl unit weight(non-inlet)	2.21 lb/ft2
Inlet section unit wgt (top)	2.75 lb/ft2
Inlet height	4.50 ft
Engine inlet ref. area	178.48 ft2
Cowl surface area	1320.37 ft2
Cowl leading edge length	46.73 ft
Max. inlet hgt. (shock on lip)	4.52 ft

Uninstl T/W 35.45

Eng. Inlet 19.83

TPS Data

Nose cap active cooling weight	150.00 lb
Active cooling weight/length	2.70 lb/ft
Active cooling weight/area	3.50 lb/ft2
Tailcone active cooled length	2.00 ft
ACC area/body area	0.40
ACC area/wing&tail area	0.15
ACC unit weight	2.00 lb/ft2
TUFI area/body area	0.33
TUFI area/wing&tail area	0.42
TUFI unit weight	0.74 lb/ft2
TABI area/body area	0.00
TABI unit weight	0.25 lb/ft2
Body & cowl passive TPS area	8175.3 ft2
Wing (top&btm) wetted area	1903.58 ft2
Tail wetted area (both)	258.09 ft2
Nozzle exit active TPS area	128.74 ft2

Wing/Tail Data

Wing leading edge sweep	76.00 deg
Wing Aspect ratio	1.00
Landing weight/Sref	42.000
Landing speed	200 knts
Theo. wing c.p. loc. (%L ref)	68.0%
Tail area(ea.)/wing ref. area	0.025
Wing thickness ratio	0.04
Cruise norm. force/gross wg	0.402
Wing Reference area	2580.9 ft2
Wing exposed planform	951.8 ft2
Tail planform area(each)	64.5 ft2
Wingspan	50.80 ft
Wing T.E. to body base length	25.67 ft
Wing exp. leading edge (ea.)	69.33 ft
Span through half-chords	113.60 ft
Theoretical center chord	101.60 ft
Thickness of expos. root chord	2.40 ft
Body diam@exp wing apex	17.26 ft
Landing wing loading	42.0 lb/ft2
Design(max.) wing limit load	321,011 lb

RCS Data

Forward RCS on-orbit ΔV	15 ft/sec
Aft RCS on-orbit ΔV	35 ft/sec
RCS Isp	420.0 sec
RCS mixture ratio (O/F)	4

Forward RCS

Total forward RCS LH2 prop.	41.55 lb
Forward RCS LH2 tank vol.	9.8 ft3
Forward RCS LH2 tank diam.	2.66 ft
Total forward RCS LOX prop.	166.19 lb
Forward RCS LOX tank vol.	2.5 ft3
Forward RCS LOX tank diam.	1.67 ft
Forward He tank diameter	1.78 ft

Aft RCS

Total aft RCS LH2 prop.	97.01 lb
Aft RCS LH2 tank vol.	23.0 ft3
Aft RCS LH2 tank diam.	3.53 ft
Total aft RCS LOX prop.	388.02 lb
Aft RCS LOX tank vol.	5.7 ft3
AFT RCS LOX tank diam.	2.22 ft
Aft He tank diameter	2.36 ft

OMS Data

OMS on-orbit ΔV (incl circ.)	625 ft/sec
OMS Isp	462.0 sec
OMS mixture ratio (O/F)	6
Total OMS LH2 prop.	765.51 lb
OMS LH2 tank vol.	181.4 ft3
OMS LH2 tank diam.	7.02 ft
Total OMS LOX prop.	4593.07 lb
OMS LOX tank vol.	67.7 ft3
OMS LOX tank diam.	5.06 ft
Aft He tank diameter	3.06 ft

	M3	ML	M12
Thrust	493k	275k	170k
Isp	3500	2750	1630

M12 Robust
HRST Requirements
No crew or cabin

Vehicle Weight Statement
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf, Mtr =12, stag. heat rate = 350 BTU/sqft-sec

	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			3,814
2.0 Tail Group			845
3.0 Body Group			28,292
4.0 Thermal Protection			10,982
5.0 Landing Gear			3,252
6.0 Main Propulsion (less cowl)			18,623
7.0 RCS Propulsion			1,056
8.0 OMS Propulsion			1,146
9.0 Primary Power			600
10.0 Electrical Conversion & Dist.			2,801
11.0 Hydraulic systems			0
12.0 Surface Control Actuation			531
13.0 Avionics			1,600
14.0 Environmental control			2,331
15.0 Personnel Equipment			0
16.0 Dry Weight Margin (15%)			11,381
Dry Weight			**87,254**
17.0 Crew and Gear			0
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			615
21.0 OMS/RCS Reserve Propellants			526
Landed Weight			**108,396**
22.0 RCS Entry Propellants (ΔV = 25 fps)			200
Entry Weight			**108,596**
23.0 RCS/OMS Propellants (on-orbit)			5,062
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			2,643
26.0 Inflight Losses and Vents			1,086
Insertion Weight			**117,386**
27.0 Ascent Propellants			352,340
Gross Liftoff Weight			**469,726**
28.0 Startup Losses			2,679
Maximum Pre-launch Weight			**472,405**

Vehicle Weight Statement
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf, Mtr =12, stag. heat rate = 350 BTU/sqft-sec

	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			3,814
Exposed wing		3,349	
Carry through		465	
2.0 Tail Group			845
3.0 Body Group			28,292
Nosecone		1,104	
Crew Cabin		0	
Payload Bay Structure		6,206	
Structure	1,513		
P/L Bay Doors	1,693		
P/L Accommodations	3,000		
LH2 Tank		6,929	
Tank Structure	5,641		
Tank Insulation	1,288		
LOX Tank		1,504	
Tank Structure	1,269		
Tank Insulation	236		
Aft Body		4,462	
Tail cone	4,294		
Base	168		
Cowl		8,086	
Cowl ring	5,983		
Cowl struts	2,102		
4.0 Thermal Protection			10,982
Active Cooling		1,101	
Nosecap	150		
Cowl leading edge	126		
Wing leading edges	374		
Engine nozzle exit	451		
Advanced Carbon/Carbon		7,200	
Body/cowl	6,532		
Wing/tails	668		
TUFI (tiles)		2,681	
Body/cowl	2,005		
Wing/tails	676		
TABI (blankets)		0	
Body/cowl	0		
Wing/tails	0		
5.0 Landing Gear			3,252
Nosegear		488	
Main gear		2,764	
6.0 Main Propulsion (less cowl)			18,623
RBCC Engines		15,900	
Ejector rockets (incl. pumps)	5,883		
Diff./Comb./Noz. (w/ cooling)	10,017		
Fan/gas generator/storage	0		
Pressurization and feed systems		2,165	
Purge Systems		558	
7.0 RCS Propulsion			1,056
Foreward RCS		268	
Thrusters (15 pressure fed)	77		
Prop. tanks/empty(195 psia)	31		
He pressnt. tank(3000 psia)	95		
He pressurant	8		
Lines,manifolds,valves,etc.	57		
Aft RCS		788	
Thrusters (22 pressure fed)	273		
Prop. tanks/empty(195 psia)	73		
He pressnt. tank(3000 psia)	222		
He pressurant	19		
Lines,manifolds,valves,etc.	202		
8.0 OMS Propulsion			1,146
Engines (4 pump fed)		309	
Prop. tanks/empty(25 psia)		81	
He pressnt. tank(3000 psia)		481	
He pressurant (for low pressure tanks)		42	
Lines,manifolds,valves,etc.		234	
9.0 Primary Power			600
Fuel cells		396	
Reactant dewers		177	
Batteries		27	
10.0 Electrical Conversion & Dist.			2,801
Power conversion and distribution		1,406	
EMA controllers		172	
Circuitry & wiring		1,169	
EMA cabling		54	
11.0 Hydraulic systems			0
12.0 Surface Control Actuation			531
Elevon EMAs		438	

