

Sub-Orbital Passenger Aircraft for Space Launch Operations

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ABSTRACT

This is a follow-on paper of our 2012 and 2014 work^{i, ii}. All papers have the same goal of providing a high-level concept that shows a Hybrid Suborbital Aircraft (HSA) can be used for passenger Point-To-Point (PTP) and Earth-To-Orbit (ETO) operations to achieve remarkable costs reductions. In previous papers, we made broad assumptions on the characteristics of the air breathing engine operations as well as we neglected the heating effects of high Mach numbers on the aircraft structure. In this paper we will take a very close look at several supersonic aircraft and validate their performance against our flight simulation program. We will set ground rules and modify the equivalents of one of those aircraft to achieve our goals, which will be confirmed by our flight simulation program. The basic goal of our aircraft is transporting 300+ passengers more than 5,000 miles or delivering a 200,000 lb gross weight upper stage and payload to the Karman line. Such an upper stage delivered to the Karman line should be capable of transporting 40,000 lb to low earth orbit. By developing and operating two versions (a passenger PTP version and a ETO version) of the same aircraft we hope to show remarkable development and re-occurring cost savings can be achieved that couldn't be materialized if operated as a single function aircraft.

- In this paper we hope to determine:

1. What is the optimum flight scheme?
 - Do we utilize the air breathing engine to its greatest altitude and Mach number before we consume all remaining propellant in the rocket engine to achieve even greater speed and altitude and then glide as far as possible? OR
 - Do we utilize the air breathing engine to its greatest altitude and Mach number; glide as far as possible, before kicking the air breathing engine on again at ~Mach 1.1 to repeat process?
2. What are the PTP flight range, flight path, wing loads, and inlet conditions of the different versions of a 675,000 lb gross weight PTP-HSA?
3. What is the maximum staging speed and altitude a 675,000 lb gross weight ETO-HSA can transport an upper stage?
4. In consideration of airport operations:
 - What are the operations, maintenance, and propellant costs of a Subsonic vs Mach 2 engine vs one of the proposed flight schemes?
 - Some people think that the Concorde was a commercial failure because of its high maintenance cost due to flying at Mach 2. How would our vehicle be more of a commercial success than the Concorde?
 - We are considering loading LH2, LOX, or Liquid methane at an airport, how is this done safely, quickly (less than 30 minutes), and cheaply?
5. Our airplane could have rocket propulsion components:

- The first concern is: The Space Shuttle required 6 months after landing before it could fly again, how could an airplane with a rocket engine and cryogenic tanks be made to fly within 30 minutes of landing?
 - The second concern is: Rockets seem to ALWAYS have launch delays, why would our airplane not have delays (even while in flight) now that it has rocket propulsion?
6. Compare the proposed system with the Andrews Space Peregrine reusable launch vehicle
 7. What are the strategic military advantages of having a civilian PTP-HSA with ETO capability?
 8. Is a Mars mission on any given day possible?

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I. NOMENCLATURE

PTP	= Point-To-Point
HSA	= Hybrid Suborbital Aircraft
ETO	= Earth-To-Orbit
LEO	= Low Earth Orbit
LOX	= Liquid Oxygen
LH ₂	= Liquid Hydrogen
Delta V	= delta velocity
MTOW	= Mean Takeoff Weight
RP1	= Rocket Propellant Number One
US	= United States
SUSTAIN	= Small Unit Space Transport and Insertion
#	= pounds or number
K	= thousand
M	= million
B	= billion
\$	= dollars
Ave	= average
ACMI	= Aircraft, Crew, Maintenance, and Insurance
~	= approximately
hr	= hour
lb	= pound
LNG	= Liquid Natural Gas
a.k.a	= also known as
PCM	= Passenger Compartment Module
&	= and
m/s	= meters per second
Atm	= atmosphere
psi	= pounds per square foot
K	= Kelvin
kg/m ³	= kilograms per cubic meter
km	= kilometer
sec	= second
DDT&E	= Design, Development, Testing, and Engineering
PCM	= Passenger Compartment Module
CBM	= Cargo Bay Module
STM	= Space Tourism Module
LCM	= Luggage Compartment Module
OEPSS	= Operational Efficiency Propulsion System Study

II. BACKGROUND

Numerous studies have determined the advantages of an air launched Earth-To-Orbit launched system versus a non-air launched system. Almost all air launched systems utilized a sub-sonic freight aircraft as a launch platform for a rocket propelled upper-stage. The two biggest problems with this approach are:

1. The upper stage must still accomplish a large delta-Vee. If Low Earth Orbit is thought of at Mach 25, then the upper stage must achieve a delta-Vee of approximately Mach 24.
2. Subsonic aircraft do not travel at very high altitudes; therefore, an air launched system must fight aerodynamic forces to separate from the air-breathing aircraft as well as travel in the atmosphere for a long time before it can behave as a typical upper stage.

The authors have published a series of papers with the theme of developing a commercially successful, supersonic passenger aircraft that is specifically designed to be modified to air launched upper stages. In previous papers, we introduced the concept of using a supersonic aircraft to transport an upper stage to a very high altitude, namely the Karman Line. We also provided a modification of the fictitious supersonic aircraft whereby it contained liquid rocket engines that would ignite once the aircraft reached a designed cruising altitude and speed using conventional air breathing engines; in the first two papers, we chose 60,000 ft and Mach 2. Bear in mind that we are using the supersonic aircraft to perform much of the same launch vehicle functions as the first stage of a 20,000 lb payload class of launch vehicle, such as a Delta IV medium, an Atlas V 401, or a Falcon 9 v1.0. To get a measure of the enormity to the re-occurring cost savings we are proposing, you should compare the costs of building, processing, and operating just the first stage and ground support equipment of those vehicles to the costs of operating a commercial aircraft.

As we previously stated in that paper, most passenger aircraft (including supersonic aircraft) have propellant carrying capacity to travel for many hours after reaching cruising altitude since these same aircraft can reach cruising altitude and speed in less than 30 minutes. We wish to utilize this propellant capacity to operate the liquid rocket engines while they propel the supersonic aircraft from cruising altitude to the Karman Line and beyond.

In that same previous paper, we provided the lower and upper limits on the costs of operating a commercial (747 size) aircraft via their Aircraft, Crew, Maintenance, and Insurance (ACMI) and private charter rates as being between \$4,600 and \$60,000 per hour respectively. We used this information to determine the lower and upper operating costs of using some sort of highly competitive, commercial, supersonic aircraft to launch our upper stage to the Karman Line as between \$102,000 and \$305,000; although in this paper you will see that that upper limit was more than doubled for the new larger and faster vehicle.

Concepts for Earth-To-Orbit air-launched systems are usually presented with little regards to the commercial success of the aircraft. In this paper, the commercial success of the aircraft is paramount to the successful operation of the launch system. Instead of presenting just another launch vehicle concept to which we hope government funding would be secured to develop a launch vehicle to compete with existing systems, we will present a commercial passenger supersonic aircraft that can be easily modified to launch an upper stage. Presently, there are no supersonic freight aircraft. Therefore air launched systems are mostly limited to subsonic aircraft. Furthermore, developing a supersonic aircraft (or flyback booster) for the single, limited purpose will be non-practical. On the other hand, if a commercially successful supersonic aircraft could be developed, the cost of modifying a unit from the fleet would be a fraction of developing a single purpose, supersonic aircraft.

