2ND GENERATION SPACE SHUTTLE

Douglas G. Thorpe KYrocketman@gmail.com

ABSTRACT: The original Space Shuttle concept that a mostly reusable launch vehicle with a high flight rate could provide remarkable reduction on access to space is still valid. Unfortunately, the original Space Shuttle failed to obtain such a high flight rate for many different reasons including: the use of SRB's, fragile tile, centralized hydraulics, multiple commodities, toxic propellants, operating the engines too hard, a cargo bay, and enclosed compartments among many other reasons. Therefore, a 2nd Generation Space Shuttle (referred to as Orbiter-2) is proposed that will utilize equipment and lessons-learned from the 1st Generation program to create a paradigm shift in the cost of going into space via Public/Private Partnership. The proposed configuration utilizes 1, 2, or 3 Flyback Boosters and 1 orbital vehicle with all vehicles resembling the original Shuttle Orbiter in dimensions and airframe. The 3booster-1orbiter version is capable to delivering 556,000 lb to near LEO velocities of which 315k is useful payload. All vehicles carry up to 12 passengers and their own LOX for all purposes, but utilize LH2 from a common external tank. The main payload for the vehicle sits on top of the external LH2 tank. The concept heavily relies on aerospike engines that utilize a propellant pump with no moving parts. Multiple vehicle configurations were studied with all vehicles utilizing LOX/LH2 and sometimes SRB boosters and sometimes using a LOX/LH2 mixture ratio of 12:1. If the vehicles are designed with minimum Launch and Flight Operations Labor, $69M to $93M in gross profit per mission at a launch rate of 50 to 500 missions per year respectively can be obtain at $400 per lb of useful payload to orbit. $17.3B can be spent on development and fleet manufacturing costs and still provide the venture with a 17% annual ROI at 50 missions per year. A future 3rd generation Shuttle Bus concept is outlined that could transport 340 space tourists at one time at <$100,000 per passenger, possibly going to a LEO space hotel. Obtaining a cost of less than $250,000 for a trip to a LEO space hotel will yield a market of 100,000 passengers per year.

NOMENCLATURE

APU	Auxiliary Power Unit	MECO	Main Engine Cut-Off
BECO	Booster Engine Cut-Off	MLP	Mobile Launch Platform
ET	External Tank	MMH	MonoMethylHydrazine
FRSI	Nomex Felt Reusable Surface Insulation	MPPF	Multiple Payload Processing Facility
FTE	Full-Time Equivalent employment	MPS	Main Propulsion System
GH2	Gaseous Hydrogen	MSS	Mobile Service Structure
GOX	Gaseous Oxygen	OPF	Orbiter Processing Facility
GSE	Ground Support Equipment	OMS	Orbital Maneuvering System
HETPF	External Hydrogen Tank Production Facility	OO2	Orbital Orbiter-2
HRSI	High-temperature reusable surface insulation	RCC	Reinforced Carbon-Carbon
Isp	Specific Impulse	RCS	Reaction Control System
KSC	Kennedy Space Center	ROA	% of Return On Assets
lb	pound	SL	Sea Level
LCC	Launch Control Center	SLWT-ET	SuperLightWeight External Tank
LEO	Low Earth Orbit	SRB	Solid Rocket Booster
LH2	liquid hydrogen	SSME	Space Shuttle Main Engine
LOX	liquid oxygen	TPS	Thermal Protection System
LRSI	Low-temperature reusable surface insulation	VAB	Vehicle Assembly Building
LSS	Life Support System	vac	Vacuum
LWT-ET	Lightweight External Tank		

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GROUND RULES FOR THE PROPOSED VEHICLES

In order to reduce development cost and operations costs, we have established the following Ground Rules. The design must:

1. Be commercially viable and not a government make-work project.
2. Where possible and beneficial, use already developed and flown hardware upgraded with latest technology.
3. Use Lessons-Learned from the Space Shuttle Program
4. Be able to handle different missions,
5. Be adaptable over time,
6. Make use of existing aerospace infrastructure, and
7. Fully employ the aerospace industry in order to achieve lower costs.

Brief Examples (details presented later in paper):

1. To be commercially viable, we recommend that:
    a. The venture provides a 20% annual ROA (or ROI) to the investors; each $1 asset yields $0.2 profit
    b. Design processing & flight operations labor to a limit of 1.5 man-hours (~$100)/lb of payload into LEO. Wherever possible, remove labor from Launch and Flight Operations; even if that means sacrificing vehicle performance or increasing development costs.
    c. No equipment will be developed that is very rarely utilized, such as the Shuttle Mate-Demate Device, instead a commercial mobile crane will be utilized. At the pad, a Saturn V type of Mobile Service Structure (that is rail-mounted) will be used instead of the more expensive Rotating Service Structure from the Shuttle era as well as the Lunch Umbilical Tower of the Saturn V era.
        i. Another seldom used piece of GSE is the Orbiter Transporter; why not use a Toyota Tundra Pickup and tow the Orbiter-2's to the pad on their own wheels.
    d. Paying passengers (space tourists) are flown in all flyback boosters as well as the orbiting vehicle. Each of the 30 flyback booster passengers would pay $100,000 each, while each of the 10 orbiter passengers would pay $1.5M. In comparison, Falcon 9/Dragon2 can lift 7 passengers who pay $8.86M each for just the cost of the Falcon 9.
    e. In addition to the $45M from space tourists, additional revenue would be generated from +300,000 lb of commercial payload that would be sold at $400/lb ($120M + $45M = $165M total). In comparison, the Falcon 9 Heavy charges $150M for 140,700 lb to LEO (or $1,066/lb).
    f. Instead of spending >$75M on each External LH2 tank and shipping them by barge around Florida, we will fabricate carbon fiber composite tanks at a new External Hydrogen Tank Production Facility (HETPF) at KSC. Tanks may bypass VAB and get mounted at the pad.
    g. Several of the 12 passengers in each vehicle can be replaced by a 20' diameter x 10' long Spacehab (or similar sized science platform) with paying scientific customers.
    h. Advertisement space would be sold on the sides of the launch vehicle for virtual advertisement or painted advertisement, which could amount to several millions in additional revenue per flight.
    i. More tourism dollars and public enthusiasm will be generated by full public access to all aspects of operations at NASA-KSC with behind-the-scenes tours (via plexiglass barricades) of the OPF, VAB, LCC Firing Rooms, MPPF, Pad B, and HETPF.
    j. No government oversight (and their associated cost) is desired except on government missions.
2. To make use of already flown hardware, we recommend that:
    a. The original Shuttle Orbiter airframe, wings, landing gear, umbilicals, bipod strut, and aft ET attachment point should be utilized with careful consideration of maintaining the same orbiter weight and flight dynamics. However, the size of the crew compartment will be expanded for 12 passengers instead of 8 and all LOX for the vehicle will be located in place of the cargo bay.

   b. RS-2200 linear aerospike and J-2 toroidal aerospike engine architecture will be utilized. The aerospike was chosen due to air protuberance and the aerospike engine development and flight certification must be completed. All engines must be designed and operated so that they don't need to be removed after every launch for inspection, similar to passenger aircraft operations.

3. To make use of the Lessons Learn rule, it is recommended that:
   a. The KSC landing strip is covered with a layer of sand so that the Orbiter's tires aren't shredded on every landing and need to be replaced.
   b. Shuttle fuel cells utilize the same LOX/LH2 as the Main Propulsion System.
   c. The toxic and hypergolic fuels for the OMS and RCS will be replaced with GOX/GH2 thrusters.
   d. The toxic and hypergolic fueled Auxiliary Power System (APU) for the hydraulic system will be replaced with enough fuel cells and batteries to handle any type of peak power requirements
   e. The Shuttle centralized hydraulics will be replaced by electro-actuators or individual hydraulic systems that are powered by electric motors via fuel cells.
   f. High temperature refractory metals (such as nickel-chromium, molybdenum, & ceramics) replace the original aluminum airframe in order to eliminate the operations intensive Shuttle tile and white Nomex Felt Reusable Surface Insulation (FRSI) blanket and other TPS. As shown in the table to the right, 600 Ni-Cr metal with an operating temperature of 1,093° C, could easily replace FRSI and LRSI. Booster vehicles would see speeds much less than Mach 10 and therefore, wouldn't come close to the maximum temperatures experienced by the Orbital vehicle.

Table 1: Original Shuttle Orbiter TPS

TPS type	color	Max Temperature (C)	Area (m^2)	Areal Density (kg/m^2)	Weight (kg)
FRSI	white	371	332.7	1.6	532.3
LRSI	off white	649	254.6	3.98	1,013.3
HRSI	black	1,260	479.7	9.2	4,413.2
RCC	light gray	1,510	38	44.7	1,698.6
misc					918.5
Total			1105		8,576.0

   g. A vehicle that has a much greater payload margin. When the original Shuttle lost a small amount of capacity due to safety concerns, it nearly wiped out all payload capacity until much lighter (and much more expensive) Al-Li ET were built. By having a vehicle with far excess capacity, we operate with a safer operating margin and operate the engines to last 100 missions without needing to be removed from the vehicle and/or inspected.

4. To handle different missions, we recommend that:
   a. The main payloads be placed on top of the External LH2 tank and not in some type of cargo bay. Placing payloads in the Space Shuttle's Cargo Bay was man-power intensive and one of the largest drivers of time between launches. By placing the payloads on top of the LH2 tank, the payload provider would be responsible for mating the payload to a payload adapter (in their facilities) and ensuring that the vehicle Center of Gravity (CG) is maintained.
   b. The orbiting vehicle and LH2 tank is independent from the 3 booster vehicles and their LH2 tank. This will allow future changes to booster design, booster fuel, and orbiter & payload design.
5. An example of designing a vehicle that can be adapted is:
   a. Unmanned vehicle instead of manned vehicles can be flown. 1, 2, or 3 booster vehicles or non-winged booster vehicles (a.k.a, Liquid Rocket Boosters) could be flown.
6. Examples of making use of existing aerospace infrastructure is:
   a. Make use of the KSC landing strip, LCC, OPF (for Orbiter processing), Pad B facilities, Range Safety, and others. If we stack in the VAB on top of the MLP, (instead of stacking directly at Pad B), we will also need the crawler-transporter.
7. An example of fully employing the aerospace industry:
   a. The problem that NASA and the SSME manufacture faced was that no one thought to set up a **continuous** production line so that a small manufacturing team would continue to produce 1 or 2 SSME per year. Instead, SSME's were ordered and manufactured piecemeal which resulted in the

Douglas G. Thorpe KYrocketman@gmail.com

manufacturer having to assemble, learn how to fabricate the engine, manufacture the engines, then lay everyone off until they received the next order sometime in the unknown future.

b. In order to achieve Aircraft Industry costs, it is recommended that production lines continuously build ALL components of the proposed vehicle and plan on retiring vehicles, components, and equipment at an established lifetime. Updated versions of all components of the flight vehicle will be released on routine intervals.

VEHICLE SUMMARY

- Please see page 7 for visual representation.
- 1.5-Stage-to-Orbit, mostly reusable launch vehicle family using only LOX-LH2 is proposed
- In order to reduce the development cost, existing and flight proven hardware, resources, and manufacturing techniques will be utilized until they are replaced by updated models.
- All major payloads are carried on top of a common LH2 tank.
- All versions of the launch vehicle family will utilize an updated Space Shuttle Orbiter, the Orbiter-2.
  - Orbiter-2's have the same dimensions as the original version, but the materials from which it is constructed will be changed in order to reduce operation costs between flights.
  - MPS, OMS, RCS, and vehicle fuel cells utilize the same propellants from the same tanks.
  - All Orbiter-2's carry 100% of all LOX they need for propulsion, fuel cells, OMS, and LSS.
  - Booster versions of the Orbiter-2's fly back to the launch area after consuming all of the propellant in the first 160 to 200 seconds of flight via turbojet engines.
  - Both booster and orbital versions of the Orbiter-2 can carry 10 passengers + 2 pilots.
  - The Orbiter-2 should be viewed as an Upgraded Space Shuttle Orbiter with a large LOX tank instead of a Payload Bay **OR** a large LOX tank with an orbiter built around it.
- Linear or Toroidal Aerospike Engines
  - There are 22.5 feet of Linear Aerospike thrusters on each side of (or 22.5 ft diameter toroidal aerospike engine surrounding) the LOX aft dome.
  - Instead of Gas Generator or Staged Combustion turbopumps, the propellants are pumped by steam injector pumps. Steam injector pumps have NO moving parts!
  - TBD: Expander cycle booster turbopump may provide higher pressure propellants to most of the thrusters
  - The OMS engines on the Orbiter-2's are essentially several thrusters of the aerospike engine that does not include the expander cycle booster, if the booster is incorporated.
  - Orbiter-2's could use their OMS engines for powered landings or go-around capability during landing. Flyback booster vehicles have turbojet engines to provide Return-To-Launch site and go-around capability. Orbital version of Orbiter-2 does not have turbojet engines.
  - All engines (including OMS) ignite before lift-off to verify their functionality before commitment to launch.
  - Several optional engines include: modified SSME, RS-83, Integrated Powerhead Demonstrator, TR-106, among others.
- The proposed vehicle is an upgraded version of the author's first technical paper in 1990, The SuperTanker Space Shuttle[i].

RATIONALE FOR THE CHOSEN DESIGN

Why 1.5 Stages-To-Orbit

All engines are verified they are operational before vehicle is released from pad. All engines help to get the vehicle off of the launch pad. In the 1.5 stage-to-orbit configuration, only the inexpensive LH2 tank, and payload adapter are expendable. Integrating LH2 tank into "aircraft" is very challenging.

Douglas G. Thorpe KYrocketman@gmail.com

Removing Commercial Cargo Payload from the Cargo Bay and placing in-line with external tank

Placing liquid propellants inside of an enclosed cargo bay was determined during the Shuttle program to be too large of a safety risk, which prevented the more efficient Centaur Upper Stage from being utilized. In addition, all communication, power, and propellants (if cryogenic) had to be supplied via the Orbiter, which required extra time and costs that would not occur if the payload was placed within its own payload shroud. Finally, extra costs also occurred when payloads are placed in a Cargo Bay due to the precise placement of payloads in order to ensure the vehicle's Center of Gravity (CG) was maintained. But most importantly, it allowed payloads to be as large as 54 feet in diameter by 400 feet long vs 15 ft in diameter by 60 ft long.