Verticals EMAs		93	
13.0 Avionics			1,600
14.0 Environmental control			2,331
Personnel systems		0	
Equipment cooling		729	
Heat transport loop		927	
Heat rejection system		675	
Radiators	512		
Flash evaporators	163		
15.0 Personnel Equipment			0
Food, water, waste manag.		0	
Seats, etc.		0	
16.0 Dry Weight Margin (15%)			11,381
Dry Weight			**87,254**
17.0 Crew and Gear			0
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			615
OMS/RCS residuals		263	
Fore LH2 RCS residuals	2		
Fore LOX RCS residuals	7		
Aft LH2 RCS residuals	4		
Aft LOX RCS residuals	17		
LH2 OMS residuals	33		
LOX OMS residuals	200		
Main Propellant residuals		352	
LH2 residuals	93		
LOX residuals	260		
21.0 OMS/RCS Reserve Propellants			526
RCS reserves		60	
Fore LH2 reserves	4		
Fore LOX reserves	14		
Aft LH2 reserves	8		
Aft LOX reserves	34		
OMS reserves		466	
LH2 reserves	67		
LOX reserves	399		
Landed Weight			**108,396**
22.0 RCS Entry Propellants (ΔV = 25 fps)			200
Forward RCS Propellants		60	
LH2	12		
LOX	48		
Aft RCS Propellants		140	
LH2	28		
LOX	112		
Entry Weight			**108,596**
23.0 RCS/OMS Propellants (on-orbit)			5,062
Forward RCS Propellants		121	
LH2	24		
LOX	96		
Aft RCS Propellants		281	
LH2	56		
LOX	225		
OMS Propellants		4,660	
LH2	666		
LOX	3,994		
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			2,643
LH2 reserves and unusables		695	
LOX reserves and unusables		1,948	
26.0 Inflight Losses and Vents			1,086
Insertion Weight			**117,386**
27.0 Ascent Propellants			352,340
LH2 ascent		92,665	
LOX ascent		259,674	
Gross Liftoff Weight			**469,726**
28.0 Startup Losses			2,679
LH2 startup		383	
LOX startup		2,296	
Maximum Pre-launch Weight			**472,405**

Robust vehicle (no crew or cabin)

Gross = 481 775

$A_c = \frac{180.6}{207} = .8725$

ejector : $\frac{64237}{66977} * 9 = 8.632$

Lox = " * 1209 = 1159.5

S_{ref} = 2628.6

wst_nacc
value2

$MR = \frac{481775}{120346} = 4.003$

LH2% $1 - \frac{266353}{361429} = .263$

Wing% $= \frac{194330}{481775} = .403$

Gross = 470328

$A_c = \frac{178.55}{207} = .8626$

ejector : $\frac{62710}{66977} * 9 = 8.427$

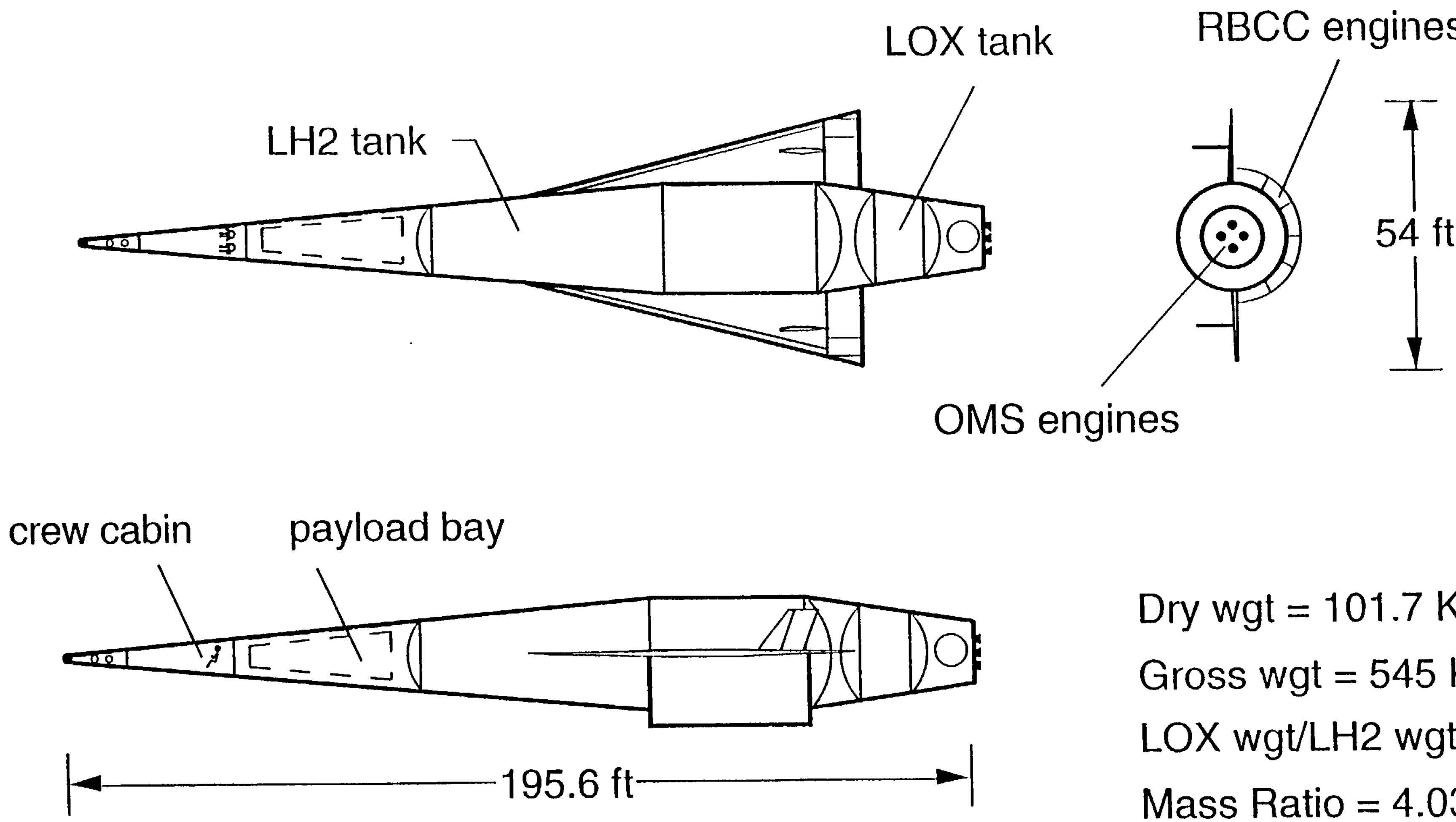
Lox = " * 1209 = 1132.0

S_{ref} = 2582.9

$MR = \frac{470328}{117552} = 4.001$

LH2% : $1 - \frac{260158}{352776} = .263$

Wing% : $\frac{188890}{470328} = .402$



Dry wgt = 101.7 Klb

Gross wgt = 545 Klb

LOX wgt/LH2 wgt = 2.75

Mass Ratio = 4.030

RBCC Single-stage-to-orbit Weights and Sizing
HRST Requirements Configuration
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf, Mtr =12, stag. heat rate = 350 BTU/sqft-sec