What we finally concluded in that paper was that if our findings were within an order of magnitude of being correct, such a launch system would be a **revolutionary leap** in reducing the cost of going into orbit!

Usual Problems with Developing an Earth-To-Orbit Air-Launched Vehicle

Most previous papers and proposals at developing an Earth-To-Orbit launch vehicle were always focused around the single purpose of placing a payload into orbit (i.e., the Pegasus L-1011 aircraft is mostly used to just launch the Pegasus and would not be commercially competitive in other aircraft markets without removing the Pegasus modifications.) The first problem with this approach is the market for Earth-To-Orbit transportation is very small at approximately \$2B per year for 28 commercial missions and just 70 total global launches (commercial, military, and government). Such a small market results in a business case that is very difficult to justify the development cost of a reusable launch vehicle or technologies that would significantly lower the cost to orbit. The second problem with most air launched vehicles is that they are subsonic. Launching very large payloads at subsonic speeds is not a trivial task. In addition, the amount of energy gained by subsonic air-launching is not very substantial especially since the upper stage will still need to “fly” through the atmosphere for a long while. Therefore we are taking a totally different approach.

III: GROUND RULES & VEHICLE SELECTION

Our Different Approach at Developing an Earth-To-Orbit Air-Launched Vehicle / Flyback Booster

The authors have published a series of papers with the theme of developing a commercially successful, supersonic passenger aircraft that is specifically designed to be modified to air launched upper stages. The commercial passenger airline industry absolutely dwarfs the Earth-to-Orbit (ETO) transportation market (\$5,000B vs \$2B) via 642 million passengers on 8.9 million airline flights each yearⁱⁱⁱ vs less than 543^{iv} to EVER go into space with a maximum of only 26 commercial space flights each year. It was our desire to fly the upper stage and payload to supersonic cruising speed and altitude in 20 minutes after leaving the runway. We would then either:

1. Utilize the remaining fuel capacity in the aircraft to feed liquid rocket engines to push the aircraft to higher Mach numbers and/or extremely high altitudes so we could launch the upper stage without much adverse effects from wind drag. **OR**
2. Carry much less fuel for the aircraft and transfer the remaining fuel capacity to a larger upper stage.

Originally, we proposed the modification of the retired Concorde since it was the only large supersonic aircraft, but since it wasn't designed to be modified as such, it quickly became impractical for such an endeavor.

Ground Rules and What We are Trying to Accomplish

1. In order to obtain the least impact to airport operation, the 1st generation aircraft can only utilize standard aviation fuel (Jet-A); a 2nd generation aircraft could use liquid hydrogen (LH2). If necessary, we would utilize water (as a coolant) and liquid oxygen (LOX) during extreme altitude or extreme Mach number operation.
2. The aircraft should be modeled in passenger capacity, Maximum Take-Off Weight (MTOW), and range after the Boeing 2707^v
 - 300 passengers
 - 675,000 lb MTOW
 - 312,500 lb = 46,575 gallons of Jet-A fuel
 - 6,000 mile range (the Boeing 2707 had a range of only 4,250 nm with 275 passengers^{vi})
 - NO bent nose (the Boeing 2707 nose bent in two places)
3. Total Expected Revenue per flight: \$400,000 (300 passengers * \$1,333 average ticket price one-way)
4. 6 flights per 16 hour work day = \$2.4M revenue per work-day vs \$2,324,638 for Qantas Flight 7
5. Obtains very high altitude & high Mach then glides as far as possible OR cruises as Mach 5
6. Target average velocity of Mach 6
7. Minimum fleet size of 75 aircraft
8. Maximum development cost of \$15B
9. Be easily modified to launch upper rocket stages (and payloads) at Mach 6⁺ or fly passengers on same day
10. We have set a target of 20,000 lb (10 tons) of useful payload if flown due east from the National Aeronautics & Space Administration at the Kennedy Space Center (NASA-KSC) into a 100 mile circular orbit.

To achieve these goals:

- The aircraft must be extremely adaptable by being able to convert from a passenger aircraft into an ETO air launcher and back into a passenger aircraft within one work shift
- Utilize the air inlet technique of the Concorde vs the SR-71
- Unlike the Boeing 2707 and similar to the Concorde, No horizontal stabilizer
- Unlike the Boeing 2707 and similar to the Concorde & Lockheed L2000-7B, No retractable wings
- Retractable forward canards like the TU-144 (the Concorde)^{vii}
- Airplane wing should be designed to take advantage of compression lift, such as the wing design by the XB-70 Valkyrie.
- A lift-to-drag ratio (L/D) that is at least 75% of the maximum theoretical L/D
- Use of aerospike engines on each wing with multiple combustion chambers for each engine

Figure 1: Boeing 2707 as reference, but the resulting aircraft would more resemble the Concorde or Lockheed L 7000-7B.



Figure 2: Boeing 2707 in relation in size to common aircraft^{viii}



Figure 3: An internal schematic of the Concorde^{ix} showing the fuel tanks, engines, and passenger chairs among other things.
NOTE: The absence of a rear horizontal stabilizer.



Figure 6: Comparing the various supersonic aircraft. The aircraft are presented from greatest number of flights hours on the left to a proposal on the right.