Why does the 2nd Generation Vehicles carry their own LOX

We wanted to utilize the original Space Shuttle airframe rather than develop a new launch vehicle that would cost several $B's. The original Space Shuttle airframe and other associated components can be utilized if the cargo bay is replaced with a LOX tank. This had the added bonus of:

1. Eliminating the possibility of the POGO and LOX geyser phenomena,
2. Simplified the External Tank design, which will make it cheaper to build,
3. Reduced the material cost of the External Tank by constructing it using composite materials (note: LOX tanks cannot be fabricated out of composites), and
4. Providing an abundant storage of LOX for OMS, RCS, Fuel Cells, and LSS systems.

Winged Flyback Boosters that carry 10 paying passengers vs Vertical Landings with no passengers

A trade study should be conducted to determine if we can find 30 sub-orbital passengers each week for more than 10 years who are willing to pay $100,000 per ride; a total of 15,000 passengers that could generate a total of $1.5B in extra revenue. Landing boosters vertically on the beach (similar to the SpaceX approach) does not generate any extra revenue (forgoing the $1.5B). Non-passenger boosters and orbiter vehicles may be necessary in order to eliminate the expense of a man-rated vehicle for a cargo flight. It would be only reasonable to think that vertical landing boosters would be cheaper to develop and have a lower re-occurring cost, but economics of scale should prove to be much cheaper to build 8 Flyback Boosters and 3 orbital vehicles with nearly the same airframe, than building 8 vertical landing boosters that have little commonality with the orbiters. It should be possible to build all 11 Orbiter-2's (not including engines) for less than $4B total, because most of the design is already flight proven. A similar sized Boeing 737-10 (with engines!) sells for $130M. Even Boeings most expensive aircraft (the Boeing 777-9 with engines) sells for only $425.8M.

Why build a composite tank at a new facility at NASA-KSC vs welded Aluminum-Lithium tanks at NASA-Michoud in New Orleans

Costs for the Space Shuttle ET varied tremendously from $38.1M for ET-41 in APR88 to $50.5M for ET-55 in FEB90 for LWT- (STS-8 to STS-95); ~$70M for SLWT-ET for STS-96 until end of program (Please See Appendix 1). A Commercial Operation should be able to build a one-million-gallon Liquid Hydrogen Composite Tank for under $2M (but we have assumed a cost of $5M). Tanks can be built at KSC at any diameter since the amount of transportation interference caused by electric lines or other size restriction on transportation would be a minimum. The cost of merely changing materials from aluminum (used on the Space Shuttle Lightweight ET from STS-6 until STS-90) to Al-Li (used on the SuperLightweight ET starting with STS-91) cost an extra $20M in order to save 7,500 lb, which equals $2,667 per lb.

TECHNOLOGIES WE WISH TO EXPAND UPON

1. Integrated Powerhead Demonstrator (full-flow staged combustion) or
2. Steam Injector Propellant pump with no moving parts as conceived by Doug Thorpe
3. RS-2200 linear and J-2 based toroidal aerospike engine
4. Composite LH2 Tank
5. Nickle-Chromium or refractory covered launch vehicle

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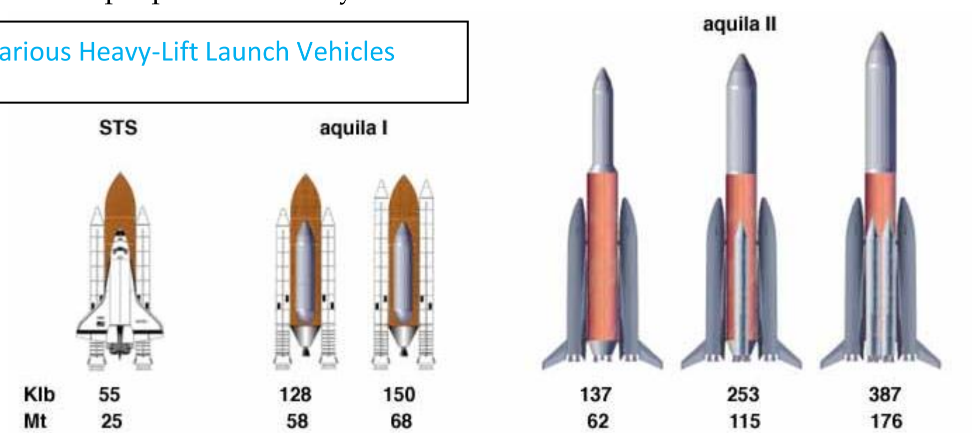
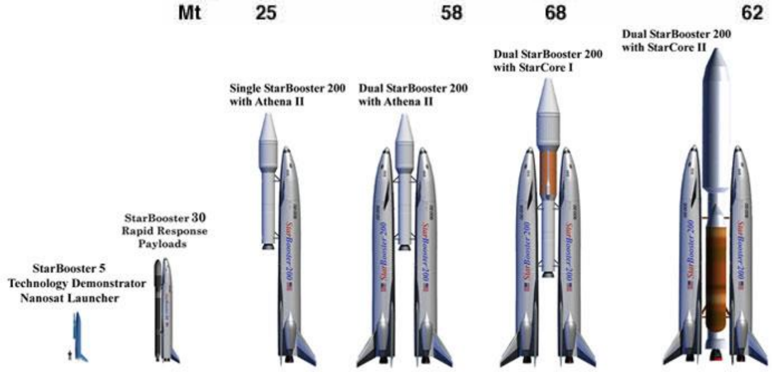
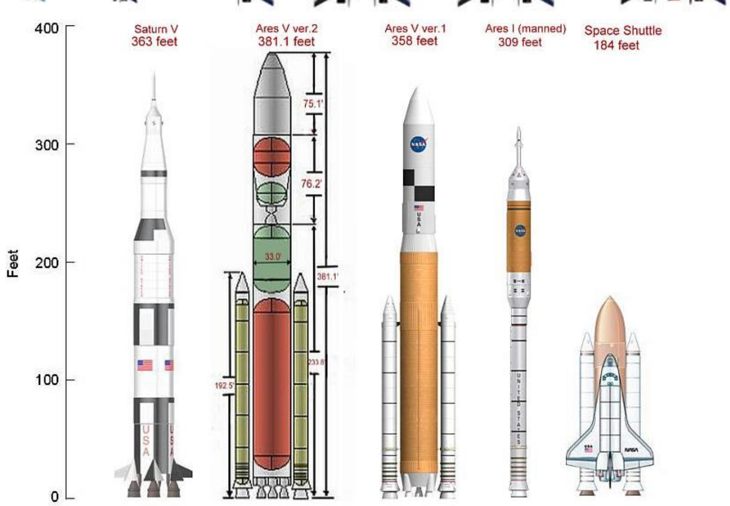
THE PROBLEM WITH PRIOR ART

The problem with most past, present, & future launch vehicle designs is that they typically utilize expendable liquid or Solid Rocket Booster vehicles that cost millions of dollars each launch or reusable, specialty-designed, winged, flyback booster vehicles that cost billions of dollars to develop. No offense to our good friend, Dr. Aldrin, his Aquila and StarBooster vehicles (while very impressive and presented below) utilizes a specialty designed, winged, LOX/Kerosene, flyback vehicle plus SRB's. But, development of a new launch vehicle, flyback booster vehicle, and engines could easily cost $5B per vehicle and $2B for engines. Plus, the use of expendable upper stages throws away several $M engines and avionics per mission. In addition, this arrangement will limit the number of flyback booster vehicles to 2. Instead of LH2, he chose kerosene for his fuel since winged vehicles grow enormously when they carry LH2 inside (this is why we chose an external LH2 tank). His expendable upper stage will most likely be single purpose, whereas our very large diameter LH2 tanks could be part of a space station or space telescope or other purposes once they have reached orbit.

Figure 1: Various Heavy-Lift Launch Vehicles







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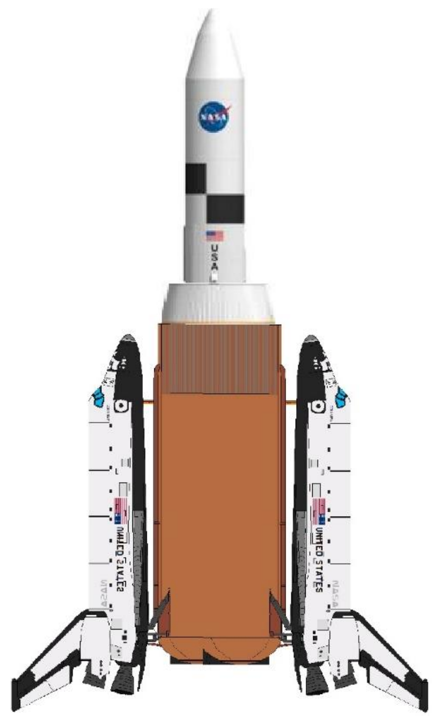
Douglas G. Thorpe KYrocketman@gmail.com

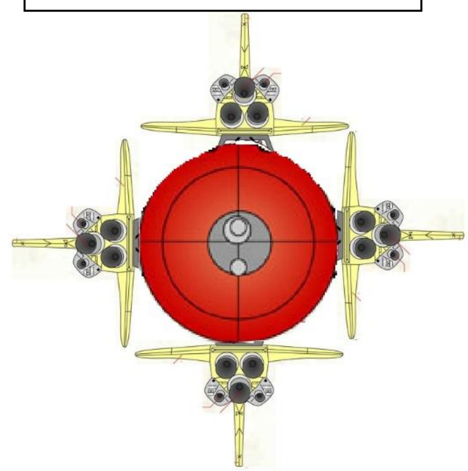
THE PROPOSED VEHICLES: (Named after the 747 jumbojet, which brought a paradigm shift in the passenger aviation world.)
The **JUMBO-2, JUMBO-3,** and the **JUMBO-4**

Figure 2: **JUMBO-2**, side view



- 1.5 stage-to-orbit vehicle with an expendable LH2 tank, but with totally reusable boosters and orbiter vehicles. It's called "JUMBO-2, -3, or -4" because two, three, or four 2nd Generation Space Shuttle Orbiter Vehicles (referred to as Orbiter-2's) are flown simultaneously (See Figure 2 & 3).
- JUMBO-4 transports 601,000 lb of total weight to MECO (including external LH2 tank) while JUMBO-2 only transports 394,000 lb.
- 1, 2, or 3 of the Orbiter-2's would be of the booster configuration and are used as booster vehicles that fly back to the launch site {referred to as **Flyback Boosters**}. One of the Orbiter-2's would be of the orbital configuration {referred to as Orbiting Orbiter-2 or **OO2**} and would be very similar in function to the original Space Shuttle orbiter.
  - Please see **page 9** for design specification for Orbiter-2's
  - Please see page 5 for cost justification of developing a winged, Flyback Booster instead of a vertical landing system (similar to the SpaceX system).
- All Orbiter-2's (Flyback Boosters & OO2's) have the same airframe dimensions, crew compartment, landing gear, 22ft diameter x 50ft long internal LOX tank & much smaller LH2 tanks, RCS, umbilical system, Fill/Drain, hydraulics, UPS, and fuel cell system, among others.

Figure 3: **JUMBO-4** Cross-sectional aft view



- All Orbiter-2's have nearly the same Gross Lift-Off Weight of ~1.65M lbs; except the Flyback Boosters will be heavier since they have more engines, larger MPS, and turbojet engines for Return-To-Launch site
- All Orbiter-2's have a metal exterior shell and no fragile silica tile or blankets. The shell and interior frame will be constructed out of the advances in refractory materials that have occurred since the original Space Shuttle was designed in the 70's.
- All Orbiter-2's utilize aerospike engines;
  - The Flyback Boosters utilize aerospike engines that produce 3 times more thrust than the OO2's and will consume all of their LOX in 160 to 190 seconds.
  - OO2's engine burn for 450 seconds after BECO.
- Each Orbiter-2 will have the following connection points:
  - A LH2 connection to the common LH2 tank
  - A LOX Fill/Drain connection to GSE.
  - A LH2 Fill/Drain connection to GSE and,
  - A GSE vehicle support arm (provides mechanical support to each Orbiter-2 which has a Gross-Lift Weight of 1.65 million lb)
  - Yes, we recognize that the GSE T-0's, crew access swing arms, and payload swing arms for this launch vehicle would be intense.
- All Orbiter-2's obtain LH2 from a common external hydrogen tank.
- All payload connections are disconnected at T-60 seconds when both MSS rollback
- Every Orbiter-2 carries Space Tourists!

- Each Flyback Booster can carry 10 **suborbital** tourists plus pilot & co-pilot OR 6 tourists and 10,000 lb internal payload
- OO2's can carry 10 **orbital** tourists plus pilot & co-pilot OR 6 tourists and 10,000 lb internal payload

- The OO2's engines throttle to ~2% after the vehicle clears the launch pad so it can preserve LOX propellant for after booster separation.
- All major payloads are carried on top of the External LH2 Tank via a Payload Adaption Ring
- Payload capacities for various engine & vehicle configurations are presented in detail on **page 17**.
- After booster separation; the OO2, its external LH2 tank, and the external payload, will continue to be propelled into orbit for an additional 450 seconds.