Directions:
Variables that can be changed are marked with bold underline.
Boxed variables are inputs that are products of other analyses
Adjust aft LH2 tank diameter until actual mass ratio matches required mass ratio

Vehicle Overall Parameters

Forebody cone half angle	5.00 deg
Aftbody cone half angle	7.50 deg
Mass Ratio (required)	4.030
LH2 ascent/total ascent prop	0.287
Payload (round trip)	20,000 lb
Forebody cone half angle	0.087 rads
Aftbody cone half angle	0.131 rads
Total vehicle length	195.61 ft
Mass Ratio (actual)	4.030
Gross Weight (actual)	545,189 lb
Dry Weight (actual)	101,686 lb
Landing c.g. (P/L in)	107.27 ft
Landing c.g. (P/L out)	118.60 ft
Gross Weight c.g. (P/L in)	152.13 ft

Eng. Thrust 72692

Nosecone Data

Nosecap Radius	0.50 ft
Structural unit weight	2.21 lb/ft2
Aft diameter	3.50 ft
Nosecone length	14.77 ft
Nosecone surface area	102.88 ft2
Nosecone volume	62.9 ft3

Crew Cabin Data

Crew cabin volume	750.0 ft3
Number of crew	2
Mission duration	2.00 days
Aft diameter	8.16 ft
Cabin length	26.66 ft

Payload Bay Data

PL bay volume	2500.0 ft3
PL bay struct. unit weight	2.21 lb/ft2
PL bay doors str. unit weight	3.50 lb/ft2
PL bay length	27.84 ft
PL bay doors surface area	465.32 ft2
PL bay area (exluding doors)	673.93 ft2

LH2 Main Tank Data

Aft diameter (incl. insulation)	22.01 ft
Tank structural unit weight	0.26 lb/ft2
Tank insulation unit weight	0.26 lb/ft2
Cryo insulation thickness	0.17 ft
Tank ullage volume/total vol.	0.0425
LH2 density	4.43 lb/ft3
Tank dome height/radius	0.707
Fore diameter	13.90 ft
Fore dome height	4.91 ft
Aft dome height	7.78 ft
Tank surface area (total)	5563.0 ft2
Tank volume (total)	26125.9 ft3
Tank length	92.34 ft

Eng. Exit 36.67

LOX Main Tank Data

Tank structural unit weight	0.32 lb/ft2
Tank insulation unit weight	0.20 lb/ft2
Cryo insulation thickness	0.13 ft
Tank ullage volume/total vol.	0.0425
LOX density	71.2 lb/ft3
Tank dome height/radius	0.707
Aft LH2 tank dome to LOX dist.	3.00 ft
Fore diameter	17.54 ft
Fore dome height	6.20 ft
Aft diameter	12.84 ft
Aft dome height	4.54 ft
Tank surface area (total)	1302.58 ft2
Tank volume (total)	4475.7 ft3
Tank length	28.57 ft

Tailcone/Base Data

Base diam/LH2 tank max diam	0.5
Tailcone struct. unit weight	2.21 lb/ft2
Base structural unit weight	1.99 lb/ft2
Base diameter	11.00 ft
Base area	95.09 ft2
Tailcone surface area	2185.42 ft2
Tailcone length	41.79 ft
Aft compartment volume	388.8 ft3

Engine Data

Vehicle liftoff T/W	1.20
Total Engine length	33.29 ft
Inlet section length	23.49 ft
AB/Rocket Trans. Mach #	12.00
Engine T/W (inst., no marg.)	23.50
Engine Isp (sea level)	420.8 sec
Liftoff mixture (LOX/LH2)	6.00
Ejectors weight %	0.37
Fan/GG/stowage weight %	0.00
Cowl wrap angle	180.00 deg
Cowl struts separation angle	20.00 deg
Cowl unit weight(non-inlet)	2.21 lb/ft2
Inlet section unit wgt (top)	2.75 lb/ft2
Inlet height	4.50 ft
Engine inlet ref. area	187.36 ft2
Cowl surface area	1386.05 ft2
Cowl leading edge length	48.70 ft
Max. inlet hgt. (shock on lip)	4.80 ft

Uninstl T/W 33.03

Eng Inlet 20.82

TPS Data

Nose cap active cooling weight	150.00 lb
Active cooling weight/length	2.70 lb/ft
Active cooling weight/area	3.50 lb/ft2
Tailcone active cooled length	2.00 ft
ACC area/body area	0.40
ACC area/wing&tail area	0.14
ACC unit weight	2.00 lb/ft2
TUFI area/body area	0.34
TUFI area/wing&tail area	0.43
TUFI unit weight	0.74 lb/ft2
TABI area/body area	0.00
TABI unit weight	0.25 lb/ft2
Body & cowl passive TPS area	9035.6 ft2
Wing (top&btm) wetted area	2251.93 ft2
Tail wetted area (both)	297.37 ft2
Nozzle exit active TPS area	136.63 ft2

Wing/Tail Data

Wing leading edge sweep	76.00 deg
Wing Aspect ratio	1.00
Landing weight/Sref	42.000
Landing speed	200 knts
Theo. wing c.p. loc. (%l_ref)	60.0%
Tail area(ea.)/wing ref. area	0.025
Wing thickness ratio	0.04
Cruise norm. force/gross wgt	0.419
Wing Reference area	2973.7 ft2
Wing exposed planform	1126.0 ft2
Tail planform area(each)	74.3 ft2
Wingspan	54.53 ft
Wing T.E. to body base length	26.24 ft
Wing exp. leading edge (ea.)	76.19 ft
Span through half-chords	121.94 ft
Theoretical center chord	109.06 ft
Thickness of expos. root chord	2.60 ft
Body diam @ exp wing apex	17.87 ft
Landing wing loading	42.0 lb/ft2
Design(max.) wing limit load	388,338 lb

RCS Data

Forward RCS on-orbit ΔV	15 ft/sec
Aft RCS on-orbit ΔV	35 ft/sec
RCS Isp	420.0 sec
RCS mixture ratio (O/F)	4