Vehicle		Concorde	Blackbird SR71	Valyrie XB-70	TU-144D	Boeing 2707- 300	Lockheed L2000-7B
Total number of aircraft		20	32	2	16	mock-up	Proposal
Program Cost	\$billion	1.3		\$ 1.5			
Unit Cost (\$2015 money)	\$million	\$ 125.00	\$ 261.75	\$ 5,389.0			
Passengers		128	2	2	140	300	273
First flight		Mar-69	Dec-64	Sep-64	Dec-68	0	0
Total missions		~90,000	3,551	129	55	0	0
Total Supersonic Time	hours	255,000	11,675	1.8	?	0	0
Average fastest speed (LA-DC)	mph		2,145		1320	0	0
Maximum fuselage width (internal)	inch	103.4	64.0			145	132
Maximum fuselage height (internal)	inch	77	n/a	n/a		84	
Length	ft	202.33	107.4	189	215.54	306	273.2
Wingspan	ft	84	55.7	105	94.48	180.3	116
Wing area	ft^2	3,856	1,795	6,297	5,457	9,000	9,423
Wing loading	lb/ft2	106.85	95.82	84.93	72.72	75.00	62.61
Empty Weight	lb	173,500	67,500	253,600	218,500	287,500	238,000
Maximum payload	lb	29,500	3,500	20,000		75,000	
Max Take-Off Weight	lb	412,000	172,000	542,000	396,830	675,000	590,000
Fuel capacity	lb	210,940	104,500	300,000	275,500	367,100	352,000
Fuel capacity	gallons	31,625	15,667	46,745	41,304	55,037	52,774
Fuel capacity to MTOW (%)	%	51.2%	60.8%	55.4%	69.4%	54.4%	59.7%
Aspect Ratio		1.55	1.939	1.751	1.66		
Max. Speed	Mach	2.04	3.3	3.08	2.15	2.7	3.0
Max Speed	mph	1,354	2,200	2,020	1,320	1,800	
Range	nmi	3,900	2,900	3,725	3,800	4,250	4,000
Service Ceiling	ft	60,000	85,000	77,350	65,600	73,000	76,500
Rate of climb	f/min	5,000	11,820		9,840		
Thrust to weight		0.373	0.440	0.314	0.44		
Lift to Drag @ mach 2		7.14		6		8.2	8.1
fuel usage	gal/hour	4,800	8,000				
exhaust temperature	f		3,400				
max nose temp	f	260	800	625			
max cowling temp	f		1,200				
Fuselage skin temperature range	f	196-201	450-640	450			
Wing skin temperature range	f	196-221					
Engine		Olympus 593 MK610	J-58	GE YJ93	kolesov RD-36- 51	GE4/J5P	GE4/J5M
length	ft-in	13'3"	17'10"	19'9"		27'4"	27'4"
Diameter	inch	47.75	57	52.5		71	71
Dry weight	lbs	7,000	6,000	3,800		11,300	11,300
compressor		7 low- 7 high	9 stage	11 stage		9 stage	9 stage
combustors		16	8 can				
turbine		1 low - 1 high	2 stage	2 stage		2 stage	2 stage
Max thrust dry	lbf	31,350	25,000	19,000	44,122	50,000	50,000
Max Thrust wet	lbf	38,050	34,000	28,800		63,200	63,200
Overall pressure ratio		15.5	7.5			12.5	12.5
thrust-to-weight ratio		5.4	5.7	7.6		6.02	6.02
air flow (lb/sec)	lb/sec	410	450	275		620	620
Specific fuel consumption (cruise)	lb/lbf-hr	1.195	0.9	0.7			
Specific fuel consumption (take-off)	lb/lbf-hr	1.39	1.9	1.8			
engines per aircraft		4	4	6	4	4	4

Figure 7: Various Skin Temperatures of SR-71 during flight

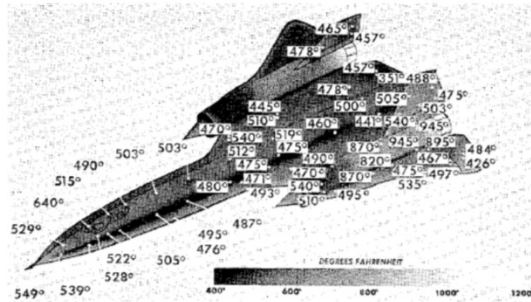


Fig. 15 SR-71 surface temperature cruise Mach. [4]

- During cruise the temperature distribution varies from 400°F to 640°F around the aircraft frame
- The external temperatures around the afterburner and ejector are around 900-1100°F
- 93% of the aircraft is built out of titanium alloys to withstand the high temperatures
- Most of the titanium used in the SR-71 came from Russia

Figure 8: Skin temperature of the X-15 at approximately Mach 6

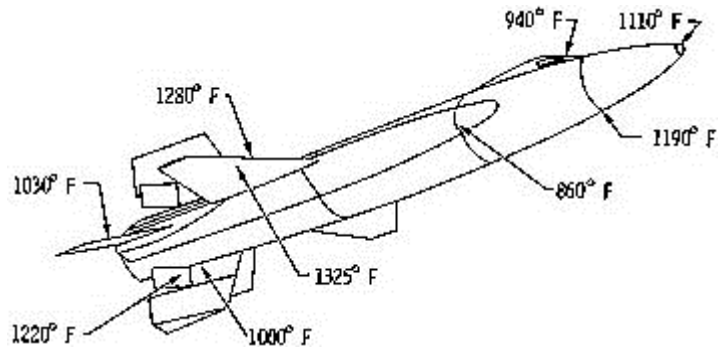


Figure 9: Skin Temperature of the Concorde at Mach 2

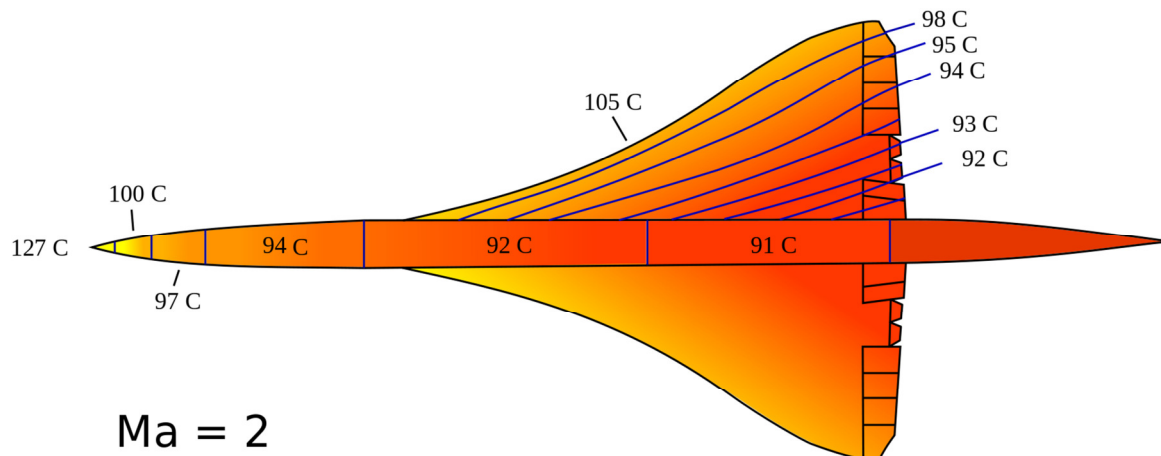
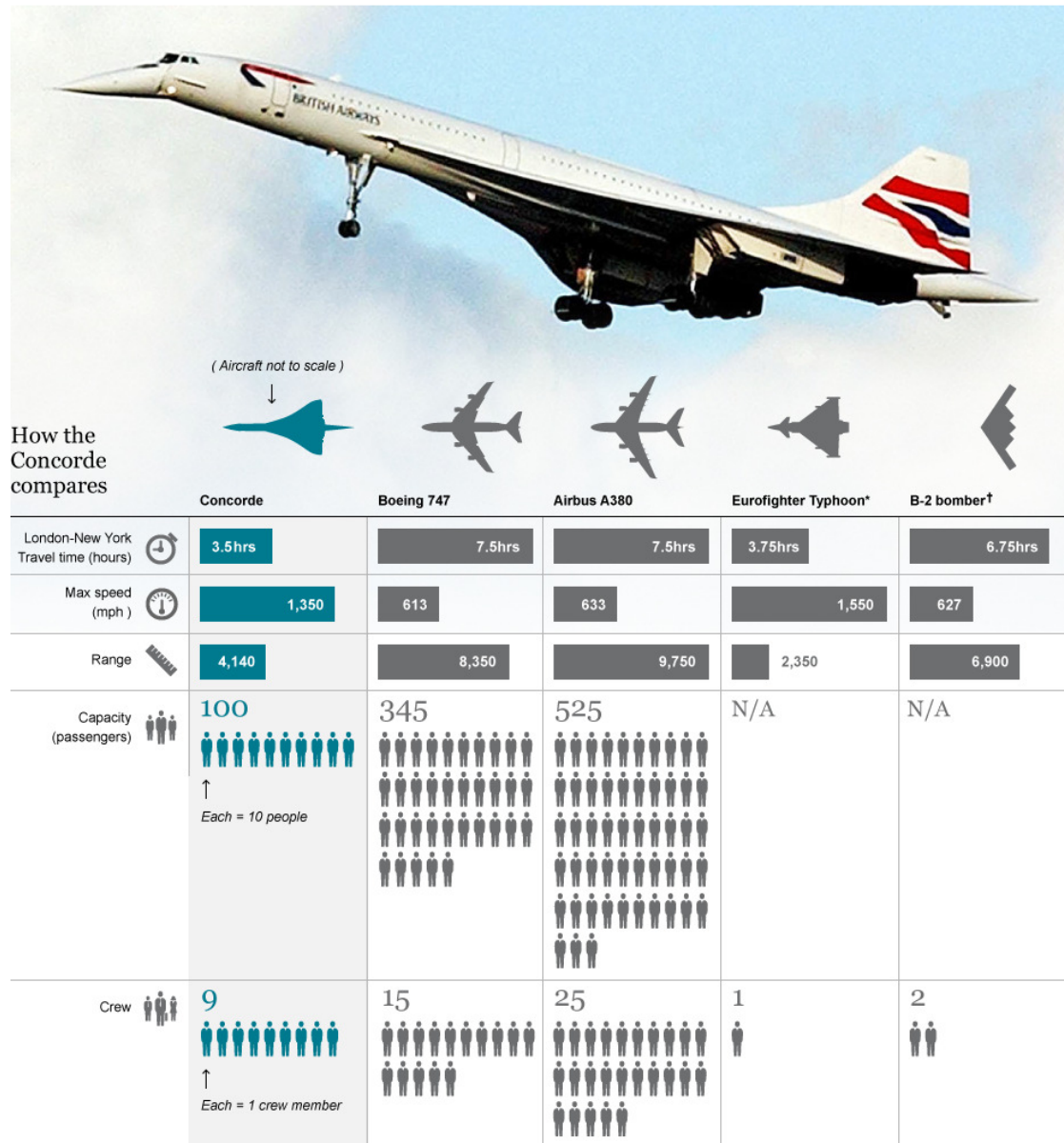