THE ORIGINAL SPACE SHUTTLE ORBITER

Original Space Shuttle Orbiter Specifications:

- Length: 122.17 ft (37.237 m)
- Wingspan: 78.06 ft (23.79 m)
- Height: 56.58 ft (17.25 m)
- Empty weight: 182,000 lb
- Mass at MECO w/ max. payload: 355,805 lb
- Maximum landing weight: 231,342 lb (STS-90)
- Payload to Landing (Return Payload): 32,000 lb
- Maximum payload: 55,250 lb
- Cargo bay in Orbiter: 15' x 60'
- **SSME – 3 engines**
  - SSME at 109% = 418,000 lb at SL; 512,300 lb in vac
  - Isp = 366 sec SL and 452.3 seconds in vac
  - Dry weight 7,775 lb each
  - Thrust Vector Control via hydraulic gimbal

Figure 4: Original Space Shuttle Orbiter

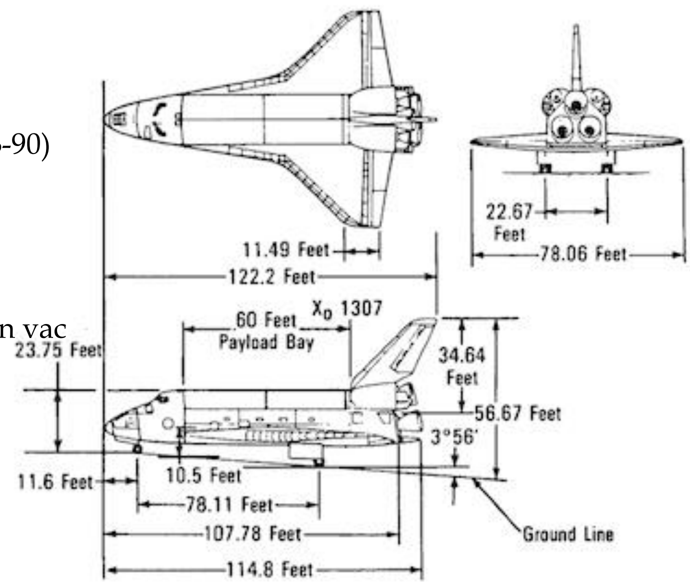


Table 2: Original Orbiter

Original Orbiter Dry Weight w/o engines	149,675
3 SSME @ 7,775 lb each	23,325
OMS/RCS Pod dry weight x 2 = total	9,000
Orbiter dry weight	182,000
Propellant trapped in SSME's at MECO	1,700
Propellant trapped in MPS at MECO	3,700
Fuel Cell - LOX	3,905
Fuel Cell - LH2	460
OMS & RCS Propellant	55,690
Orbiter Wet Weight at MECO	247,455
Cargo Bay Payload	55,250
ET Dry weight	53,100
Total weight to MECO	355,805
Payload % of Total WT to MECO	15.5%

Table 3: Orbiter-2 (Flyback Booster)

Orbiter-2 Dry Weight w/o engines	149,675
160 of 9" aerospike thrusters	62,400
Two Saturn AL-41F-1S turbofan engines	6,262
Orbiter dry weight	218,337
LOX-LH2 RCS & Fuel Cell propellant	5,000
Orbiter Wet Weight at BECO	223,337
Internal Payload	10,000
Payload Shroud divided by 3	6,000
Total weight to BECO/Booster	239,337
Payload % of Total WT to BECO	4.2%

Table 4: Orbiter-2 (OO2 or Orbiting Vehicle)

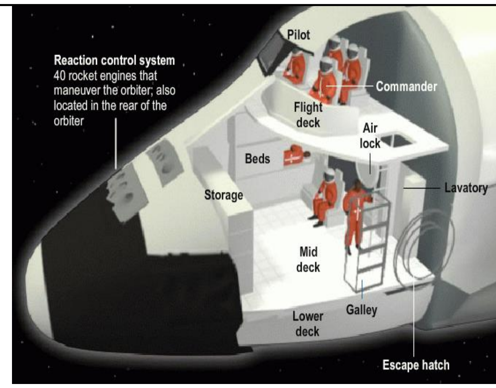
Orbiter-2 Dry Weight w/o engines	149,675
3 SSME @ 7,775 lb each	23,325
Orbiter dry weight	173,000
LOX-LH2 OMS propellant	29,700
LOX-LH2 RCS & Fuel Cell propellant	8,433
Orbiter Wet Weight at MECO	211,133
Internal Payload	10,000
External Payload (JUMBO-4)	305,000
External LH2 tank (JUMBO-4)	78,938
Payload Adapter	15,000
Total weight to MECO	605,071
Payload % of Total WT to MECO	52.1%

Douglas G. Thorpe KYrocketman@gmail.com

ORBITER-2

- The Orbiter-2 should be viewed as an Upgraded Space Shuttle Orbiter with a large LOX tank instead of a Payload Bay OR a large LOX tank with an orbiter built around it.
- Length: 122.17 ft (37.237 m)
- Wingspan: 78.06 ft (23.79 m)
- Height: 56.58 ft (17.25 m)
- Maximum payload: 10,000 lb
- Cargo bay in Orbiter-2: 22.5′diameter x 10′ long (may house 10′ longer Mid-Deck for 4 extra passengers, SpaceHab, etc)
- Each Orbiter-2 has a 22.5 ft diameter x 50 ft long LOX tank that can carry as much as 1,638,698 lb of LOX.
  - As a reference, the width of the aft end of the Orbiter (where the OMS pods are located) is 22 ft wide and the Space Shuttle External Tank carried 1,387,457 lbs of LOX.

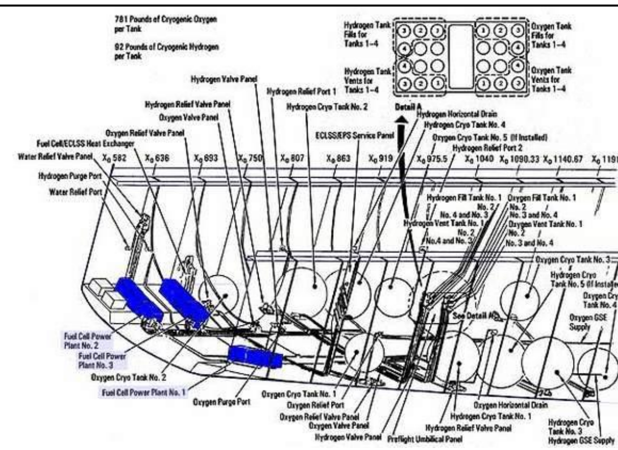
Figure 5: Original Orbiter Crew Compartment



Propellants for OMS, RCS, and Fuel Cells

- Each Orbiter-2 carries 5,000 lbs of LH2 for OMS, RCS, and Fuel Cells.
- Each Orbiter-2 can house up to 12 passengers or 8 passengers and 22.5′ x 10′ scientific equipment
- OMS, RCS, and Fuel Cells for Orbiter-2's utilize LOX-LH2 and are all connected to the same manifold.
- Large source of LOX-LH2 will be propellants trapped in the MPS and SSME.
  - At MECO, there is 1,700 lb of propellant trapped in the SSME's and 3,700 lbs of propellant trapped in the MPS on the original Orbiter. The "trapped" gaseous propellant would need to be pumped into fuel cells or RCS engines as needed until a vacuum is created.
  - The original Orbiter contains 5 sets of Oxygen and Hydrogen tanks for the fuel cells. Each tank set contains 781 lb of oxygen and 92 lb of hydrogen with dry weights of 201 lb and 216 lb respectively. The tanks contain a total of 3,905 lb of oxygen and 460 lb of hydrogen with a combine dry tank weight of 2,085 lb.
  - By powering the Fuel Cells on the propellants that remained trapped in the MPS and engines without utilizing any other tanks will result in weight savings of approximate 5,000 lbs.

Figure 6: GH2 & GOX tank bottles in original Orbiter



- Orbiter-2's utilize LOX-LH2 for OMS and GOX-GH2 for RCS instead of hypergolic fuel (MMH/N2O4).
  - After MECO, the OMS engines are fed by the remaining 30,000 lb of LOX and 5,000 lb of LH2 in the on-board tanks.
  - The original Shuttle OMS pods contained 55,690 lb of hypergolic propellant that had an Isp of 316 seconds vs 444 seconds for typical LOX/LH2 engines such as RL-10A. The OMS require 27,672 lb of propellant to produce a 300 m/s delta-v with the original 302,705 lb orbiter & payload. OO2's weigh only 230,133 lb and would only need 15,363 lb of LOX-LH2 to fulfill the same orbital insertion requirements; 47,257 lb for hypergolic vs 29,700 lb for LOX-LH2 total. The remaining 8,433 lb of hypergolic propellant in the original Orbiter is for RCS or in case it is needed by OMS to bring the payload back; our RCS utilizes the more efficient GOX-GH2, but we have 13,728 lb of LOX/LH2 as a larger margin since we use LOX in many more ways than original.

Douglas G. Thorpe KYrocketman@gmail.com

Thermal Protection System on Exterior of Orbiter-2's

- The original Orbiter used extremely fragile and man-power intensive silica tile and insulating blankets. (The sketch to the right is an early concept for the original Space Shuttle using high temperature metals).
  - All Orbiter-2's have a metal exterior shell and NO fragile silica tile or blankets. The shell and interior frame will be constructed out of the advances in refractory materials that have occurred since the original Space Shuttle was designed in the 70's.
  - The refractory metals include Nickle-Chromium, Molybdenum, Titanium, Niobium, Rhenium, (including carbides and alloys), and ceramics.
  - It's indeterminate what material will replace the RCC on the forward leading surfaces on OO2's.

Figure 7: Early Space Shuttle Concept using refractory metals instead of tile TPS

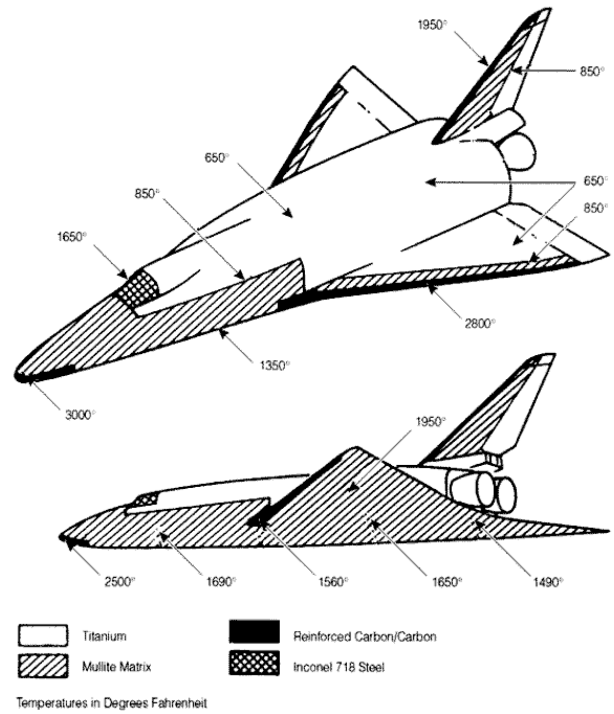
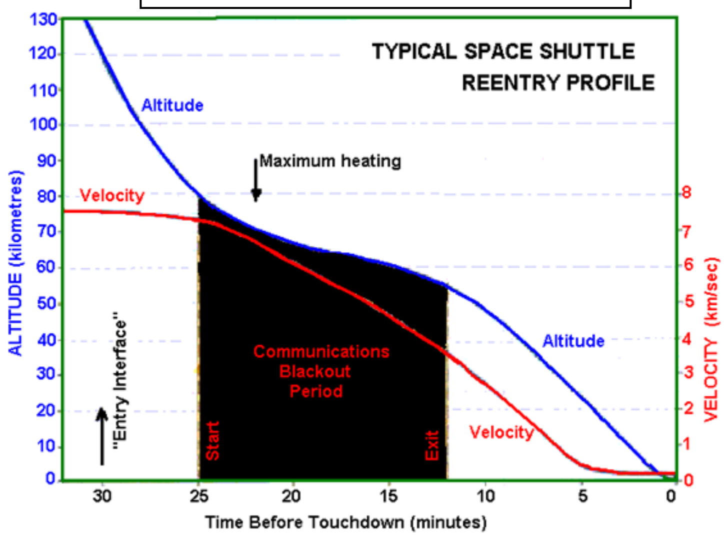


Figure 8: Orbiter Re-Entry Profile for Temperature & Altitude vs Time



The original Orbiter used RCC in order to survive the 3,500 deg F re-entry from orbital velocities, but they become thin and weaken over time. NOTE: The X-37B does NOT have RCC.

- As you can see by the re-entry profile (shown left), the orbiter slowed down from 7km/sec (Mach 20) to less than 3.5 km/s (Mach 10) in 12 minutes. During that 12-minute period of maximum heating, the refractory shell could be cooled via the discharge and evaporation of waste water from the fuel cells or LOX and LH2 in emergencies.

  - The Original Orbiter's outer structural skin is constructed primarily of aluminum and graphite epoxy and must be kept below 350 deg F. On Orbiter-2's, the aluminum internal structure, FRSI, and LRSI locations on the original shuttle will be replaced with nickel-chromium (and assume no weight savings or penalties; BTW: Most of the structure of the Orbiter-2 is the LOX tank). HRSI-22 tile will be replaced

Table 5: Original Space Shuttle Orbiter TPS; temperature ranges & weight

TPS Type	material	Description	Color	Max Oper Temp (deg C)	Area (M^2)	Weight (kg)	Location
FRSI	Nomex	Felt Blankets	White	371	333	532	upper wing, upper payload bay doors, part of OMS pods, & aft fuselage
LRSI	Silica Tiles	Tile (replaced by FIB)	Off-White	649	255	1,013	fuselage areage, vertical tail, and OMS pods
HRSI-22	LI-900 Silica	Tile	Black	1,260	498	4,413	Doors & bottom surfaces
RCC	RCC	composite laminate	light gray	1,510	38	1,699	wing leading edges
Misc						919	
				Total	1,123	8,576	

Douglas G. Thorpe KYrocketman@gmail.com

by the more exotic refractory metals. To keep the Ni-Cr below its operating temperature of 1,093°degC, the 6,877 kg (15,129 lb) of TPS will be replaced with 1,818 gallons of water that will be sprayed (at a rate of 151 gallons / minute) onto a nickel-chromium shell over the 12 minutes of maximum heating. It is anticipated that far less water will be needed than the 1,818 gallons.
  - The function of the water is to cool the gases that is transferring heat via convection to the Orbiter's surface from 1,510°deg to below 1,093°deg.
- The following is a direct quote by the design team on the Original Shuttle: *"Titanium, has the ability to withstand temperatures of 650 °F, compared with 300 degrees for aluminum. This brought a considerable reduction in the weight of the thermal protection, for two reasons. The temperature resistance of titanium would make it possible to build the top areas of the wing and fuselage of this metal alone, without additional thermal protection, for they would be shielded against the extreme temperatures of re-entry by the bottom of the vehicle. In addition to this, a titanium structure could function as a heat sink, absorbing some heat and thereby reducing the thickness and the effectiveness of thermal protection where it would be needed.[ii] Overall, the advantages of titanium promised a complete orbiter, including thermal protection that would weigh some fifteen percent less than a counterpart built of aluminum. With the titanium orbiter requiring less thermal protection, it also would cost less to refurbish between missions."*
  - In accordance to the original shuttle design, we will utilize refractory metals rather than tile.
- No weight savings or penalty has been calculated for this option; however, this should be a major penalty on weight (~5,000 to 10,000 lb) but is a MAJOR savings in schedule and operations.