Forward RCS

Total forward RCS LH2 prop.	47.87 lb
Forward RCS LH2 tank vol.	11.3 ft3
Forward RCS LH2 tank diam.	2.79 ft
Total forward RCS LOX prop.	191.49 lb
Forward RCS LOX tank vol.	2.8 ft3
Forward RCS LOX tank diam.	1.75 ft
Forward He tank diameter	1.87 ft

Aft RCS

Total aft RCS LH2 prop.	111.77 lb
Aft RCS LH2 tank vol.	26.5 ft3
Aft RCS LH2 tank diam.	3.70 ft
Total aft RCS LOX prop.	447.09 lb
Aft RCS LOX tank vol.	6.6 ft3
AFT RCS LOX tank diam.	2.33 ft
Aft He tank diameter	2.48 ft

OMS Data

OMS on-orbit ΔV (incl circ.)	825 ft/sec
OMS Isp	462.0 sec
OMS mixture ratio (O/F)	6
Total OMS LH2 prop.	882.04 lb
OMS LH2 tank vol.	209.1 ft3
OMS LH2 tank diam.	7.36 ft
Total OMS LOX prop.	5292.22 lb
OMS LOX tank vol.	78.0 ft3
OMS LOX tank diam.	5.30 ft
Aft He tank diameter	3.20 ft

H12 Robust
HRST Requirements
with crew.

Vehicle Weight Statement
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf. Mtr =12. stag. heat rate = 350 BTU/sqft-sec

	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			4,674
2.0 Tail Group			986
3.0 Body Group			31,636
4.0 Thermal Protection			12,187
5.0 Landing Gear			3,747
6.0 Main Propulsion (less cowl)			22,625
7.0 RCS Propulsion			1,252
8.0 OMS Propulsion			1,321
9.0 Primary Power			958
10.0 Electrical Conversion & Dist.			2,901
11.0 Hydraulic systems			0
12.0 Surface Control Actuation			612
13.0 Avionics			2,200
14.0 Environmental control			2,521
15.0 Personnel Equipment			802
16.0 Dry Weight Margin (15%)			13,263
Dry Weight			**101,686**
17.0 Crew and Gear			1,890
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			713
21.0 OMS/RCS Reserve Propellants			606
Landed Weight			**124,896**
22.0 RCS Entry Propellants (ΔV = 25 fps)			231
Entry Weight			**125,127**
23.0 RCS/OMS Propellants (on-orbit)			5,832
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			3,074
26.0 Inflight Losses and Vents			1,251
Insertion Weight			**135,284**
27.0 Ascent Propellants			409,905
Gross Liftoff Weight			**545,189**
28.0 Startup Losses			3,109
Maximum Pre-launch Weight			**548,298**

Vehicle Weight Statement
5 degree cone, VTO RBCC SSTO with engine #10
q = 2000 psf, Mtr =12, stag. heat rate = 350 BTU/sqft-sec

	Level 3	Level 2	Level 1
1.0 Wing Group			4,674
Exposed wing		4,080	
Carry through		594	
2.0 Tail Group			986
3.0 Body Group			31,636
Nosecone		227	
Crew Cabin		2,058	
Payload Bay Structure		6,118	
Structure	1,489		
P/L Bay Doors	1,629		
P/L Accommodations	3,000		
LH2 Tank		8,108	
Tank Structure	6,662		
Tank Insulation	1,446		
LOX Tank		1,722	
Tank Structure	1,468		
Tank Insulation	254		
Aft Body		5,019	
Tail cone	4,830		
Base	189		
Cowl		8,383	
Cowl ring	6,281		
Cowl struts	2,102		
4.0 Thermal Protection			12,187
Active Cooling		1,171	
Nosecap	150		
Cowl leading edge	132		
Wing leading edges	411		
Engine nozzle exit	478		
Advanced Carbon/Carbon		7,934	
Body/cowl	7,204		
Wing/tails	730		
TUFI (tiles)		3,082	
Body/cowl	2,274		
Wing/tails	808		
TABI (blankets)		0	
Body/cowl	0		
Wing/tails	0		
5.0 Landing Gear			3,747
Nosegear		562	
Main gear		3,185	
6.0 Main Propulsion (less cowl)			22,625
RBCC Engines		19,456	
Ejector rockets (incl. pumps)	7,199		
Diff./Comb./Noz. (w/ cooling)	12,257		
Fan/gas generator/storage	0		
Pressurization and feed systems		2,512	
Purge Systems		657	
7.0 RCS Propulsion			1,252
Foreward RCS		316	
Thrusters (15 pressure fed)	93		
Prop. tanks/empty(195 psia)	36		
He pressnt. tank(3000 psia)	109		
He pressurant	10		
Lines,manifolds,valves,etc.	69		
Aft RCS		936	
Thrusters (22 pressure fed)	330		
Prop. tanks/empty(195 psia)	84		
He pressnt. tank(3000 psia)	255		
He pressurant	22		
Lines,manifolds,valves,etc.	245		
8.0 OMS Propulsion			1,321
Engines (4 pump fed)		355	
Prop. tanks/empty(25 psia)		93	
He pressnt. tank(3000 psia)		554	
He pressurant (for low pressure tanks)		48	
Lines,manifolds,valves,etc.		270	
9.0 Primary Power			958
Fuel cells		396	
Reactant dewers		531	
Batteries		32	
10.0 Electrical Conversion & Dist.			2,901
Power conversion and distribution		1,406	
EMA controllers		198	
Circuitry & wiring		1,231	
EMA cabling		66	
11.0 Hydraulic systems			0
12.0 Surface Control Actuation			612

Elevon EMAs		505	
Verticals EMAs		107	
13.0 Avionics			2,200
14.0 Environmental control			2,521
Personnel systems		141	
Equipment cooling		729	
Heat transport loop		976	
Heat rejection system		675	
Radiators	512		
Flash evaporators	163		
15.0 Personnel Equipment			802
Food, water, waste manag.		502	
Seals, etc.		300	
16.0 Dry Weight Margin (15%)			13,263
Dry Weight			**101,686**
17.0 Crew and Gear			1,890
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			713
OMS/RCS residuals		303	
Fore LH2 RCS residuals	2		
Fore LOX RCS residuals	8		
Aft LH2 RCS residuals	5		
Aft LOX RCS residuals	19		
LH2 OMS residuals	38		
LOX OMS residuals	230		
Main Propellant residuals		410	
LH2 residuals	109		
LOX residuals	300		
21.0 OMS/RCS Reserve Propellants			606
RCS reserves		69	
Fore LH2 reserves	4		
Fore LOX reserves	17		
Aft LH2 reserves	10		
Aft LOX reserves	39		
OMS reserves		537	
LH2 reserves	77		
LOX reserves	460		
Landed Weight			**124,896**
22.0 RCS Entry Propellants (ΔV = 25 fps)			231
Forward RCS Propellants		69	
LH2	14		
LOX	55		
Aft RCS Propellants		162	
LH2	32		
LOX	129		
Entry Weight			**125,127**
23.0 RCS/OMS Propellants (on-orbit)			5,832
Forward RCS Propellants		139	
LH2	28		
LOX	111		
Aft RCS Propellants		324	
LH2	65		
LOX	259		
OMS Propellants		5,369	
LH2	767		
LOX	4,602		
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			3,074
LH2 reserves and unusables		821	
LOX reserves and unusables		2,253	
26.0 Inflight Losses and Vents			1,251
Insertion Weight			**135,284**
27.0 Ascent Propellants			409,905
LH2 ascent		109,445	
LOX ascent		300,460	
Gross Liftoff Weight			**545,189**
28.0 Startup Losses			3,109
LH2 startup		444	
LOX startup		2,665	
Maximum Pre-launch Weight			**548,298**