Figure 10: An internet picture^{xi} that compares the flight time, speed, and range of various aircraft.



IV: FLIGHT SIMULATIONS

We modified our flight simulation program which was originally created for Earth-To-Orbit rocket launches to incorporate air breathing engines and wings (no small feat). We operated the flight simulation program multiple times to optimize range in a commercial passenger Point-To-Point operation. We verified the accuracy of the results by utilizing the data of known aircraft (i.e., the Concorde and the SR-71) to make sure we obtained the same range and cruising altitude. The results of those flight simulations are shown in the following figures.

No matter which supersonic air breathing engine we chose, the **greatest range** of the Passenger Point-To-Point operation was obtained when the aircraft flew to a high altitude and Mach number on air breathing engines (the first 18 minutes of a normal flight) then switched over to liquid rocket engines to obtain as high altitude and as great of Mach number as possible then to glide as far as possible (essentially we turned our aircraft into a flyback booster).

We made a comparison between two vehicles that used rocket engines to travel to Mach 9. One of the vehicles used wings to generate vertical lift while the rocket engine provided thrust in the horizontal direction. Another vehicle relied solely on the thrust of the rocket engine for both horizontal and vertical lift. Although it should have seemed obvious for straight and level flight, the winged vehicle yielded more thrust going to the horizontal axis than the rocket vehicle as a result of the lift-to-drag ratio provided by the wing. However, the benefit is less pronounced with increasing Mach numbers and greater thrust.

Figure 11: Figure showing advantages of winged vehicle vs rocket vehicle for booster stage. Even at Mach 9, wings provide 4 times more lift than drag produced; by contrast, a wingless launch vehicle has less X-axis acceleration because much of the thrust is going to support the vehicle in the Y-Axis.

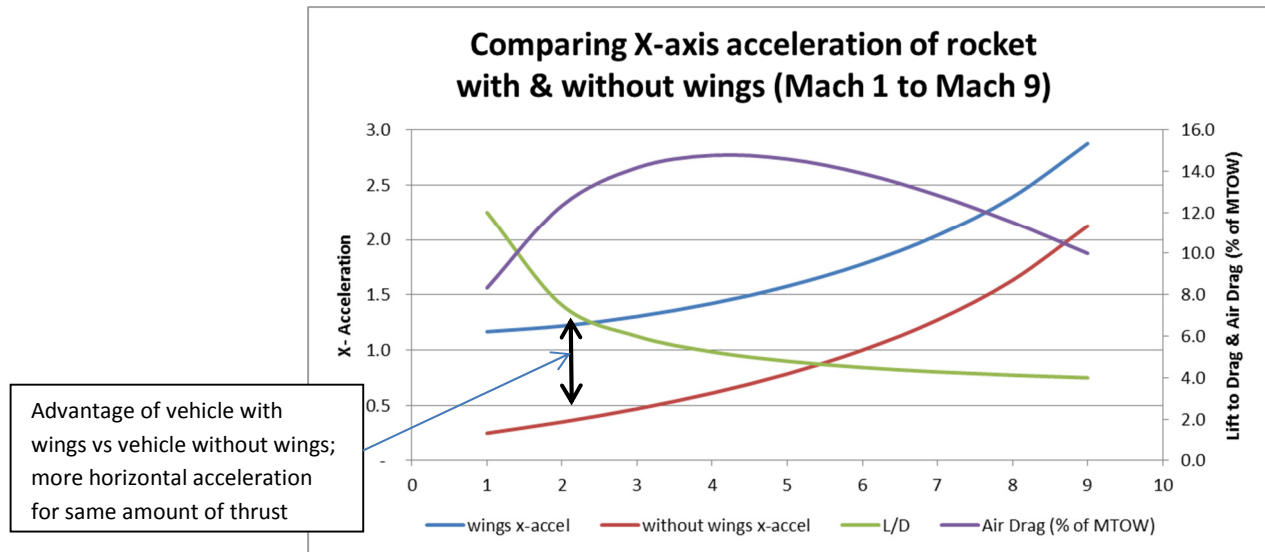
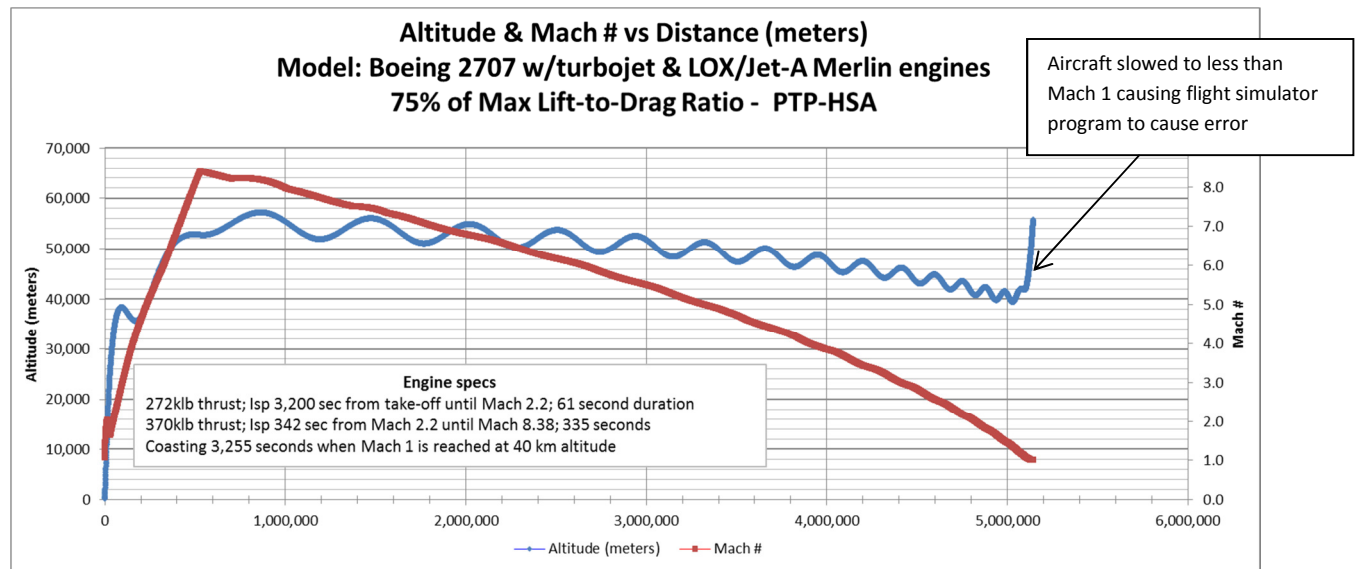