Internal Cooling via High-Temperature Heat Pump & Radiator

- On the original Orbiter, Freon-21 was routed through the 1,195 sq ft cargo bay doors and was used to cool the vehicle avionic systems among other equipment at a maximum rate of 29,000 btu/hr. During reentry & descent, water was used via flash evaporation for internal Orbiter cooling until the Orbiter descends below 100,000 ft at which time ammonia was used for flash evaporation.
- Orbiter-2's replace the Freon, water, and ammonia cooling systems (and the associated nitrogen pressurization systems that are used as pressurants) by simply using a heat pump to pump high pressure, high temperature (~300 deg F) GOX through the 2,386 sq ft Orbiter-2 Aerospike Nozzle/LOX tank aft dome (of course, after the nozzle cools following insertion into orbit). When the heat pump system can't send heat to the nozzle (e.g., during ascent and on the ground), it will send heat (~300 deg F GOX) to flash evaporate water; 29,000 btu/hr will require evaporating 3.5 gallons of water per hour even while on the ground.
- No weight savings or penalty is assumed for this option; however, this should be a major savings on weight and is a big savings in schedule and operations.

Auxiliary Power Units (APU)

- The original Orbiter used hypergolic powered Auxiliary Power Units (APU) to drive a hydraulic system that gimbled engines, moved Orbiter aerocontrol surfaces, lowered the wheels, and assist with wheel braking. Orbiter-2's utilizes electro-mechanical actuators that are fed by LOX-LH2 fuel cells.
- Peak power to Orbiter-2 electro-mechanical systems could be obtained via:
  - Ultra-capacitors (batteries),
  - Flywheels,
  - More fuel cells,
  - Hydraulic accumulator, and/or
  - Ultra-small LOX-LH2 turbine-generator.
- Orbiter-2's will have automatic flight controls (similar to the Russian Shuttle, Buran) that will allow remote launching and landing so that unmanned missions can be flown for cargo-only missions or to prove new revolutionary flight hardware without the risk of life.
- No weight savings or penalty is assumed for this option; however, this should be a weight penalty, but is a major savings in schedule and operations.

Douglas G. Thorpe KYrocketman@gmail.com

ORIGINAL SHUTTLE EXTERNAL TANK vs Orbiter-2 LH2 TANKS

Original Space Shuttle External Tank

- Dry Mass: 58,500 lb (Super Light Weight Version)
- LOX: 1,387,457 lb
- LH2: 234,265 lb
- Total 1,680,000 lb
- Cost: (please see Appendix 1) Varied tremendously from $38.1M for ET-41 in APR88 to $50.5M for ET-55 in FEB90 for LWT- (STS-8 to STS-95); ~$70M for SLWT-ET for STS-96 until end of program
- LOX tank dimensions: 54.6 ft x 27.6 ft diameter = 19,541.7 ft^3
- Intertank dimensions: 22.6 ft x 27.6 ft diameter
- LH2 tank dimensions: 97.0 ft x 27.6 ft diameter = 52,881.6 ft^3
  - Total ET height: 153.8 ft
- LOX tank has a pointed ogive on forward end.
- Feed lines: 17" diameter
  - The 17" LOX feedline travels down the side of the LH2 tank and causes problems with POGO, LOX geysering, as well as problems with removing latent heat, which leads to long countdowns. Parallel tanks as designed in Orbiter-2's would have prevented these problems.
- Multiple types of insulating foam are sprayed onto the exterior aluminum substrate to prevent frost formation (which could cause tile damage) and for heat abating.
- A heavy thrust beam bisects the intertank to transmit the force from the 2 SRB's to the vehicle. The thrust beam, stiffened, and elongated inner tank acts as dead weight (6,000 lb penalty[iii] on the original Shuttle Program) that must travel all the way to orbit.

Orbiter-2 LH2 External Tank

- A single external LH2 tank supplies liquid hydrogen to all Orbiter-2's.
- All Orbiter-2's consume the same amount of LH2, the Flyback Boosters consume theirs faster than the OO2 because they have more engines.
- There are presently only 3 configurations; 3 Boosters and 1 OO2 connected to a 53.6 ft diameter LH2 tank (JUMBO-4); 2 Boosters and 1 OO2 connected to a 47.32 ft diameter LH2 tank (JUMBO-3); and 1 Booster opposite 1 OO2 connected to a 39.62 ft diameter LH2 tank (JUMBO-2).
  - JUMBO-4: Four Orbiter-2's with 78 ft wingspans would form a 78 ft square box when viewed from above. There is 11.9 feet from the underside of the Orbiter-2 to the side of the Lower LH2 Tank.
  - JUMBO-3: Three Orbiter-2's would form a 78 ft triangular box when viewed from above, which would require a minimum of 45 feet tank diameter to encircle. Instead our LH2 tank diameter is 47.32 ft, in order to have the same aft and forward connection points and tank barrel length as the Jumbo-4.
  - JUMBO-2: Two Orbiter-2's would be mounted opposite a 39.62 ft diameter LH2 tank. Again, the tank diameter was chosen to have the same tank barrel length, but this tank could easily be built to the same 27.6 ft diameter as the Original ET, if desired.
- Although the Space Shuttle's ET had foam sprayed on the outside of an aluminum substrate, the Orbiter-2's LH2 External Tank will have foam sprayed on its inner surface. While cryogenic temperatures may make aluminum stronger (hence, the reason for spraying the foam on the outside of the original ET), cryogenic temperatures may make composites weaker or brittle. Although foam and ice discharging from the original ET was detrimental to the fragile silica tile on the original orbiter, the Orbiter-2's don't have any fragile TPS.
- It is our desire to fly 2, 3, or 4 Orbiter-2 that would connect on the same bottom ringframe of the lower LH2 tank. On the original ET, this ringframe (referred to as the 2058 ringframe) was the location where the aft end of the SRB's attached to the ET and approximately same location as the Orbiter Aft Attachment.

Table 6: The weight of the Orbiter-2 Liquid Hydrogen tank was calculated per the following:

Compare Wt of Original ET to Orbiter-2 Liquid Hydrogen Tank	Units	Original Shuttle LWET Shuttle ET	Orbiter-2 LH2 Aluminum	Orbiter-2 LH2 Carbon Fiber	Orbiter-2 LH2 Aluminum	Orbiter-2 LH2 Carbon Fiber	Orbiter-2 LH2 Aluminum	Orbiter-2 LH2 Carbon Fiber	Rationale for weight estimate between Original LWET and Aluminum & Composite LH2 tank
			4 O2's		3 O2's		2 O2's		
		LOX & LH2	LH2		LH2		LH2		
LH2 volume in tank	gallons	395,582	1,851,636		1,388,727		925,818		
LH2 volume in tank	ft^3	52,882	247,545		185,659		123,772		
Mass of LH2	lbs	234,265	1,092,465		819,349		546,233		
Mass of LOX	lbs	1,387,457	n/a		n/a		n/a		
Tank diameter	feet	27.6	53.6		47.32		39.62		
Tank diameter	inch	331.2	643.2		567.84		475.44		
Barrel Section Length	feet	71	71		71		71		
LOX Tank Weight	lb	12,000	n/a		n/a		n/a		Part of Orbiter-2
Innertank Weight	lb	12,100	n/a		n/a		n/a		Part of Payload Support
LH2 Tank Weight	lb	29,000	109,373	54,686	85,245	42,622.54	59,760	29,879.88	Weight is function of diameter squared
Orbiter Attachment	lb	9,100	36,400	18,200	27,300	13,650	27,300	13,650	4 Orbiter-2 attached to LH2
TPS weight	lb	4,823	4,800	4,800	4,134	4,134	3,462	3,462	Foam wt is function of diameter. LH2 tank only
TOTAL WEIGHT		**67,023**	**150,573**	**77,686**	**116,680**	**60,407**	**90,521**	**46,992**	

Assumption: Carbon Fiber composite will weigh half Aluminum component

The External LH2 tank for the JUMBO-4 vehicle is nearly twice the diameter of the ET for Shuttle (54.2ft vs 27.6ft). As a result, the JUMBO-4 LH2 tank should weigh 4 times as much as the original LWET. There will also be 4 Orbiter attachments on the Orbiter-2, resulting in 4 times the weight. Although we estimated that there is twice as much surface area on the JUMBO-4 LH2 tank as the original LWET, the JUMBO-4 TPS will weigh nearly the same, since the original LWET TPS weight estimate of 4,823 lb considered the TPS weight for all tanks including the LOX and intertank. In the carbon fiber column, the weight of the LH2 tanks and Orbiter-2 attachments has been estimated by assuming tanks constructed of carbon/epoxy composites will weigh half as much as aluminum components. This results in a LH2 tank that is slightly heavier than the original LWET even though the JUMBO-4 LH2 contains 4.4 times more LH2.

Although carbon fiber plus epoxy resin costs ~$10/lb vs ~$1/lb for Aluminum, the expected cost of producing an Orbiter-2 LH2 tank will be less than $1.6M (but we list them on the balance sheet on page 19 as $5M to be conservative), which is far less than the cost of an original Shuttle Lightweight ET at a cost of $28M to $75M each. The lower production and operational costs are a result of:

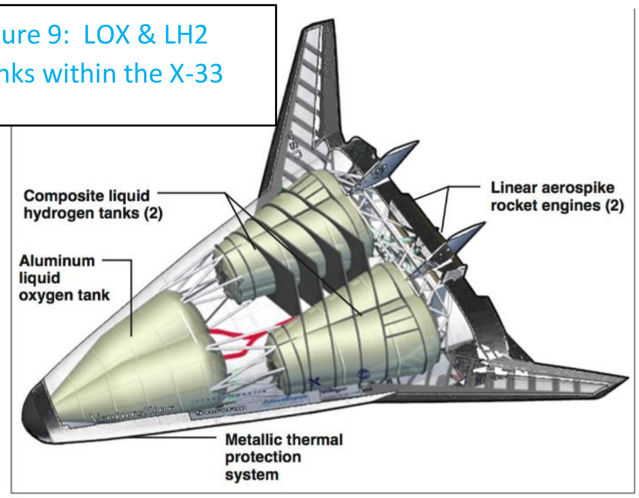
1. Much lower manpower required to set up composites
2. No epoxy substrate on composites vs aluminum.
3. No concerns of corrosions with composites.
4. Very little shipping cost for the Orbiter-2 LH2 Tank since it will be constructed at KSC vs the Shuttle External Tank was constructed in New Orleans.
5. Foam is very fragile and is easily damaged, which leads to expensive repairs during VAB checkout or pad operations. By having foam sprayed on the inside of the Orbiter-2 External LH2 tank, dings will no longer be a problem.
6. Only the OO2 provides heated GH2 to maintain ullage pressure on the large external LH2 tank; there is no need to have a separate GH2 line from each flyback booster.
7. The LOX tanks are self-pressurized with cold GOX. Upon reaching orbit, the remaining LOX and GOX is used by the fuel cells for power along with the LH2 in the Orbiter-2 tanks.

Why will the Orbiter-2 Composite LH2 Tank succeed where the X-33 tank failed?

Orbiter-2 will use Composite Cryotank Technologies and Demonstration (CCTD) project technology that was demonstrated by a 5.5-meter diameter composite tank in 2014; tank was built by the Boeing Company and tested by NASA-Marshall. (See Figure Below)

The Alliant Techsystems tank for the X-33 by Lockheed in 1998 was a quad-lobe structure of a sandwich-honeycomb graphic epoxy construction. The problem with their tank was, if hydrogen gas infiltrated via cracks in the inner plies into the honeycomb structure while under pressure, the gas would become trapped when pressure was removed.

Figure 9: LOX & LH2 Tanks within the X-33



Source: NASA.

Figure 10: X-33 Tank Construction

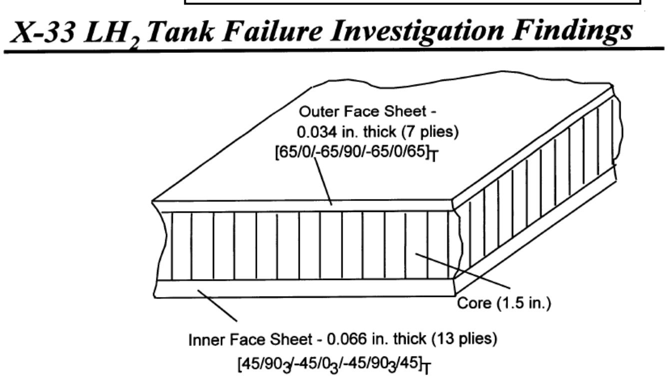
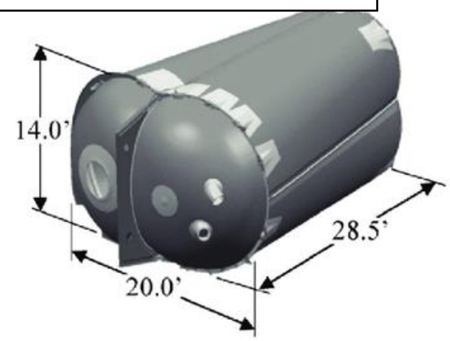


Figure 11: X-33 Tank Configuration



The external LH2 tank for JUMBO's will more resemble the 2014 Technology by the Boeing Company as part of Composite Cryotank Technologies and Demonstration (CCTD) project technology. Boeing developed a fluted core structure that varies significantly from honeycomb in that the core of that structure is essentially a hollow tube. If gases escape, they are very easily vented or purged through that hollow structure, according to Boeing. Although the CCTD only tested a 5.5-meter cryogenic tank, JUMBO-4 will require a 16.4-meter diameter tank.