New POST trajectory calcs for Robust Design

nrst.inp
rasp12

$MR = \frac{502289}{125575} = 4.00$

$opcLH2/Total = 1 - \frac{277887}{376714} = .262$

$Wing\% = \frac{209625}{502289} = .417$

$\frac{T}{W_e + C} = \left(\frac{T}{W}\right)_i$

$\left(\frac{T}{W_e}\right)_w$

$\frac{T}{W_e} = \frac{\left(\frac{T}{W}\right)_i (W_e + C)}{W_e}$

$\left(\frac{T}{W}\right)_w = \left(\frac{T}{W}\right)_i * \left(1 + \frac{C}{W_e}\right)$

Gross = 574103

spreadsheet

A_c ratio = .939.

ejector ratio = 1.143 * 9 (+ rocket)

Lox rate = 1.143 * 1209

Sref = 3154.4

$MR = \frac{574103}{141923} = 4.045$

$LH2\%/W_P = 1 - \frac{316657}{432180} = .267$

$Wing\% = \frac{249846}{574103} = .435$

Gross = 590871

A_c ratio $= \frac{196.5'}{207} = .949$

ejector = $\overline{.977}$ * 9 (rocket). 10.586

Lox rate = 1.176 * 1209

Sref = 3210.7

check
POST
output

$MR = \frac{590871}{146007} = 4.047$

$\%LH2 = 1 - \frac{325450}{444864} = .268$

$Wing\% = \frac{256437}{590871} = .434$

← changed payload volume to 2500 ft³

Robust
Vab#2

Gross = 552303

$A_c = \frac{188.31}{207} = .910$

ejector rockets : $\frac{73640}{66977} \times 9 = 9.895$ (and rockets)

wox = " $\times 1209 = 1329.3$

Sref = 3001.1

POST

$MR = \frac{552303}{137429} = 4.019$

$LH2\% = 1 - \frac{304887}{414874} = .265$

$Wing\% = \frac{228920}{552303} = .414$

Gross = 539132 ← error in last A_c?

$A_c = \frac{186.33}{207} = .900$

ejector = $\frac{71884}{66977} \times 9 = 9.659$

wox = " $\times 1209 = 1297.6$

Sref = 2949.8

$MR = \frac{539132}{133759} = 4.03$

$LH2\% = 1 - \frac{297345}{405373} = .266$

$Wing\% = \frac{225819}{539132} = .419$

Gross = 544569

$A_c = \frac{187.11}{207} = .904$

ejector = $\frac{72609}{66977} \times 9 = 9.757$

wox = " $\times 1209 = 1310.7$

Sref = 2969.9

$MR = \frac{544569}{135145} = 4.03$

$LH2\% = 1 - \frac{300200}{409424} = .267$

→ Done.

HRST Vehicle w/RBCC Weights and Sizing

HTO sled launch RBCC with engine #11
V launch = 800 fps, q = 2000 psf, Mr = 6

Directions:
Variables that can be changed are marked with bold underline.
Boxed variables are inputs that are products of other analyses
Adjust ascent propellant until actual mass ratio matches required mass ratio

Vehicle Overall Parameters

Ascent Propellant (iterate)	831,000 lb	
Vehicle diameter (max.)	20.78 ft	
Mass Ratio (required)	6.125	
LH2 ascent/total ascent prop	0.198	
Payload (round-trip)	20,000 lb	
Mass Ratio (actual)	6.125	
Total vehicle length	238.73 ft	
Fineness ratio (targ. 11.5)	11.49	
Gross Weight (actual)	993,134 lb	
Dry Weight (actual)	127,755 lb	
Landing c.g. (P/L in)	174.45 ft	73.07%
Landing c.g. (P/L out)	172.87 ft	72.41%
Gross Weight c.g. (P/L in)	185.19 ft	

Nosecone Data

Nosecap radius	0.75 ft
Structural unit weight	2.21 lb/ft2
Nosecone angle	6.50 deg
Total forebody length	85.34 ft
Nosecone length	12.80 ft
Nosecone aft diameter	4.42 ft
Nosecone surface area	119.74 ft2
Nosecone volume	95.1 ft3

Crew Cabin Data

Number of crew	2
Mission duration	2.00 days
Cabin length	12.00 ft

Payload Bay/Intertank Data

PL bay volume	2500.0 ft3
PL bay struct. unit weight	2.21 lb/ft2
PL bay doors str. unit weight	3.50 lb/ft2
PL bay length	7.38 ft
Margin to domes	1.50 ft
Payload section length (total)	10.38 ft
PL bay doors surface area	200.00 ft2
PL bay area (exluding doors)	1422.47 ft2

LH2 Main Tank Data

Tank structural unit weight	0.26 lb/ft3
Tank insulation unit weight	0.26 lb/ft2
Cryo insulation thickness	0.17 ft
Tank ullage volume/total vol.	0.0425
LH2 density	4.43 lb/ft3
Tank dome height/radius	0.707
Tank volume (total)	39129.2 ft3
LH2 tank length (cyl. sect.)	85.70 ft
LH2 tank length (cone sect.)	57.16 ft
Fore dome diameter	7.42 ft
Fore dome height	2.62 ft
Aft dome diameter	20.44 ft
Aft dome height	7.23 ft
Total tank length	152.72 ft
Tank surface area (total)	8624.3 ft2

LOX Main Tank Data

Tank structural unit weight	0.33 lb/ft3
Tank insulation unit weight	0.20 lb/ft2
Cryo insulation thickness	0.13 ft
Tank ullage volume/total vol.	0.0425
LOX density	71.2 lb/ft3
Tank dome height/radius	0.707
Tank volume (total)	9871.0 ft3
LOX tank length (cyl. section)	20.16 ft
Fore dome height	7.26 ft
Aft dome height	7.26 ft
Total tank length	34.67 ft
Tank surface area (total)	2373.96 ft2

Tailcone/Base Data

Aftbody cone half angle	10.00 deg
Base diam/fuselage diam	0.7
Tailcone struct. unit weight	2.21 lb/ft2
Base structural unit weight	1.99 lb/ft2
Tailcone length (cyl. section)	5.00 ft
Tailcone length (total)	22.67 ft
Base diameter	14.54 ft
Base area	166.10 ft2
Tailcone surface area	1321.90 ft2
Aft compartment volume	4428.3 ft3