Figure 12: 1st Generation Fictitious Boeing 2707 sized aircraft with turbojet and LOX / Jet-A rocket engines. Our Lift-to-Drag = 7.49 @ Mach 2; Concorde was ~7.14 (but we spend VERY little time at Mach 2); our L/D = 6 @ Mach 3; SR-71 had L/D of ~6 @ Mach 3. Our minimum L/D is 4.07, which occurs at maximum speed of Mach 8.38, but since all fuel has been consumed at that point and vehicle weighs only 45% of take-off weight, the aircraft experiences same drag it would encounter at Mach 1.49 when fully loaded. Nearly all \$55,600 (100,260 lb of Jet-A and 267,900lb of LOX) propellants are consumed after aircraft has traveled 3,400 miles in 65 minutes and reached a maximum altitude of 57km (187,000 ft). **NOTE:** LOX is a renewable energy source that is derived from electricity and costs about \$0.04 per pound.



Total Flight Simulation Time: 3,663 seconds

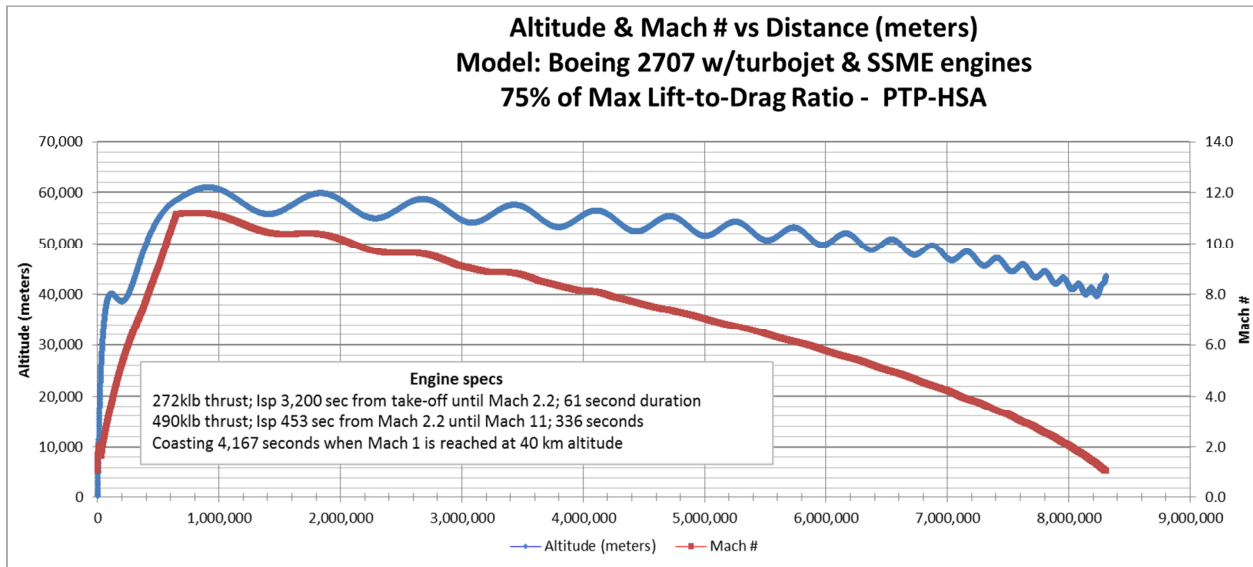
Average Mach #: 4.2

Average velocity: 1,405 m/s

Average Altitude: 46,278 meters

Beginning/Maximum/Final Aircraft Energy: 21,200 / 632,200 / 84,540 Megajoules (Energy gained and used by aircraft to coast/glide as far as possible as well as this is the energy that will heat up the fuselage and leading edges.)

Figure 13: 2nd Generation Fictitious Boeing 2707 with turbojet and large LOX-LH2 engines. Since it is nearly the same aircraft as the 1st generation (but a very large LH2 tank at the end of the fuselage), we have assumed the same L/D ratios as the 1st generation aircraft: 7.49 @ Mach 2 and 6 @ Mach 3. Our minimum L/D is 3.81, which occurs at maximum speed of Mach 11.08, but since all fuel has been consumed at that point and vehicle weighs only 45% of take-off weight, the aircraft experiences same drag it would encounter at Mach 1.68 when fully loaded. (BTW: Lift-Induced drag is 0.5% as much at Mach 11 as it is at Mach 1.68). All \$135,000 (5,500 lb of Jet-A, 51,600 lb of LH2, and 310,000 lb of LOX) propellants are consumed after aircraft has traveled 5,400 miles in 77 minutes and reached a maximum altitude of 61.4km (201,000ft). Note: 96% of propellant cost is cost of LH2, which can vary from \$2 to \$6.50 per pound; we chose \$2.50 per pound.



Total Flight Simulation Time: 4,580 seconds

Average Mach #: 5.44

Average velocity: 1,816 m/s

Average Altitude: 48,600 meters

Beginning/Maximum/Final Aircraft Energy: 21,200 / 1,022,600 / 79,500MJ (62% more energy than LOX/Jet-A system)

Figure 14: Actual Boeing 2707 with six GE4 engines and no rocket engines. Same Lift-to-Drag ratios at all speeds as before. Maximum speed of Mach 2.71 is obtained. All \$164,373 (54,800 gallons, 367,100 lb) of Jet-A fuel is consumed as the vehicle only travels 5,330 km (~3,300 miles) in 127.1 minutes. Stated cruising speed and range for the Boeing 2707 is Mach 2.7 and 7,870 km respectively. NOTE: Could not get the aircraft to climb faster without major porpoising (bouncing).