Figure 12: CCTD Tank Construction 5.5-meter tank

Douglas G. Thorpe KYrocketman@gmail.com

SPACE SHUTTLE MAIN ENGINES vs ORBITER-2 LIQUID ROCKET ENGS

Original Space Shuttle Main Engines

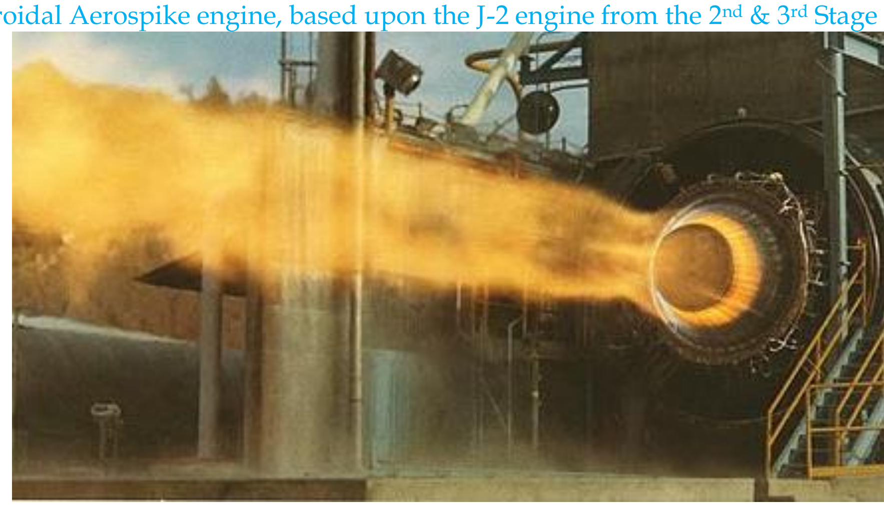
- Quantity per orbiter: **3**
- SSME at 109% throttle: 418,000 lb @ SL; 512,300 lb in vac
- Isp: 366 sec @ SL; 452.3 sec in vacuum
- LH2 flow rate: 161.8 lb/sec
- LOX flow rate: 970.9 lb/sec
- Dry weight 7,775 lb each
- Length: 168"; Diameter: 96"
- Expansion Ratio: 70:1
- Cost: ~$25M to $110M each
- Refurbishment cost $9.5M each after each mission

Figure 13: SSME's being installed in aft end of Orbiter

Orbiter-2 Main Propulsion & OMS Engines

Toroidal aerospike engine architecture has been chosen as the base design over SSME, RS-68, and other LOX-LH2 bell-nozzle engines, because of wind protuberance issues. The Flyback Boosters must generate far more thrust than what can easily fit behind the LOX tank/aft fuselage on the Orbiter-2's.

Figure 14: 250k lb Toroidal Aerospike engine, based upon the J-2 engine from the 2nd & 3rd Stage of the Saturn V.



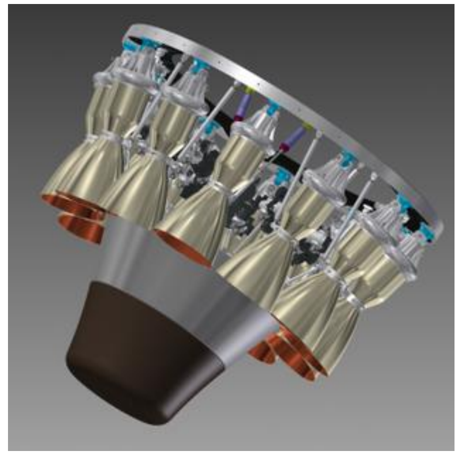
Toroidal aerospike engine will be based upon components of the RS-2200 linear aerospike shown below.

FIGURE 15: RS-2200 engine (without turbopump) in shipping crate

Figure 16: five of twenty 9.3" diameter thrusters

Douglas G. Thorpe KYrocketman@gmail.com

Figures 17a & 17b: Recent work on the Toroidal Aerospike Engine



Engine calculations will be based on the RS-2200 Linear Aerospike engine since there is not very much information on the J-2T toroidal aerospike or many other aerospike engines.

- **Original RS-2200 Linear Aerospike Engine**
  - Dimensions: 252″ wide x 93″ long at the top vs 93″ wide x 93″ long at the bottom by 170″ tall
  - Engine comprised of twenty 9.3″ diameter thrusters (10 on each side)
  - Thrust vacuum: 495,000 lbs
  - Thrust Sea Level: 431,000 lbs
  - Isp vac/S.L (seconds): 455 / 347 seconds
  - Chamber Pressure: 2,250 psi
  - Gas Generator
  - Turbopump placed between nozzle halves
  - Thrust Vector Control by gimballing engine
- **Flyback Booster Toroidal Aerospike Engine**
  - One Toroidal engine consisting of 160 thrusters that are 9.3″ dia each (same as OO2 thrusters)
  - 85 thrusters in 21′ dia circle and 75 thrusters in 20.4′ dia circle
  - Thrust vacuum: 3,943,600 lbs
  - Thrust Sea Level: 3,447,900 lbs
  - Isp vac/S.L (seconds): 455 / 347 seconds
  - Chamber Pressure: 2,250 psi
  - Expander Cycle booster & separate steam injector pump w/ two 3″ globe valves for every thruster
  - 54.4 lb/sec of propellant per thruster; 7.77 lb/sec LH2 and 46.6 lb/sec (294gpm) of LOX
  - TBD: Expander Cycle booster to manifold with separate steam injector pump for every thruster
  - Thrusters at the 4 “corners” are not connected to expander booster and can operate independently. They will produce 99,033 lb of thrust and act as the OMS engines.
  - Engine nozzle is also part of the aft dome of LOX tank Orbiter-2
  - Thrust Vector Control is via thrust differential; engine does not gimbal
- **OO2 SSME or Toroidal Aerospike Engine**
  - Engine comprised of 3 SSME’s or sixty 9.3″ dia thrusters in 21′ dia circle about 22.5ft diameter LOX tank
  - Thrust vacuum: 1,485,500 lbs
  - Thrust Sea Level: 1,293,000 lbs
  - Isp vac/S.L (seconds): 455 / 347 seconds
  - Chamber Pressure: 2,250 psi
- **Engine Development and Production Cost**:
  - Over $500M has already been invested in developing the RS-2200 technology.
  - Development cost is reduced because a standard 9.3″ diameter thruster will be utilized for all engines.
  - Estimate remaining development cost of all engines is less than $1B total
  - Using a conservative cost estimate of $20,000 per thruster (including control valves & steam injectors); OO2 & flyback booster engines should cost less than $1.2M and $3.2M respectively.

What is a Locomotive Steam Injector Pump?

FIGURE 18: Steam Injector animation (with control valve on left and one-way valve before boiler)

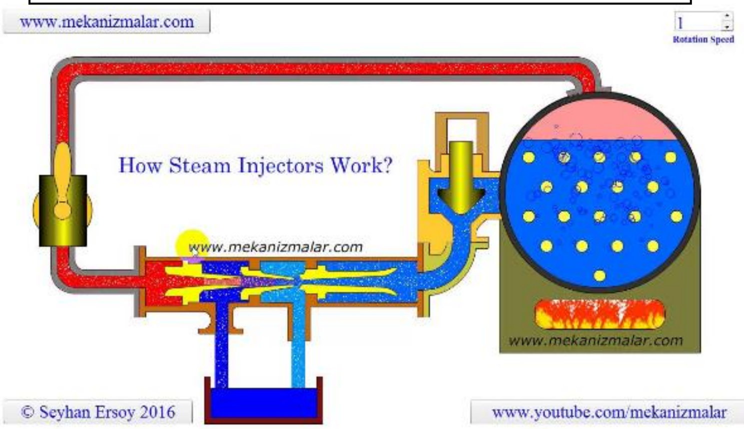
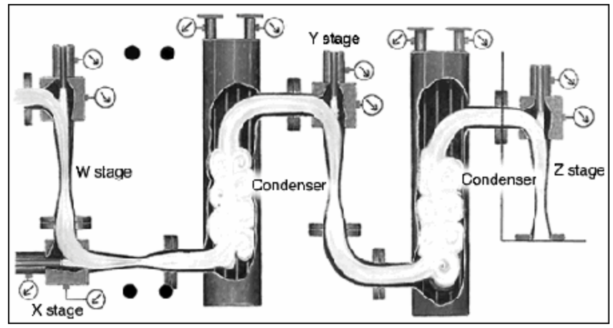


Figure 19: Multiple steam injectors in cascade to achieve higher pressures



The propellant pump for our rocket engine taps the high-pressure gases within the combustion chamber to operate a steam locomotive injector pump. The only moving part to the pump is a control valve (globe valve). The Tap-Off cycle has been demonstrated on the Blue Origin BE-3 engine and developed during the J-2S engine for the Saturn V. The Steam Locomotive Injector pump (also known as Live Steam Ejectors or just steam injectors) has operated steam locomotives for over 160 years. In this case, there is no steam and there is no locomotive; that is just what the pump has been called for 160 years! Instead of steam, high pressure H+/O2- plasma is created in the combustion chamber of a LOX-LH2 engine (a LOX/Kerosene engine combustion reactants will be slightly different). It is hoped that the high-pressure plasma can still operate the Steam Injector pump to pressurize the different propellants. When the plasma converts to steam, it will mostly likely be condensed into ice by the cryogenic propellants. NOTE: We are utilizing Steam Locomotive Injector pumps instead of stationary boiler injector pumps because the locomotives operate at higher pressure and throughput.

Engine Cooling

The Aerospike nozzle is comprised, in part, of the end dome of the LOX tank. Within the nozzle /tank dome are channels and passageways that route LOX via ullage pressure from the bottom of the aft end of the LOX dome to the beginning of the LOX tank barrel section. There, it would enter a toroidal LOX manifold for the aerospike engine. From the LOX manifold, the steam injectors pressurize LOX and send it into the combustion chambers for each thruster. The interior of the channels to the nozzle /tank dome is insulated so the heated LOX doesn't send heat into the tank. Foam is also sprayed on the exterior of the nozzle / tank dome so ambient heat doesn't enter the LOX tank while it is full of propellant in preparation of launch. Of course, the foam will burn away as soon as the engines are started. Spraying foam onto the exterior of the nozzle/tank dome must occur before each launch.

The aft most section of the aerospike engine receives much heat from the combustion products, on the Flyback Boosters. This section is cooled by LOX in route to the LOX manifold, but on the OO2, this section is cooled by LH2 that is sent to the external LH2 tank as ullage gas.

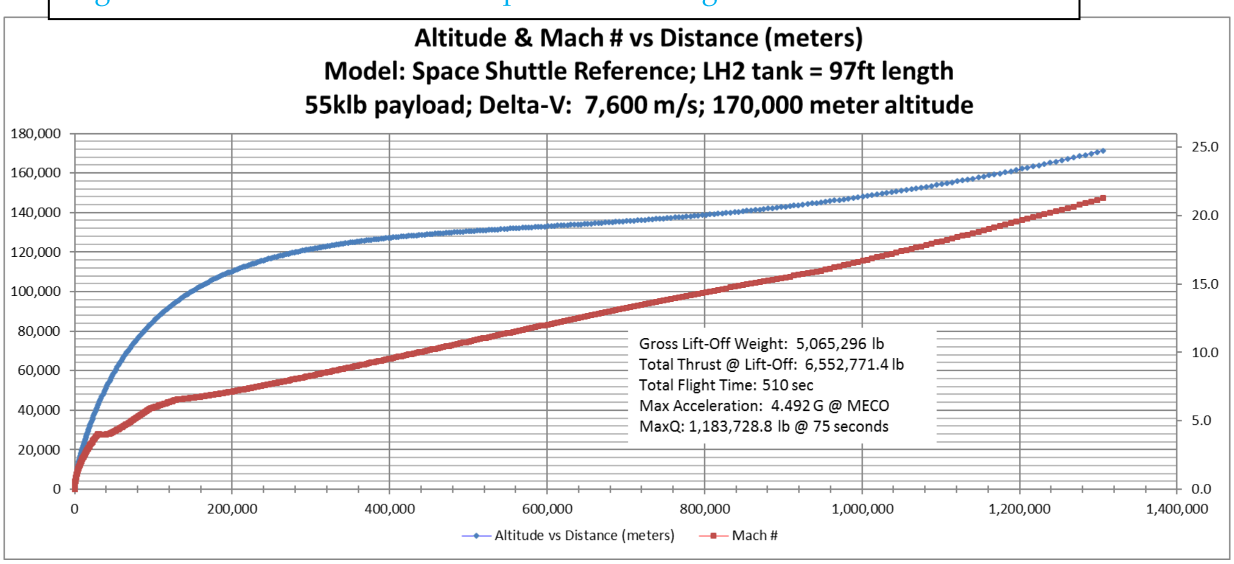
A second toroidal manifold surrounds the LOX tank and it holds LH2 that has been pumped to 100 psi by electric motors and powered by fuel cells and batteries from the OO2. Steam injectors from each thruster sends high pressure LH2 to the thruster jacket to cool down each thruster. The photo in Figure 16, shows the LH2 tube surrounding the thruster as a white tube. After cooling the throat and combustion chamber, the LH2 is routed directly into the combustion chamber.