RBCC Engine Data

Vehicle T/W (SLS)	0.55
AB/Rocket Trans. Mach #	6.00
Engine T/W (instl, no marg)	23.50
Engine Isp (sea level)	460.0 sec
Liftoff mixture (LOX/LH2)	6.00
Engine length/diameter	5.0
Ejectors weight %	0.27
Fan/GG weight %	0.28
Req'd thrust (SLS, both)	546,224 lb
Inlet/capture area (both)	179.16 ft2
Engine diameter (ea.)	10.68 ft
Total engine length (ea.)	53.40 ft
Inlet section length (ea.)	32.04 ft

Rocket Engine Data

Transition Wgt/Gross Wgt.	0.74
Vehicle T/W @ transition	1.05
Engine T/W (instl, no marg)	70.00
Rocket thrust (vac.)	766,451 lb
Isp (vac)	455.0 sec
Mixture ratio (LOX/LH2)	6.00
Nozzle exit area	81.54 ft2

TPS Data

Nose cap active cooling weight	0.00 lb
Active cooling weight/length	0.00 lb/ft
Active cooling weight/area	0.00 lb/ft2
ACC area/body area	0.05
ACC area/wing&tail area	0.05
ACC unit weight	2.00 lb/ft2
TUFI area/body area	0.20
TUFI area/wing&tail area	0.55
TUFI unit weight	0.74 lb/ft2
TABI area/body area	0.75
TABI unit weight	0.25 lb/ft2
Approx. body passive TPS area	15581.1 ft2
Wing (top&btm.) wetted area	3784.88 ft2
Tail wetted area (both)	359.49 ft2

Wing/Tail Data

Wing leading edge sweep	68.00 deg
Landing weight/Sref	42.000
Landing speed	200. knts
Tail area(on 1/wing ref. area	0.025
Wing thickness ratio	0.05
Wing taper ratio	0.10
Cruise norm. force/gross wgt	0.677
Wing Reference area	3594.9 ft2
Wing Aspect ratio	1.322
Wing exposed planform	1892.4 ft2
Tail planform area(each)	89.9 ft2
Wingspan	68.95 ft
Theoretical center chord	94.80 ft
Tip chord	9.48 ft
Exposed root chord	69.09 ft
Wing exp. leading edge (ea.)	64.29 ft
Span through half-chords	109.70 ft
Thickness of expos. root chord	3.45 ft
Design(max.) wing limit load	######## 1,142,998
Required landing Cl	0.3721

Body Flap Data

Body flap length	0.00 ft
Body flap unit weight	2.21 lb/ft2
Body flap planform area	166.20 ft2
Body flap area (top&btm)	332.40 ft2

OMS Data

OMS on-orbit ΔV (deorbit)	250 ft/sec
OMS Isp	462.0 sec
OMS mixture ratio (O/F)	6
Total OMS LH2 prop.	421.15 lb
OMS LH2 tank vol.	99.8 ft3
OMS LH2 tank diam.	5.76 ft
Total OMS LOX prop.	2526.89 lb
OMS LOX tank vol.	37.3 ft3
OMS LOX tank diam.	4.14 ft
Aft He tank diameter	2.50 ft

RCS Data

Forward RCS on-orbit ΔV	15 ft/sec
Aft RCS on-orbit ΔV	35 ft/sec
RCS Isp	420.0 sec
RCS mixture ratio (O/F)	4

Forward RCS

Total forward RCS LH2 prop.	57.87 lb
Forward RCS LH2 tank vol.	13.7 ft3
Forward RCS LH2 tank diam.	2.97 ft
Total forward RCS LOX prop.	231.49 lb
Forward RCS LOX tank vol.	3.4 ft3
Forward RCS LOX tank diam.	1.87 ft
Forward He tank diameter	1.99 ft

Aft RCS

Total aft RCS LH2 prop.	135.12 lb
Aft RCS LH2 tank vol.	32.0 ft3
Aft RCS LH2 tank diam.	3.94 ft
Total aft RCS LOX prop.	540.48 lb
Aft RCS LOX tank vol.	8.0 ft3
AFT RCS LOX tank diam.	2.48 ft
Aft He tank diameter	2.64 ft

SERJ with crew.

Vehicle Weight Statement
HTO sled launch RBCC with engine #11
V launch = 800 fps, q = 2000 psf, Mtr = 6

	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			15,942
2.0 Tail Group			1,213
3.0 Body Group			29,073
4.0 Thermal Protection			8,898
5.0 Landing Gear			4,530
6.0 Main Propulsion			37,190
7.0 RCS Propulsion			1,710
8.0 OMS Propulsion			1,088
9.0 Primary Power			978
10.0 Electrical Conversion & Dist.			3,781
11.0 Hydraulic Systems			0
12.0 Surface Control Actuation			998
13.0 Avionics			2,200
14.0 Environmental Control			2,687
15.0 Personnel Equipment			802
16.0 Dry Weight Margin (15%)			16,664
Dry Weight			**127,755**
17.0 Crew and Gear			1,890
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			1,001
21.0 OMS/RCS Reserve Propellants			340
Landed Weight			**150,986**
22.0 RCS Entry Propellants (ΔV = 25 fps)			279
Entry Weight			**151,265**
23.0 RCS/OMS Propellants (on-orbit)			3,123
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			6,233
26.0 Inflight Losses and Vents			1,513
Insertion Weight			**162,134**
27.0 Ascent Propellants			831,000
Gross Liftoff Weight			**993,134**
28.0 Startup Losses			2,375
Maximum Pre-launch Weight			**995,509**

Vehicle Weight Statement HTO sled launch RBCC with engine #11 V launch = 800 fps, q = 2000 psf, Mtr = 6			
	Level 3	*Level 2*	*Level 1*
1.0 Wing Group			15,942
Exposed wing		10,930	
Carry through		5,012	
2.0 Tail Group			1,213
3.0 Body Group			29,073
Nosecone		265	
Crew Cabin		2,058	
Payload Bay/Intertank Structure		6,844	
Structure	3,144		
P/L Bay Doors	700		
P/L Accommodations	3,000		
LH2 Tank		12,220	
Tank Structure	9,978		
Tank Insulation	2,242		
LOX Tank		3,701	
Tank Structure	3,238		
Tank Insulation	463		
Aft Body		3,252	
Tail cone	2,921		
Base	331		
Body Flap		735	
4.0 Thermal Protection			8,898
Active Cooling		0	
Nosecap	0		
Wing leading edges	0		
Advanced Carbon/Carbon		1,973	
Body/cowl	1,558		
Wing/tails	414		
TUFI (tiles)		4,004	
Body/cowl	2,312		
Wing/tails	1,691		
TABI (blankets)		2,921	
Body/cowl	2,921		
Wing/tails	0		
5.0 Landing Gear			4,530
Nosegear		679	
Main gear		3,850	
6.0 Main Propulsion			37,190
RBCC Engines (installed)		23,244	
Ejector rockets (incl. pumps)	6,191		
Diff./Comb./Noz. (w/ cooling)	10,449		
Fan/gas generator	6,604		
Main Rocket Engine		10,949	
Pressurization and feed systems		1,919	
Purge Systems		1,079	
7.0 RCS Propulsion			1,710
Foreward RCS		425	
Thrusters (15 pressure fed)	137		
Prop. tanks/empty(195 psia)	43		
He pressnt. tank(3000 psia)	132		
He pressurant	11		
Lines,manifolds,valves,etc.	101		
Aft RCS		1,285	
Thrusters (22 pressure fed)	488		
Prop. tanks/empty(195 psia)	101		
He pressnt. tank(3000 psia)	309		
He pressurant	27		
Lines,manifolds,valves,etc.	361		
8.0 OMS Propulsion			1,088
Engines (4 pump fed)		430	
Prop. tanks/empty(25 psia)		44	
He pressnt. tank(3000 psia)		265	
He pressurant (for low pressure tanks)		23	
Lines,manifolds,valves,etc.		327	
9.0 Primary Power			978
Fuel cells		396	
Reactant dewers		531	
Batteries		52	
10.0 Electrical Conversion & Dist.			3,781
Power conversion and distribution		1,406	
EMA controllers		323	
Circuitry & wiring		1,919	
EMA cabling		132	
11.0 Hydraulic Systems			0
12.0 Surface Control Actuation			998
Elevon EMAs		610	
Verticals EMAs		129	