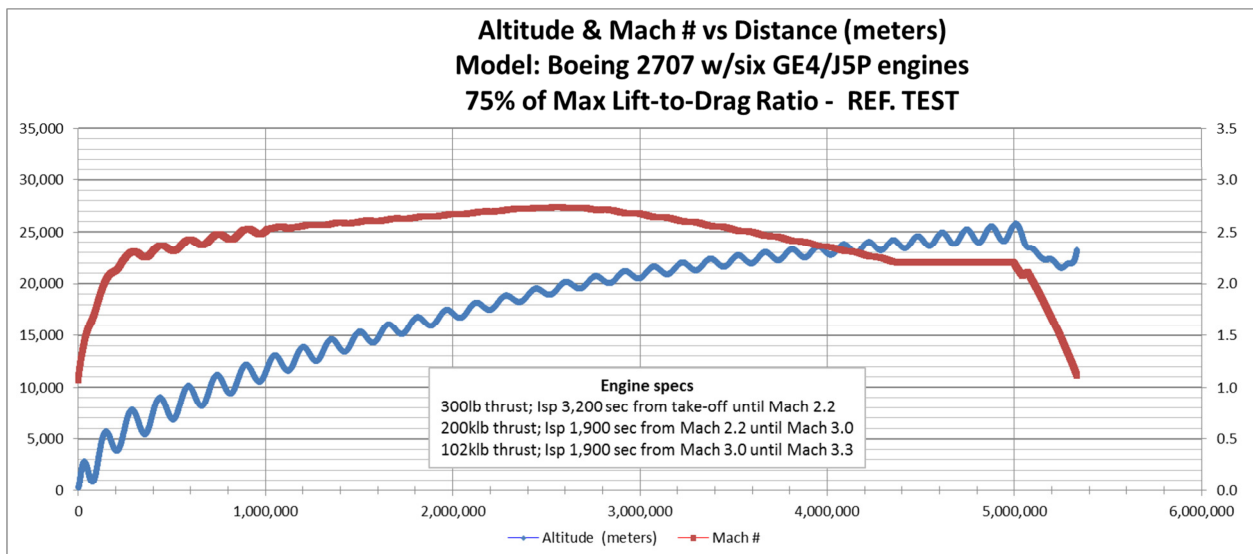


Figure 15: Using the same program on the SR-71 as an authentication. Normal SR-71 has a range of 5,400 km, but our flight simulation allowed the aircraft to only fly 3,500 km before it runs out of fuel. Normal SR-71 can reach speeds of Mach 3.3, but our flight simulation only allowed the aircraft to reach speeds of Mach 3.08. If we increased the L/D ratio to 80% of maximum theoretical, maximum speed increased to Mach 3.1, but minimum L/D was 6.3, which doesn't match the actual specifications for the SR-71. Stated L/D for the SR-71 at Mach 3 was 6 and not 6.3, so obviously the thrust and efficiency parameters we set for the J-58 engines are off a bit.

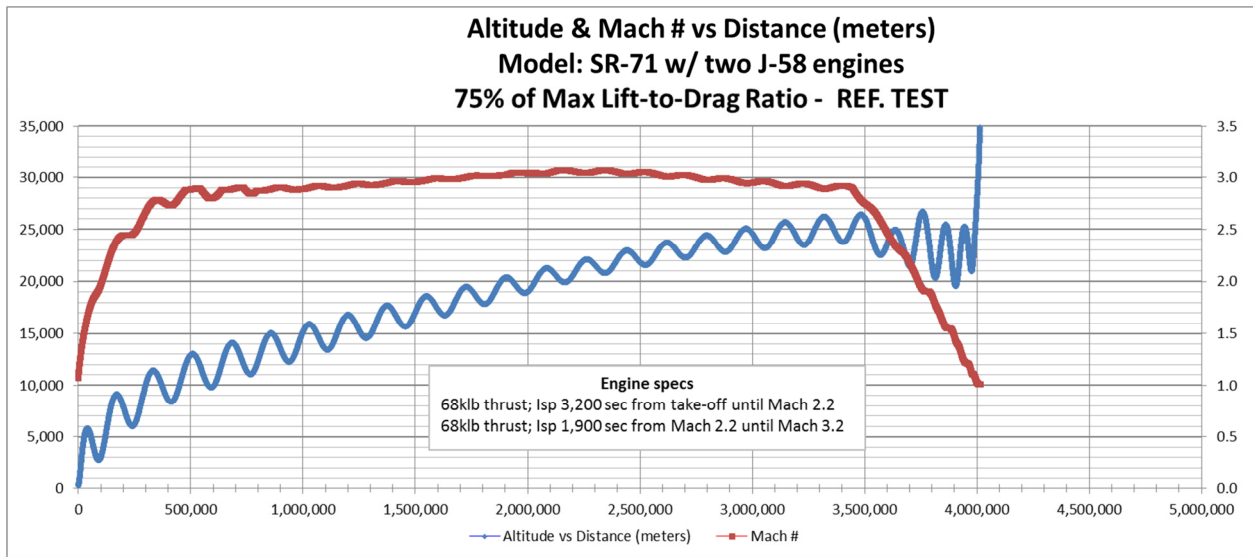


Figure 16: Using the same program on the Concorde as another authentication. The Normal Concorde has a maximum speed of Mach 2.2, a range of 7,222 km, and a Service Ceiling of 18,300 meters. To test the program, we ran a simulation on the Concorde aircraft and found a maximum speed of Mach 2.2, and a range of 7,400 km after 3.26 hours before we ran out of fuel. Our aircraft exceeded the service ceiling of 60,000 ft when its weight was reduced from burning fuel, but with constant changes to the throttle and angle of attack (and actually flying the aircraft) we could have smooth out the porpoising.