PAYLOAD CAPABILITY:

- Payload capability was calculated for various launch vehicle configurations using our flight simulator
    - Flight simulator calculates position of supersonic aircraft or launch vehicle on a second-by-second basis and includes changes in vehicle drag & lift and Isp due to pressure and temperature
    - All flight profiles terminate at: Delta V = 7,600 m/s & 200,000 meters altitude
    - All Flyback Booster Orbiter-2s (BECO) are staged at 165 seconds
    - All OO2's have 3 SSME engines; assumed for **our flight simulator only** for identical comparisons
    - All Flyback Boosters have eight RS-2200 Linear Aerospike Engine for ease of comparison
    - No provisions to limit acceleration since that would affect identical comparison.
- In the table below, 3 options (160Spike-4MAX, 160Spike-3MAX, and 160Spike-2MAX) for the proposed vehicles are shown in comparison to the Space Shuttle with its aluminum-lithium tank.
    - 160Spike-4MAX = there are 160 thrusters to the aerospike engine and there are 3 Orbiter-2 Flyback Boosters with one OO2 orbiting vehicle.
- Also presented two options (SRB-5TRI-1MAX and 5RS68-3MAX) for comparison with different boosters and different engines
    - SRB-5TRI-2MAX = there are 2 Shuttle SRBs and one Flyback Booster with 5 Tri-UMP (SSME size w/ 2LOX & 1 LH2 turbopumps) engines that operate at 12:1 LOX-to-LH2 mixture ratio
    - 6RS68-4MAX = there are 3 Flyback Boosters that utilize 5 RS-68 engines each. Additional air drag from RS-68 engine protuberance was not considered.

Model	Space Shuttle	160Spike-4MAX	160Spike-3MAX	160Spike-2MAX	SRB-5TRI-2MAX	5RS68 - 3MAX
SRB (Yes or NO)	Yes	NO	NO	NO	Yes	NO
# of Orbiter-2 Boosters	0	3	2	1	1	3
# & Type of Booster Engines	n/a	12 RS-2200	12 RS-2200	12 RS-2200	5 TRIumphs	5 RS68
LOX-LH2 Ratio (BO2 only)	6:1	6:1	6:1	6:1	12:1	6:1
Length of LH2 Tank (ft)	94.2	114.2	109.5	103.7	98.8	114.2
Diameter of LH2 Tank (ft)	29.9	53.6	47.3	39.6	33.1	53.6
Weight of LH2 Tank (lbs)	58,500	77,686	60,407	46,992	37,356	77,686
Gross LOW (lbs)	5,065,296	7,748,265	5,799,373	3,830,344	6,549,313	7,841,526
Dry Weight (lbs)	714,175	1,191,911	882,557	553,067	976,906	1,258,761
MECO weight (lbs)	364,437	555,686	458,407	340,992	404,356	559,686
Payload (lbs)	65,937	315,000	235,000	131,000	204,000	310,000
Payload @ 90% capacity (lb)	29,494	259,431	189,159	96,901	163,564	254,031
Maximum Thrust (lbs)	6,552,771	11,591,258	8,146,855	4,700,838	9,739,326	11,193,341
Max. Q (lbs)	1,183,729	3,186,418	1,512,540	1,005,256	1,687,883	3,023,946
90% Payload to MECO wt (%)	8.1%	46.7%	41.3%	28.4%	40.5%	45.4%

Figure 20: This chart shows the Space Shuttle Flight Profile as a reference



Douglas G. Thorpe KYrocketman@gmail.com

Figure 21: This chart shows the Jumbo-4 model (referred to as 160Aerospike-4MAX) that stages 3 Booster Orbiter-2s at 165 seconds

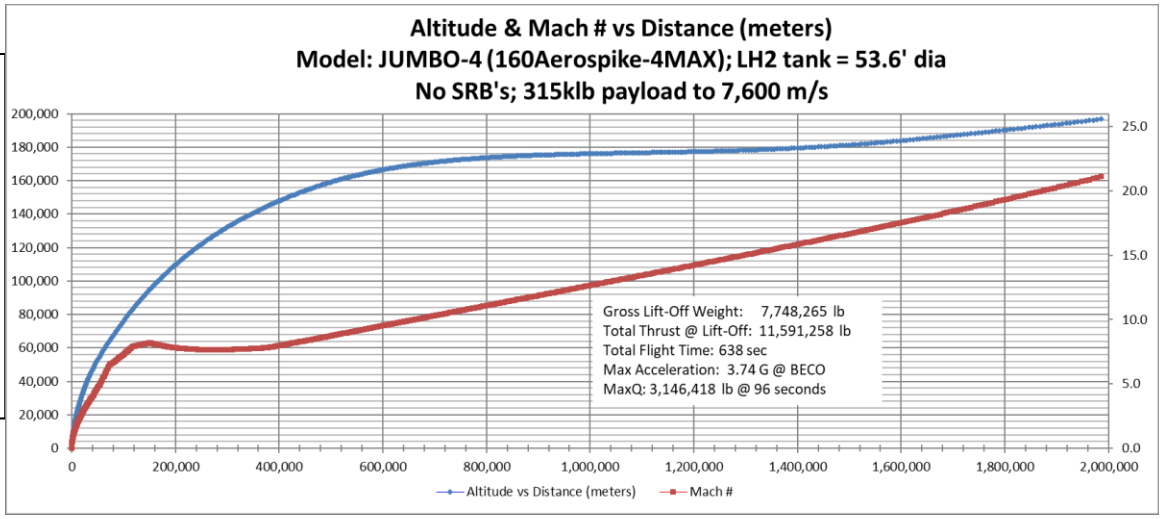


Figure 22: Saturn V with MLP/LUT and LSS

LAUNCH OPERATIONS

During the Apollo and Shuttle eras, the launch vehicle was stacked in the VAB on top of the Mobile Launch Platform (MLP) where the launch vehicles were connected to fluids, gases, sensors, and electrical interfaces to the MLP structure (which included swing arms and T-0's). The crawler-transporter would carry the MLP with the vehicle to Pad A or Pad B during an 8-hour night and set the structure on 4 posts. The same fluids, gases, sensors, and electrical interfaces would now need to be made between the ground and the MLP. This requires enormous amount of man-power and time.

The photo to the left shows the Saturn-V with MLP (with its Launch Umbilical Tower and swing arms on the right side) and a Mobile Service Structure (MSS) on the left. To reduce launch operations, it is proposed that the MLP is left at the pad and two 125ft tall MSS's provide access to all 4 Orbiter-2's and a Mobile crane would lift and stack the Orbiter-2's, LH2 tank, and external payload at the pad. The MSS's will be mounted on rails that will allow them to be quickly moved away (at T-60 seconds) from the pad in preparation for launch or quickly to the pad so the passengers could egress after a failed launch attempt. The original MSS stood 402 feet tall and weighed 12 million lbs. It only provided access platforms at 3 levels, had an elevator, and a "clean room" around the command module. Orbiter-2s need access to only 125 ft above the MLP surface. Our MSS will provide commodities to the payloads until T-60 seconds. A 750-ton mobile crane could place 175-ton payloads that go 500 feet above the MLP surface on top of the LH2 tank.

TECHNICAL ASSISTANCE REQUESTED

An estimated $4B is needed to develop and $4B to build the Orbiter-2 fleet. As part of a public-private partnership, Technical Assistance is Requested from:

- NASA-Marshall on the design, construction, material selection, and certification of the Toroidal Aerospike engines.
- NASA-Stennis on the certification of the Toroidal Aerospike engines.
- NASA-KSC on reduction in costs and man-power for engine and orbiter processing, range safety, launch operations, and man rating certification.
- NASA-JSC on the requirements and design of crew compartment and payloads

Douglas G. Thorpe KYrocketman@gmail.com

JUMBO-x FINANCIAL JUSTIFICATION

A balance sheet is derived on the amount of Revenue and Costs per mission for the proposed vehicles. Assumed 10 passengers per sub-orbital vehicle with passengers paying $100,000 and 10 orbital passengers paying $1.5M per mission. Using only 90% of payload capacity, revenue from commercial payloads was estimated at $400/lb for Total Revenue of ~$134M per JUMBO-4 mission and $106.7M for each JUMBO-3 mission.

Each JUMBO-4 mission would require ~$6M in propellant (assumed boil-off, refill, and price fluctuation would cause 100% cost increase) and a $5M disposable LH2 tank. 100 flight life-time (same as the Space Shuttle) was assumed for the $360M Orbiter-2 vehicles which results in a cost of $3.6M per vehicle per flight or $14.4M for each flight of the JUMBO-4 and $10.8M for each flight of the JUMBO-3. In like manner, the engines to each JUMBO-4 have a 100 flight life-time and would cost $0.11M total per flight. This results in a Total Variable Cost of ~$25.5M per mission for JUMBO-4 and ~$19.4M per mission for JUMBO-3. For the Worst Case, we assumed ET would cost $20M, each Orbiter-2 will cost $1.08B, & the engines will cost $40,000 per thruster.

In order to calculate the cost of Launch and Flight Operations and to determine when the JUMBO-x is not profitable, we first examine SpaceX. In 2018, SpaceX launched 15 of their Falcon 9 and Falcon Heavy's from KSC LC-39A and Cape Canaveral SLC-40 with approximately 320 vehicles in the parking lots. As a private company, there is no other way of knowing the number of employees other than counting vehicles. If SpaceX can launch and recover the boosters from 15 launch vehicles per year with 320 employees times two 60-hour shifts (=~800 FTE), then it should be possible for a well-designed JUMBO-3 or -4 to have 50 missions per year with only 1,500 employees and perhaps 500 missions per year with 10,000 employees. At an average salary of $89,000 plus 50% overhead, Launch & Flight Operations will only cost ~ $200M annually for 50 missions and $1,335M per year for 500 missions. As a Worst Case, we assumed 2,500 employees for 10 missions, which results in a cost of $33.4M per mission just for launch and flight operations.

In order to determine the upper and lower expectant annual gross profit, we looked at 500 JUMBO-4 missions vs only 10 JUMBO-3 Worst Case missions. Gross profit varied from $93.6M/mission for each of the 500 JUMBO-4 missions vs a **PROFIT** of $2.08M/mission for the Worst Case.

Table 8: Balance Sheet (Profit/Loss) per mission

BALANCE SHEET (REVENUE/COST)	**JUMBO-4**	**JUMBO-3**	**JUMBO-3 Worst Case**
Sub-Orbital Passengers/mission	30	20	20
Orbital Passengers/mission	10	10	10
Payload (90%) capacity (lbs)	259,431	189,159	189,159
Revenue per Mission			
Sub-Orbital Passenger Price ($)	$ 100,000	$ 100,000	$ 100,000
Orbital Passenger Price ($)	$ 1,500,000	$ 1,500,000	$ 1,500,000
Payload Price ($/lb)	$ 400	$ 400	$ 400
Sub-Orbital Passenger Revenue ($M)	$ 3.00	$ 2.00	$ 2.00
Orbital Passenger Revenue ($M)	$ 15.00	$ 15.00	$ 15.00
Payload Revenue ($M)	$ 103.77	$ 75.66	$ 75.66
JUMBO-4/3 Total Revenue per mission ($M)	**$ 121.77**	**$ 92.66**	**$ 92.66**
Expenses per Mission			
LOX (lbs) per mission; all vehicles	6,554,791	4,916,094	4,916,094
LH2 (lbs) per mission; all vehicles	1,092,465	819,349	819,349
LOX ($/lb) = $0.04/lb x 2 for refill and loss	$ 0.08	$ 0.08	$ 0.08
LH2 ($/lb) = $2.50/lb x 2 for refill and loss	$ 5.00	$ 5.00	$ 5.00
LOX Cost per mission ($M)	$ 0.52	$ 0.39	$ 0.39
LH2 Cost per Mission ($M)	$ 5.46	$ 4.10	$ 4.10
JUMBO-4/3 Total Propellant Costs ($M)	**$ 5.99**	**$ 4.49**	**$ 4.49**
JUMBO-4/3 External LH2 Tank Cost ($M)	**$ 5.00**	**$ 4.00**	**$ 20.00**
Orbiter-2 replacement cost/100 flights	$360M	$360M	$1,080M
JUMBO-4/3 replacement cost $M/flight	$ 14.40	$ 10.80	$ 32.40
Engine replacement cost/100 flights	$10.8M	$7.6M	$30.4M
JUMBO-4/3 Engine replacement $M/flight	$ 0.11	$ 0.08	$ 0.32
JUMBO 4/3 vehicle & engine replacement cost/flight ($M)	**$ 14.51**	**$ 10.88**	**$ 32.72**
Total Variable Cost per mission ($M)	**$ 25.49**	**$ 19.37**	**$ 57.21**
Missions per year (High/Medium/LOW)	**500**	**50**	**10**
Launch & Flight Operations man-power	10,000	1,500	2,500
Launch & Flight OPS ($M cost/year)	$ 1,335.00	$ 200.25	$ 333.75
Launch & Flight OPS $M/mission	**$ 2.67**	**$ 4.01**	**$ 33.38**
Total Cost/mission ($M)	**$ 28.16**	**$ 23.37**	**$ 90.59**
Gross Profit/mission ($M)	**$ 93.61**	**$ 69.29**	**$ 2.08**
Gross Profit/year ($M)	**$ 46,803.85**	**$ 3,464.63**	**$ 20.79**
Upper Limit of Development Cost to remain Profitable w/20% ROA ($M)	$234,019	$ 17,323	$ 104

Finally, we determined the Upper Limit for Development Cost for the Venture to provide a $20 ROI. The calculations show that if $17.323B is spent to develop a vehicle that is only launched 50 times per year, it would provide less than 17% ROI. Unfortunately, it shows in the Worst-Case scenario only $104M could be spent on development before the Venture was not profitable. But, at a price of $400/lb, it seems very unlikely that the vehicle will only be used 10 times per year.

Obviously, the way to ensure the 2nd Generation Space Shuttle venture is profitable is to design a mostly reusable, LOX/LH2 vehicle that requires less than 1.5 man-hour (~$100)/lb payload to process, launch, fly, and recover. All vehicles must be conservatively design and operated so engines and vehicle can endure 1,000's of missions and parts requiring Removal & Replacement after every launch is kept to a minimum. Incredibly, development cost is NOT a factor if a high enough launch rate is obtained. One of the greatest costs is vehicle and engine replacement after 100 flights; if we can find business to sustain 500 flights per year for the JUMBO-4, we would need to build 20 Orbiter-2's per year! Note: Boeing 747's can expect 35,000 flights in their lifetime[iv].