Body Flap EMAs		259	
13.0 Avionics			2,200
14.0 Environmental Control			2,687
Personnel systems		141	
Equipment cooling		729	
Heat transport loop		1,142	
Heat rejection system		675	
Radiators	512		
Flasn evaporators	163		
15.0 Personnel Equipment			802
Food, water, waste manag.		502	
Seats, etc.		300	
16.0 Dry Weight Margin (15%)			16,664
Dry Weight			**127,755**
17.0 Crew and Gear			1,890
18.0 Payload Provisions			0
19.0 Cargo (up and down)			20,000
20.0 Residual Propellants			1,001
OMS/RCS residuals		170	
Fore LH2 RCS residuals	3		
Fore LOX RCS residuals	10		
Aft LH2 RCS residuals	6		
Aft LOX RCS residuals	23		
LH2 OMS residuals	18		
LOX OMS residuals	110		
Main Propellant residuals		831	
LH2 residuals	165		
LOX residuals	666		
21.0 OMS/RCS Reserve Propellants			340
RCS reserves		84	
Fore LH2 reserves	5		
Fore LOX reserves	20		
Aft LH2 reserves	12		
Aft LOX reserves	47		
OMS reserves		256	
LH2 reserves	37		
LOX reserves	220		
Landed Weight			**150,986**
22.0 RCS Entry Propellants (ΔV = 25 fps)			279
Forward RCS Propellants		84	
LH2	17		
LOX	67		
Aft RCS Propellants		196	
LH2	39		
LOX	156		
Entry Weight			**151,265**
23.0 RCS/OMS Propellants (on-orbit)			3,123
Forward RCS Propellants		168	
LH2	34		
LOX	134		
Aft RCS Propellants		392	
LH2	78		
LOX	314		
OMS Propellants		2,564	
LH2	366		
LOX	2,197		
24.0 Cargo Discharged			0
25.0 Ascent Reserve and Unusable Propellants			6,233
LH2 reserves and unusables		1,234	
LOX reserves and unusables		4,998	
26.0 Inflight Losses and Vents			1,513
Insertion Weight			**162,134**
27.0 Ascent Propellants			831,000
LH2 ascent		164,538	
LOX ascent		666,462	
Gross Liftoff Weight			**993,134**
28.0 Startup Losses			2,375
LH2 startup		339	
LOX startup		2,036	
Maximum Pre-launch Weight			**995,509**

olds
7-20

Revised Mag.lifter calcs. with crew.
Vi = 800 fps.

POST

triton

$$MR = \frac{889370}{142210} = 6.254$$

$$W2\% = 1 - \frac{595029}{747160} = .204$$

$$Wing\% = \frac{599631}{889370} = .674$$

$$W_{900} = \frac{635289}{889370} = .714$$

Gross = 1065470

Sref = 3776.1

$$engine = \frac{586009}{169193} = 3.464 \qquad Lox = 3.464 \times 31289 = 1083.7$$

$$A_c = \frac{192.21}{207} = .9286$$

Rocket = 794308 lb (84.5 ft²)

$$MR = \frac{1065470}{172503} = 6.177$$

$$W2\% = 1 - \frac{713734}{892967} = .201$$

$$Wing\% = \frac{716186}{1065470} = .672$$

$$W_{900} = \frac{781866}{1065470} = .734$$

Gross = 1023756 ← change data Mach 6,10 to 1.3

Sref = 3673.8

$$engine = \frac{563066}{169193} = 3.328 \qquad Lox = 1041.3$$

$$A_c = \frac{184.69}{207} = .8922$$

Rocket = 784709 (83.5)

$$MR = \frac{1023756}{167105} = 6.126$$

$$W2\% = 1 - \frac{686870}{856651} = .198$$

$$Wing\% = \frac{693146}{1023756} = .677$$

$$W_{900} = \frac{752731}{1023756} = .735$$

Gross = 997641

Sref = 3605.9

engine = $\frac{548703}{169193}$ = 3.243 Lox = 1014.72

A_c = $\frac{17997}{202}$ = .869

Rocket = 769930 (82)

MR = $\frac{997641}{162890}$ = 6.125

LH2% = $1 - \frac{669295}{834751}$ = .198 ← Done.

Wing% = $\frac{675484}{997641}$ = .677

Wgoo $\frac{732879}{997641}$ = .735

Mlr = 10

WEIGHT STATEMENT - LEVEL I (lb)

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 25klb p/l - 51.6 inc.,

1.0 Wing	10815.
2.0 Tail	1899.
3.0 Body	62349.
4.0 Induced environment protection	19573.
5.0 Undercarriage and aux. systems	7016.
6.0 Propulsion, main	52919.
7.0 Propulsion, reaction control (RCS)	3626.
8.0 Propulsion, orbital maneuver (OMS)	2275.
9.0 Prime power	2339.
10.0 Electric conversion and distr.	6331.
11.0 Hydraulic conversion and distr.	0.
12.0 Control surface actuation	1285.
13.0 Avionics	1314.
14.0 Environmental control	2395.
15.0 Personnel provisions	0.
18.0 Payload provisions	0.
19.0 Margin	26121.
EMPTY	200257.
20.0 Personnel	0.
21.0 Payload accomodations	0.
22.0 Payload	25000.
23.0 Residual and unusable fluids	13044.
25.0 Reserve fluids	7289.
26.0 Inflight losses	3804.
27.0 Propellant, main	2143459.
28.0 Propellant, reaction control	2886.
29.0 Propellant, orbital maneuver	19369.
PRELAUNCH GROSS	2415109.
	0.
Prelaunch gross	2415109.
Start-up losses	-32121.
Gross lift-off	2382988.
Ascent propellant	-2111338.
Insertion	271650.
Ascent reserves	-5910.
Ascent residuals	-10984.
Inflight losses	-3804.
Aux. propulsion propellant	-21561.
Payload delivered	-25000.
Payload accepted	25000.
Entry	229391.
RCS prop. (entry)	-695.
Landed	228697.
Payload (returned)	-25000.
Landed (p/l out)	203697.
Personnel	0.
Payload accomodations	0.
Subsystem residuals	-592.
Aux. propulsion residuals	-1468.
Aux. propulsion reserves	-1379.
Empty	200257.