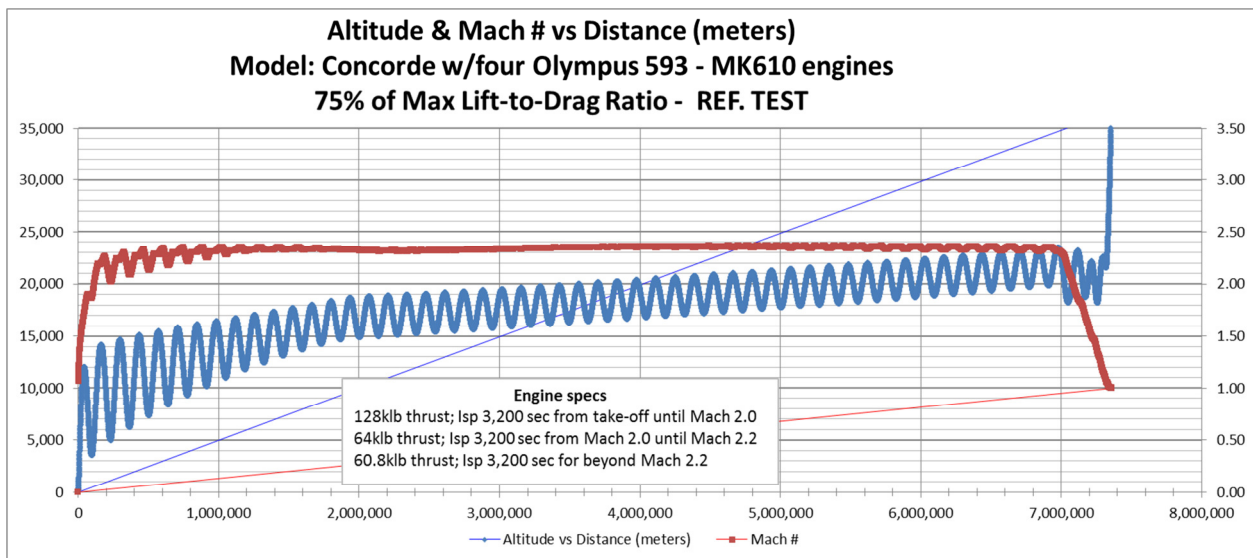


Figure 17: Passenger Service is great, but the point of this paper is to develop an aircraft that can be modified into an air launcher. By adding two equivalent SSME's (for a total of 3) and maintaining the same MTOW of 675 klb, our aircraft can launch **140klb** of upper stage & payload to Mach 9.11 and 224.7 km altitude; max energy of plane & payload is 918,414 MJ.

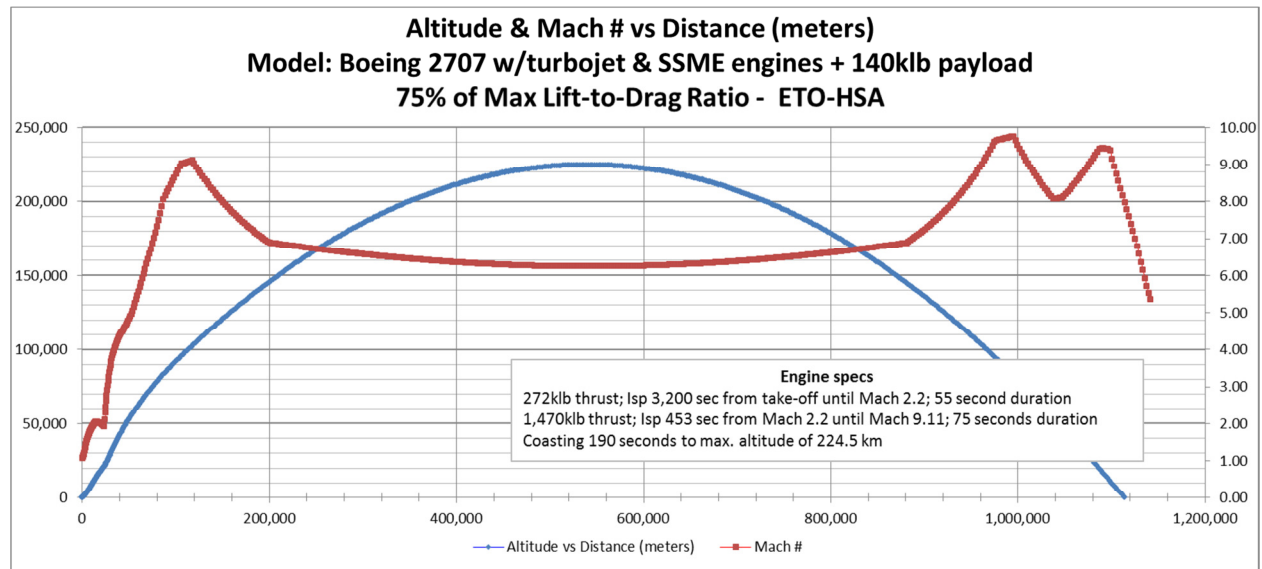
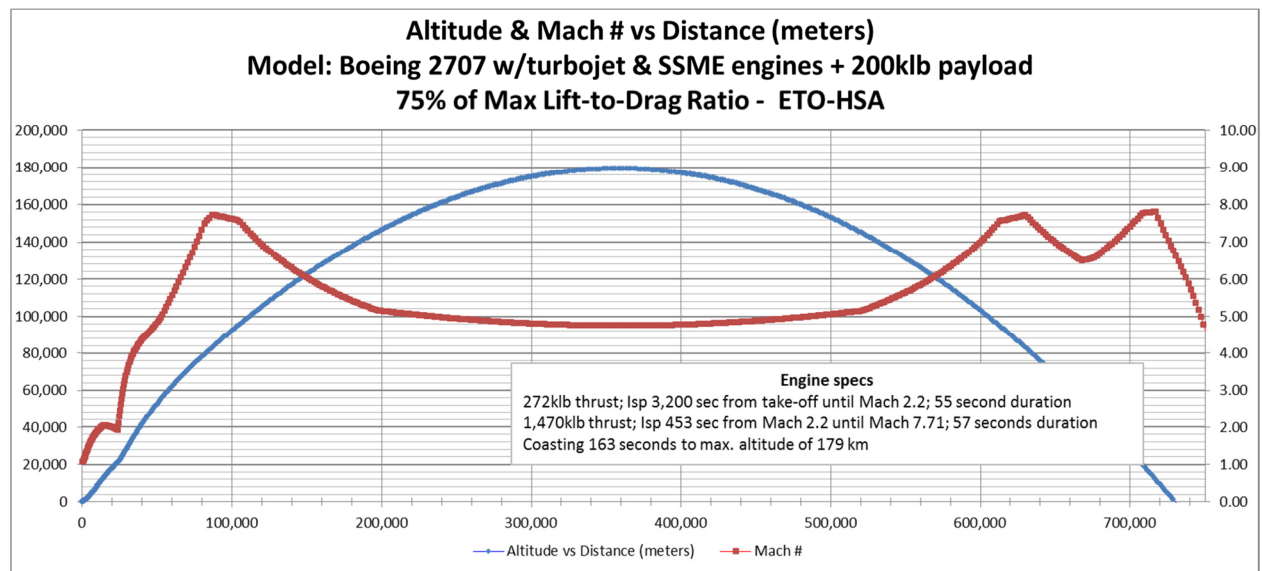
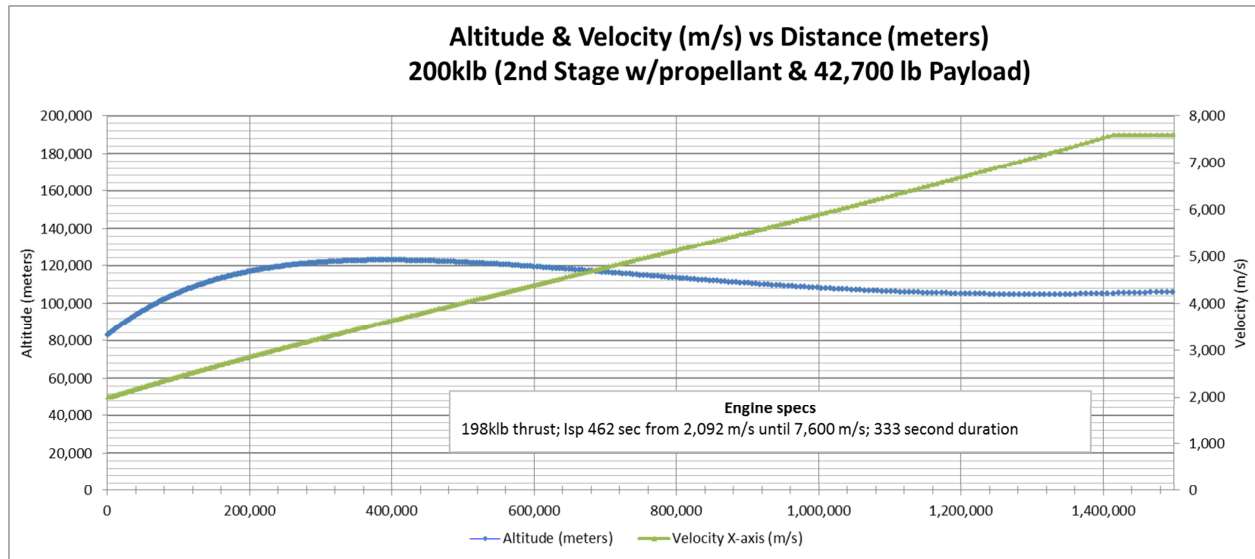