Wasn't the Shuttle Too Expensive & How Are We Going to Greatly Reduce the Cost?

From Table 9 below[v], the Solid Rocket Motor and the Solid Rocket Booster (the aft end that doesn't have propellant) amount to 19.5% of the total annual costs to operate the Space Shuttle. Launch Operations costs doesn't include ET and SRB processing and stacking, which are extremely man-power intensive and major cost and **schedule drivers**; making the SRB's much more than 19.5% of the total budget. There are no SRB's in the proposed 2nd Generation Space Shuttle design. Therefore, Launch Operations costs should be dramatically reduced and 100 missions (if not 500 missions) per year should be possible.

Flight Operations for the original Space Shuttle amounted to 25.5% of all Space Shuttle costs in 1997. This cost will be dramatically reduced in the proposed 2nd Generation Space Shuttle, because our Flight Operations costs stop once we reach orbit and the customer (be it NASA, USAF, or others) will pick up all expenses until the vehicle returns to earth. Our astronauts are only trained to fly the Orbiter-2's; any training beyond that will be at the expense of the customers.

Logistics and Orbiter Maintenance amounted to 11.8% of the cost of the Space Shuttle and most of it was related to the tile, hydraulics, payloads, and multiple commodities. These items have been eliminated or reduced and shouldn't be a large factor with the 2nd Generation Space Shuttle. The following is presented to show how low these costs can be: American Airlines is the world's largest passenger airline. It has nearly 2.5M flights per year, operates 956 aircraft with its 123,200 employees for a total revenue of $11,559M in 2017[vi]. It's Maintenance, Materials, and Repairs cost was only $526M, which represents 4.8% of all of their operating expenses. Therefore, MMR for American Airline aircraft only amounts to an incredibly low value of only $210.40 per flight[vii]. Logistics Operations and Orbiter Maintenance of 4 "aircraft" that flew 8 times per year, cost $375.3M and represented 5.7% & 6.1% of all expenses respectively. Instead of $210.40 per flight, Logistics, Maintenance, and Repairs for the Space Shuttle amounts to $46,912,500.00 per flight! Obviously, there is plenty of room for improvement in the design of the Shuttle to reduce its logistics and maintenance costs.

Table 9: Comparing Shuttle Cost Elements per mission; per year; percent of total annual cost vs JUMBO-3 expectant costs per mission for 50 missions/year

	Space Shuttle			JUMBO-3
Fiscal year	Fiscal Year 1997			FY 2019
Cost/Mission | Annual Cost | % Total (All Costs listed in $M)	At 9 flights/yr	Total Annual Costs	% of Total	At 50 flights/year
Launch Operations	$ 77.2	$ 694.8	21.8%	$ 4.01
Flight Operations	$ 90.6	$ 815.4	25.5%	
Logistics Operations	$ 20.1	$ 180.9	5.7%	$ -
Propellants	$ 2.6	$ 23.4	0.7%	$ 4.49
Redesigned Solid Rocket Motor	$ 47.0	$ 423.0	13.2%	$ -
Solid Rocket Booster	$ 22.4	$ 201.6	6.3%	$ -
External Tank	$ 52.0	$ 468.0	14.7%	$ 4.00
Space Shuttle Main Engines	$ 18.1	$ 162.9	5.1%	$ 0.08
Orbiter Maintenance & Support	$ 21.6	$ 194.4	6.1%	$ 10.80
Contract Administration	$ 3.2	$ 28.8	0.9%	$ -
Shuttle Operations cost/mission	**$ 354.8**	**$ 3,193.2**	100.0%	**$ 23.38**
Total Shuttle Funding per year	**$ 3,193.2**			**$ 1,169.0**
Civil Service Personnel & travel	$ 45.0	$ 405.0		

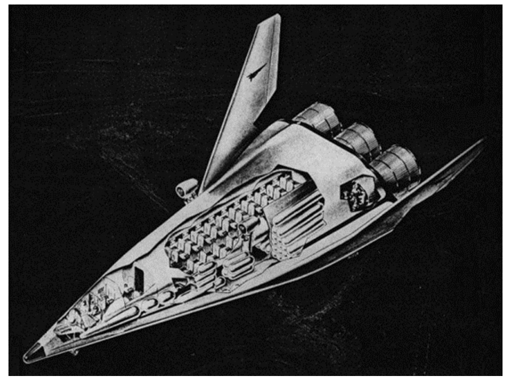
Douglas G. Thorpe KYrocketman@gmail.com

Furthermore, the SpaceX Falcon 9 Heavy expendable has 28 engines and has a price to customers of $150M[viii]. If the engines represent 50% of the cost, each engine couldn't cost more than $2.68M to manufacture and fly. From Table 9, the refurbishment (not purchasing!) of the 3 SSME's is $18.1M ($28.4M in 2018 money) per mission or $9.5M for each of the 3 engines in 2018 money! It costs 3.5 times as much to refurbish the SSME's as it does to fabricate a new SpaceX Merlin. Obviously, if the Orbiter-2's engines are designed properly and operated conservatively, we can eliminate their refurbishment cost and plan on replacing them and the Orbiter-2's after every 100+ missions.

FUTURE REVISIONS – 3rd Generation Space Shuttle W/JUMBO-2

One of the first revisions would be the development of an Orbital ShuttleBUS perhaps several years after Orbiter-2 operations begin.

Figure 23: 1960's Shuttle Bus Concept



On missions where the transportation of space tourists is the mission and not cargo payload, the development of an Orbital ShuttleBUS would be warranted. The vehicle configuration would basically be a JUMBO-2 with the OO2 more resembling the Original Space Shuttle and the common external tank would carry LH2 for both vehicles but also LOX for the OO2 only. Instead of a 22 ft diameter LOX tank carried within the OO2, there would be two decks of cots and a transparent top.

The cots are spaced over 20 rows with 17 cots per row resulting in accommodations for 340 passengers. The cots are arranged in a 4-4 seating with one isle/ladder.

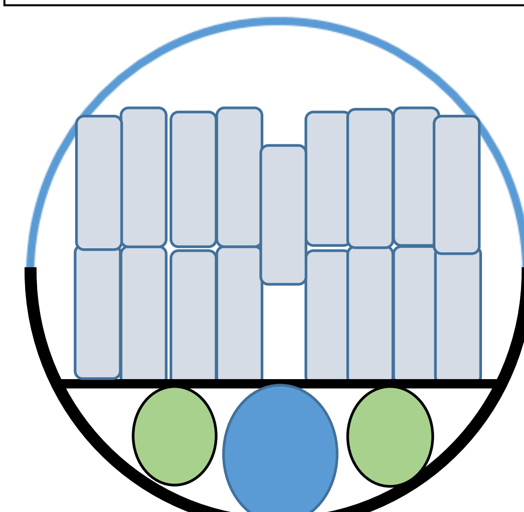
WHAT DO WE MEAN BY COTS?

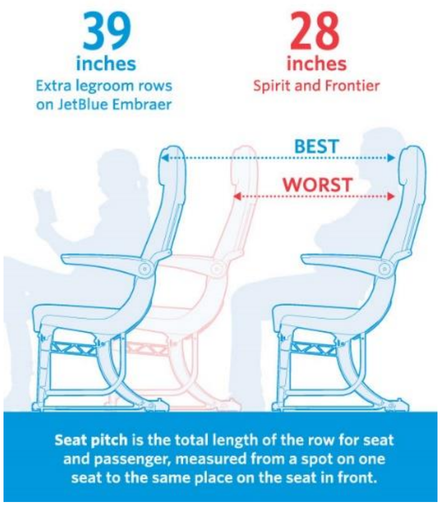
It's only a 10-minute ride! Why should the passengers have chairs?

Below-left are cots from a typical USA Navy vessel. Orbiter-3 cots are: 2ft wide x 6ft tall; will have a foot pad to stand on when shuttleBUS lands; will restrain passenger movement by them being zipped up in a attached sleeping bag; and can fold out of the way once in orbit. Below-right is a cross-section of the Orbiter-3 showing two layers of cots, 8 rows per layer with 1 isle cot. Below the deck is a central LH2 tank and two LOX tanks for OMS/RCS/Fuel Cells/LSS. To the right and above the cots is a transparent hemisphere (shown as a thick blue line). From the outside, the Orbiter-3 appears to be identical to an Orbiter-2.

Figure 24: Photo of allowable seat pitch of cots

Figure 25: Cross-Sectional view of Orbiter-3 (without wings) showing layout of cots, deck, & tanks





SEAT PITCH

The seat pitch (the distance between cots) is nearly the same as most airlines at 32".

ShuttleBUS COST PER ORBITAL TOURIST

Extrapolating from Table 8, a JUMBO-2 or a ShuttleBUS should cost $16.15M/mission in quantities of 500 missions per year. Each of the 340 ShuttleBUS passengers will need to pay at least **$47,500 plus profit or $100,000 for a ride to a LEO hotel**. Again, nearly half of $16.15M cost per mission is the cost of replacing the ShuttleBUS after every 100 missions. If vehicle lifetime could be increased to 300 or even 1,000 flights, rides to a LEO hotel could be dropped to $25,000 plus profit.

WHERE WILL WE FIND 100,000's PASSENGERS TO FLY THE SHUTTLEBUS?

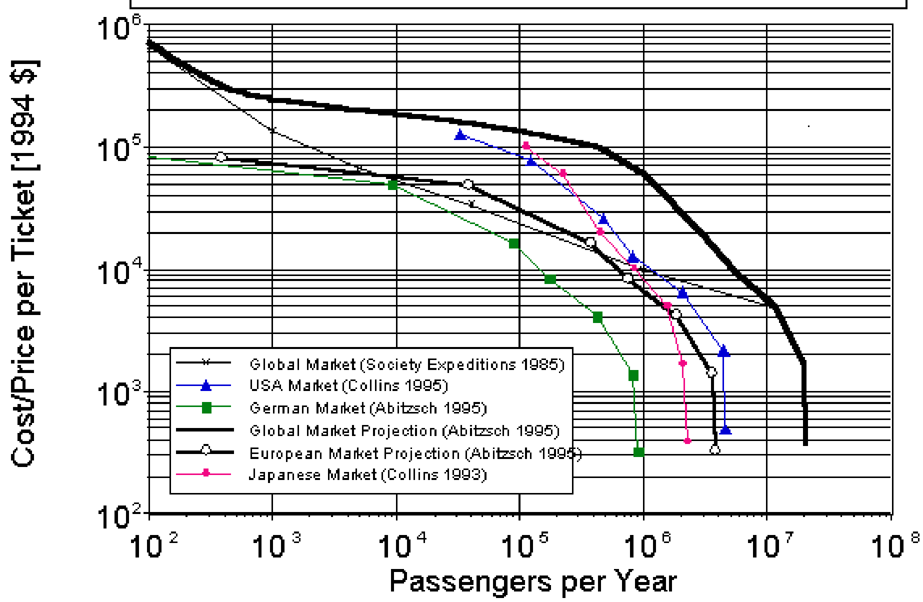
Three types of tourists will need to be discovered for all JUMBOs:

1. 10 to 30 sub-orbital tourists per mission who will pay $100k to fly 10 minutes on the Flyback Boosters for the thrill and 5 minutes of zero-G. Price of Flyback Boosters with ShuttleBUS will be less than $10k.
2. 10 orbital tourists per mission who will pay $1.5M to fly in the OO2 into orbit to ISS or small space lab. Or they may be satisfied with merely floating in the OO2 for several 90-minute orbits and return to the launch site on the same day.
3. 340 orbital tourists per mission who would pay $100k to fly in the ShuttleBUS to a Space Hotel

Cost of 1 week stay at ISS or Space Hotel will be an additional charge. Tourists may be taken to another vehicle that will take them to the Moon, Mars, or beyond.

To the right is a chart[ix] from 1994 that shows various space tourism markets. At $100,000 in 2018 money, one million passengers per year can be found from the Global Market. At $250,000 in 2018 money, the number of expectant passengers will fall to 100,000 per year. 100,000 space tourists per year will require 294 ShuttleBUS missions, or nearly a flight every single day of the year. Total revenue from the ShuttleBUS would be $85M per mission or $25B per year. The ShuttleBUS would be mostly independent revenue from any cargo and Orbiter-2 missions. 294 missions would require a new ShuttleBUS orbiter built every year.

Figure 24: If cost of ShuttleBUS ticket is $100,000 in 2018 money, the Global Market size is 1,000,000 tourists per year



Douglas G. Thorpe KYrocketman@gmail.com

RESCUE & PAYLOAD RETURN TO SURFACE CAPSULES

One of the most known features of the original Space Shuttle was its ability to place payloads in its cargo bay and return them back to the surface of the earth. The Orbiter-2's have a very limited payload capability of 10,000 lb and a space of 20ft by 10 ft. It may be possible, but not recommended to recover small payloads in place them in this area, which would mean a removable hatch that was 20ft by 10ft in size. In addition, the Orbiter-3 has the ability to take a great number of the people to space, who may need to return to the surface at greater a rate that is greater than the 340 seats.

As a result, a **Rescue and Payload Return to Surface Capsule** should be developed. Although this task will be left to others since it is not part of the Orbiter-2 or Orbiter-3 functions, some logical designs of such a R&P capsule are presented. JUMBO-4 should be able to loft a 53ft diameter capsule that resembles an over-size Apollo capsule in outer appearance. Such a capsule could be 50ft or more in height. A Rescue version would have multiple layers of cots to which people would lay for the trip back. A payload version would be hollow and any size payload (satellite, asteroid, etc) would be placed within. Rather than land in the ocean, it would make more sense to land in the middle of the American desert by using parachutes and retro rockets in similar manner as the Russian vehicles.

SUMMARY CONCLUSION

This paper took a whole different approach at what should be possible for a true Space Shuttle by incorporating as many of the lessons learned for the original Space Shuttle program. No where else are launch vehicle designers proposing 100's missions per year for vehicles that can loft 350,000 lb @ $400/lb or transporting 340 passengers at a time at less than the price of a Tesla Model X or a Corvette.