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 25klb p/l - 51.6 inc.,

DESIGN DATA

payload volume (cu. ft.)	5300.0000
payload weight (lb)	25000.0000
oms delta v req. (ft./sec.)	1100.0000
lift-off t/w ratio	1.2000
mass ratio	8.7723
rocket reduction factor	0.0000
body_length_______________ft_	185.6307
body_width_______________ft_	28.5815
body_volume____________cu_ft_	105695.2521

body_tps_wetted_area___sq_ft_	15562.2168
nose_section_area_______sq_ft_	415.3967
intertank_area__________sq_ft_	4771.9390
aft_body_area___________sq_ft_	907.3516
engine_bay_area_________sq_ft_	1075.3585
lox_tank_wetted_area___sq_ft_	4831.3502
lox_tank_volume_________cu_ft_	25893.2187
lh2_tank_wetted_area___sq_ft_	6494.1135
lh2_tank_volume_________cu_ft_	39414.3510
ker_tank_volume_________cu_ft_	4361.0188
wing_tps_wetted_area___sq_ft_	5061.8321
carry_through_width________ft_	25.7999
exposed_wing_span__________ft_	67.1504
exposed_wing_root_chord___ft_	59.4901
exposed_wing_planform__sq_ft_	2441.9017
exposed_wing_taper_ratio_____	0.2324
exposed_wing_aspect_ratio____	1.8472
body flap length (ft)	8.1338
tip fins (2) planform area (ft2)	271.3015

SIZING PARAMETERS

Mass ratio	8.7723
Propellant mass fraction	0.8860
Body length (ft.)	185.6
Wing span (ft.)	93.0
Theoretical wing area (sq. ft.)	4188.6
Wing loading at design wt (psf)	54.6
Wing planform ratio, sexp/sref	0.58
Sensitivity of volume to burnout wt (cu. ft./klb.)	383.9
Burnout weight growth factor (lb/lb)	4.36

	BODY	WING
Total volume (cu. ft.)	105695.	13351.
Tank volume (cu. ft.)	68875.	0.
Fixed volume (cu. ft.)	0.	0.
Tank efficiency factor	0.6516	0.0000
Ullage volume fraction	0.0300	0.0300

PROPELLANT	FRACTION	DENSITY (lb/cu. ft.)	FLUID VOLUME (cu. ft.)	TANK VOLUME (cu. ft.)
lh2	0.0782	4.42	37377.	38983.
hc	0.0983	50.50	4108.	4317.
lox	0.8235	71.14	24440.	25575.
lox (Wing)	0.0000	71.14	0.	0.

WEIGHT STATEMENT - LEVEL I (lb)

unmanned ssv, ssme-50 der. - 25 klb p/l, 51.6 deg incl.

1.0 Wing	13855.
2.0 Tail	2000.
3.0 Body	85702.
4.0 Induced environment protection	23370.
5.0 Undercarriage and aux. systems	8910.
6.0 Propulsion, main	81834.
7.0 Propulsion, reaction control (RCS)	4039.
8.0 Propulsion, orbital maneuver (OMS)	2851.
9.0 Prime power	2339.
10.0 Electric conversion and distr.	9483.
11.0 Hydraulic conversion and distr.	0.
12.0 Control surface actuation	1631.
13.0 Avionics	1314.
14.0 Environmental control	2348.
15.0 Personnel provisions	0.
18.0 Payload provisions	0.
19.0 Margin	35951.
EMPTY	275627.
20.0 Personnel	0.
21.0 Payload accomodations	0.
22.0 Payload	25000.
23.0 Residual and unusable fluids	16170.
25.0 Reserve fluids	9800.
26.0 Inflight losses	5688.
27.0 Propellant, main	2603305.
28.0 Propellant, reaction control	3847.
29.0 Propellant, orbital maneuver	25807.
PRELAUNCH GROSS	2965244.
	0.
Prelaunch gross	2965244.
Start-up losses	-36014.
Gross lift-off	2929230.
Ascent propellant	-2567291.
Insertion	361939.
Ascent reserves	-7959.
Ascent residuals	-13421.
Inflight losses	-5688.
Aux. propulsion propellant	-28727.
Payload delivered	-25000.
Payload accepted	25000.
Entry	306144.
RCS prop. (entry)	-927.
Landed	305217.
Payload (returned)	-25000.
Landed (p/l out)	280217.
Payload accomodations	0.
Personnel	0.
Subsystem residuals	-790.
Aux. propulsion residuals	-1959.
Aux. propulsion reserves	-1841.
Empty	275627.

unmanned ssv, ssme-50 der. - 25 klb p/l, 51.6 deg incl.

DESIGN DATA

payload volume (cu. ft.)	5300.0000
payload weight (lb)	25000.0000
oms delta v req. (ft./sec.)	1100.0000
mass ratio	8.0932
rocket reduction factor	0.0000
body_length_______________ft_	181.8398
body_width________________ft_	36.3160
exp_wing_span_____________ft_	71.2390
exp_wing_root_chord_______ft_	64.6798

nose_section_area______sq_ft_	346.2860
intertank_area_________sq_ft_	5008.5921
aft_skirt_area_________sq_ft_	1430.1457
engine_bay_area________sq_ft_	1353.7546
body_tps_wetted_area__sq_ft_	19534.1742
wing_tps_wetted_area__sq_ft_	5872.5821
exposed_wing_planform_sq_ft_	2845.3984
theo_wing_planform____sq_ft_	4817.4159
body_volume____________cu_ft__	168203.1476
carry_through_width_ft________	29.8881
exposed_wing_taper_ratio______	0.2359
exposed_wing_aspect_ratio_____	1.7836

SIZING PARAMETERS

Mass ratio	8.0932
Propellant mass fraction	0.8764
Body length (ft.)	181.8
Wing span (ft.)	101.1
Theoretical wing area (sq. ft.)	5087.0
Wing loading at design wt (psf)	60.0
Wing planform ratio, sexp/sref	0.56
Sensitivity of volume to burnout wt (cu. ft./klb.)	458.3
Burnout weight growth factor (lb/lb)	5.57

	BODY	WING
Total volume (cu. ft.)	168203.	19426.
Tank volume (cu. ft.)	119103.	0.
Fixed volume (cu. ft.)	0.	0.
Tank efficiency factor	0.7081	0.0000
Ullage volume fraction	0.0300	0.0300

PROPELLANT	FRACTION	DENSITY (lb/cu. ft.)	FLUID VOLUME (cu. ft.)	TANK VOLUME (cu. ft.)
lh2	0.1429	4.42	83001.	86768.
lox	0.8571	71.14	30931.	32335.
lox (Wing)	0.0000	71.14	0.	0.