The 2nd Generation Space Shuttle program should be strictly a private enterprise venture. Even at the worst case of 10 flights per year, the 2nd Generation Space Shuttle is still profitable. The absolute key to a successful and profitable launch vehicle program is to remove as much as possible the processing labor that is required to get the reusable launch vehicle prepared for the next launch. A target for launch operations labor should be no more than 1.5 man-hours per pound (which equals ~$100/lb) of useful payload into orbit. To reduce labor requirements, sacrifices in performance and extra development costs are warranted, but this doesn't mean developing GSE that is rarely utilized, such as the Mate-Demate Device or Orbiter Transporter. To further reduce costs, vehicles should be stacked at the pad using commercial mobile cranes.

Space Shuttle Discovery (OV-103) completed 39 missions, the most of any of the original orbiters, but it this is just over a third of its 100-mission life. When the flight rate approaches the numbers proposed herein, a 100-mission life requirement for the 2nd Generation Space Shuttles is a major expense.

The 2nd Generation Space Shuttle will accomplish the goals and dreams of the original Space Shuttle, but it will be a commercial operation. We will never be a space faring society until the costs presented here are a reality.

The concept should be fully vetted by the nation's aerospace community and if found accurate, a Public/Private Partnership should be created.

The only thing stopping the 2nd Generation Space Shuttle from becoming a reality is a charismatic trusted leader who can find the financial resources to make it happen. Please contact the author if you wish to join/participate/assist in making the 2nd Generation Space Shuttle a reality.

The author is receptive and appreciative to all comments, corrections, and good advice.
Doug Thorpe

Douglas G. Thorpe KYrocketman@gmail.com

Appendix 1: DD-250 for Space Shuttle ET-41 & ET-55

[M]ATERIAL INSPECTION AND [R]ECEIVING REPORT

1. PROC. INSTRUMENT IDEN (CONTRACT): NAS8-33708 | (ORDER) NO. | 6. INVOICE NO. | DATE | 7. PAGE 1 OF 1 | 8. ACCEPTANCE POINT S

2. SHIPMENT NO.: MAF2746 | 3. DATE SHIPPED: 88APR22 | 4. B/L TCN: NASA Barge | 5. DISCOUNT TERMS: N/A

9. PRIME CONTRACTOR CODE 10860
Martin Marietta Manned Space Systems
Post Office Box 29304
New Orleans, LA 70189

10. ADMINISTERED BY CODE AP43
Procurement Office
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

11. SHIPPED FROM (if other than 9) CODE FOB: S
"See Block 9"

Q.I. COPY

12. PAYMENT WILL BE MADE BY CODE BF52
Financial Management Officer
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

13. SHIPPED TO CODE
Michoud Assembly Facility
National Aeronautics and Space Administration
New Orleans, Louisiana 70189
Attention: Mr. J. W. Hill, SA39

14. MARKED FOR CODE
For Contract NAS10-10900

RECEIVED
DATE 3-13-92

15. ITEM NO.	16. STOCK/PART NO. DESCRIPTION (Indicate number of shipping containers - type of container - container number.)	17. QUANTITY SHIP/REC'D*	18. UNIT	19. UNIT PRICE	20. AMOUNT
A[R]T. IB	P/N 80901010000-080 External Tank Dwg. DCN Level: CU S/N 0000041 CEI Spec No.: CPT01M09A Part I Spec. SCN Level: 212 Part II Spec. SCN Level: 024		EA.	ESTIMATED PRICE	$8,100,000.00
ART. IC	Acceptance Data Package for Above	1	EA.		
	NOTE: Ship Loose Hardware - Pack and Ship Items that are part of the above Contract End Item will be shipped via MIRR No. MAF2745.				

VOUCHER # DLSOC92-0154
SIGNATURE Hugh S. Jordan
QC M. Petersen 3-16-92
POSTED

21. PROCUREMENT QUALITY ASSURANCE

A. ORIGIN
[X] PQA [X] ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents.
88APR22 — DATE; Henry B. Logan — SIGNATURE OF AUTH GOVT REP
TYPED NAME AND OFFICE: HENRY B. LOGAN NQOAC

B. DESTINATION
[ ] PQA [ ] ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents.
DATE — SIGNATURE OF AUTH GOVT REP
TYPED NAME AND TITLE

22. RECEIVER'S USE
Quantities shown in column 17 were received in apparent good condition except as noted.
DATE — SIGNATURE OF AUTH GOVT REP
TYPED NAME AND OFFICE
* If quantity received by the Government is the same as quantity shipped, indicate by (✓) mark. If different, enter actual quantity received below quantity shipped and encircle.

23. CONTRACTOR USE ONLY

SHIPPING INSTRUCTIONS: N/A
BOX SIZES: 1-ET S/N41 & Data Pkg.
PRESERVED FOR: N/A
WT: N/A | CUBE: N/A | PACKED BY: N/A
LEVEL OF PACK: N/A
ACCT NO.: N/A
REMARKS
VOUCHER NO. 88-1129
[signature] 4/22/88 — MARTIN MARIETTA QUALITY — DATE

DISTRIBUTION
[N]CAS[-]F, RMQ-1 Bldg. 102 (2)
[N]AS[A/MSFC], SA39 (1)
[N]AS[A/MSF]C, SA34 (1)
[N]ASA/MSFC, AP43 (2)
[N]ASA/MSFC, SA83 (1)
[N]ASA/MSFC, SA31 (1)
MMC/MAF, 3300 (3)
MMC/MAF, 3840 (2)
MMC/MAF, 3720 (2)
MMC/MAF, 3742 (1)

DD FORM 250

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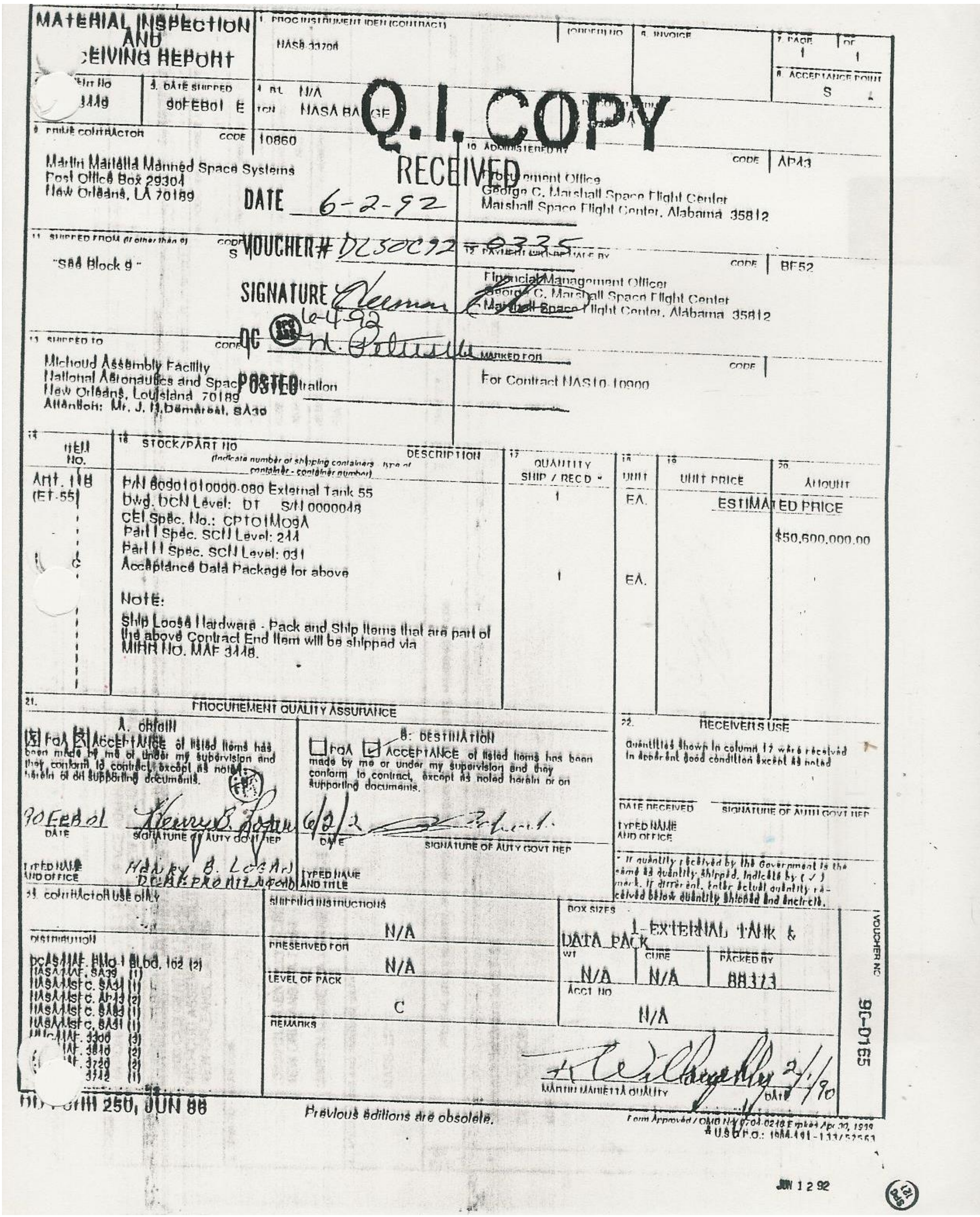
Douglas G. Thorpe KYrocketman@gmail.com



MATERIAL INSPECTION AND RECEIVING REPORT

PROC INSTRUMENT IDEN (CONTRACT) NAS8 33708

7. PAGE 1 OF 1

8. ACCEPTANCE POINT S

3. DATE SHIPPED 90FEB01

B/L N/A

TCN NASA BADGE

Q.I. COPY

RECEIVED DATE 6-2-92

9. PRIME CONTRACTOR CODE 10860

Martin Marietta Manned Space Systems
Post Office Box 29304
New Orleans, LA 70189

10. ADMINISTERED BY CODE AP43

Procurement Office
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

11. SHIPPED FROM (If other than 9) CODE

"SAA Block 9"

VOUCHER# DL30C92-0335

12. PAYMENT WILL BE MADE BY CODE BF52

Financial Management Officer
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SIGNATURE 6-4-92

QC

13. SHIPPED TO CODE

Michoud Assembly Facility
National Aeronautics and Space Administration
New Orleans, Louisiana 70189
Attention: Mr. J. H. Demarest, SA39

POSTED

14. MARKED FOR CODE

For Contract NAS10-10000

15. ITEM NO.	16. STOCK/PART NO. DESCRIPTION (Indicate number of shipping containers - type of container - container number)	17. QUANTITY SHIP/REC'D	18. UNIT	19. UNIT PRICE	20. AMOUNT
Att. 1 18 (ET-55)	P/N 80901010000-080 External Tank 55 Dwg. DCN Level: 01 S/N 0000048 CEI Spec. No.: CP101M09A Part I Spec. SCN Level: 244 Part II Spec. SCN Level: 031	1	EA.	ESTIMATED PRICE	$50,600,000.00
	Acceptance Data Package for above	1	EA.		
	Note: Ship Loose Hardware - Pack and Ship Items that are part of the above Contract End Item will be shipped via MIRR No. MAF 3448.				

21. PROCUREMENT QUALITY ASSURANCE

A. ORIGIN

☒ PQA ☒ ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents.

90FEB01 DATE — SIGNATURE OF AUTH GOVT REP

TYPED NAME AND OFFICE: HARRY B. LOGAN

B. DESTINATION

☐ PQA ☒ ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents.

6/2/2 DATE — SIGNATURE OF AUTH GOVT REP

TYPED NAME AND TITLE

22. RECEIVER'S USE

Quantities shown in column 17 were received in apparent good condition except as noted

DATE RECEIVED — SIGNATURE OF AUTH GOVT REP

TYPED NAME AND OFFICE

* If quantity received by the Government is the same as quantity shipped, indicate by (✓) mark, if different, enter actual quantity received below quantity shipped and encircle.

23. CONTRACTOR USE ONLY

SHIPPING INSTRUCTIONS N/A

PRESERVED FOR N/A

LEVEL OF PACK C

REMARKS

BOX SIZES: 1-EXTERNAL TANK & DATA PACK

WT N/A — CUBE N/A — PACKED BY 88373

ACCT NO N/A

DISTRIBUTION

DCAS MAF, Bldg. 102 (2)
NASA MAF, SA39 (1)
NASA MSFC, SA31 (1)
NASA MSFC, AP43 (2)
NASA MSFC, SA63 (1)
NASA MSFC, SA31 (1)
MMC MAF, 3300 (3)
MAF, 3840 (2)
MAF, 3720 (2)
3742 (1)

MARTIN MARIETTA QUALITY DATE 2/1/90

VOUCHER NO. 9C-D165

DD FORM 250, JUN 88 Previous editions are obsolete.

Form Approved / OMB No. 0704-0248

JUN 1 2 92

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[ii] http://www.nss.org:8080/resources/library/shuttledecision/chapter08.htm

[iii] http://space.nss.org/media/SSP-Boeing-CR151558-1977-Part1Vol5-Transportation-Descriptions.pdf, page 137

[iv] https://www.flexport.com/blog/decommissioned-planes-salvage-value

[v] US GAO, Report to the Chairman, Subcommittee on Investigations and Oversight committee on Science, Space, and Technology, House of Representatives, "*Space Transportation, The Content and Uses of Shuttle Cost Estimates*", January 1993.

[vi] https://americanairlines.gcs-web.com/news-releases/news-release-details/american-airlines-group-reports-third-quarter-2018-profit

[vii] https://americanairlines.gcs-web.com/financial-results/financial-aal

[viii] https://www.cnbc.com/2018/02/12/elon-musk-spacex-falcon-heavy-costs-150-million-at-most.html

[ix] M Reichert, "*The Future of Space Tourism*", 50th International Astronautical Congress, 4-8 October 1999, Amsterdam, The Netherlands