Figure 18: Same setup as above with MTOW of 675 klb and three SSME, but with increased upper stage and payload mass of **200 klbs**. SSME only fire for 57 seconds to propel aircraft to Mach 7.71 and 179 km altitude; maximum energy is 712,900 MJ.



2nd Generation Boeing 2707 aircraft with LOX-LH2 engines
 Flight Simulation Time from Mach 1 to Apex: 274 seconds
 Maximum G loading: 2.84
 Maximum Mach #: 7.71
 Maximum velocity: 2,092 m/s
 Maximum Altitude: 179,162 meters
 Maximum Aircraft Energy: 712,861 MJ (Maximum energy of aircraft and payload)

Figure 19: Flight simulation of 200 klb gross weight upper stage & payload. 45.2klb payload & 14.8 klb dry weight upper stage



V: Aircraft Conversion

How do we quickly convert a Passenger Aircraft into a Freighter?

We start with an aircraft that has a flat fuselage except for the flight deck compartment; please see figure 17 below. With this clean deck, we can attach four (48 ft long) **Passenger Compartment Modules (PCM)** that each carry 75 passengers. The PCM are totally self-contained and include everything from passenger chairs, windows, galleys, bathrooms, HVAC, oxygen, CO₂ absorbing LiOH canisters, pressurization system and doorways, and parachutes large enough to support a single PCM. If a leak or some other problem occurs in one module, the passengers can run into another module and seal off the problem PCM. Luggage may be in a separate compartment module at the extreme rear of the aircraft.

The aircraft can be quickly converted into a freighter by removing 1 or more PCM and replacing with a **Cargo Bay Module (CBM)** AFTER the cargo has been attached to the deck. The CBM is not airtight because it is merely sides and powered cargo doors that closely resemble the Space Shuttle Cargo Bay with its big cargo bay doors.

A third variation on the modules would be a sub-orbital **Space Tourism Module (STM)** that would essentially be a PCM without most of the passenger chairs and galleys. A STM would allow space tourists to fly along with Earth-To-Orbit payloads who want the experience of going into space (but only for a few minutes). After the aircraft has delivered the ETO upper stage and payload, the aircraft could fly very long parabolic arcs to give the space tourists many minutes of weightlessness.

The PCM, CBM, and STM and ETO upper stages could be designed to be loaded onto the aircraft via a rail system. Rails would be permanently installed along the edge of the fuselage by which the modules and upper stages could be very quickly rolled onto and off of the aircraft. The ETO upper stages would be loaded onto self-contained carts with wheels that match the railing on the aircraft; the carts and CBM stay with the aircraft after the upper stage is deployed. The carts would travel to the satellite manufacturer and be modified to provide whatever air conditioning, power, and communication as seen fit by them for the 30 minute ride until deployment.

It is quite conceivable that an aircraft could complete 6 PTP missions during first and second shifts of one day, then off-load the PCMs, and load an upper stage & payload with a CBM. If designed properly, the aircraft could launch the upper stage and return to the same airport and exchange the CBM for PCM and be ready for PTP service before the next morning shift.

The **Luggage Compartment Module (LCM)** is a pressurized compartment that is between the last PCM and the Vertical Stabilizer. Because it is a compartment, it can be rapidly loaded and unloaded with the passengers without interruption of the hazardous fueling service.

Figure 20: This is a very simple representation of the 4 PCM being removed from the HSA and leaving a flat fuselage. We are making our illustration using the Concorde because there are ample examples of the Concorde on the web versus the very few of the Lockheed L2000-7B aircraft. Each 48 ft long PCM is totally self-contained and contains a parachute. **NOTE:** If the tail was removable, the PCM could be rolled onto the aircraft via rails. Notice also that the vertical stabilizer would be in the way of the deployment of any upper stage. If possible, twin vertical stabilizers should be relocated to the ends of the delta wings; any Thrust Vector Control systems that could stabilize the aircraft during extremely thin air conditions should also be located at the extreme ends of the delta wing.

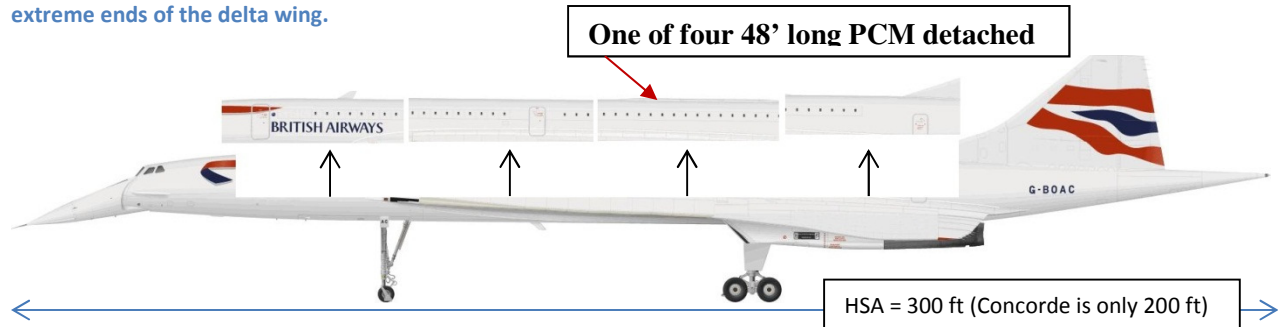


Figure 21: 2nd generation aircraft with large removable LH2 tank hanging off the end of the fuselage. LH2 tank would be shorted if tail also held LH2. Luggage is placed in front of LH2 tank.



Figure 22: The LH2 tank must be tilted 10 deg. during take-off and landings so it does not come into contact with the ground, but would become in-line with the fuselage after the aircraft leaves the runway.



Figure 23: Boeing 2707 passenger seating capacity & fuselage dimension. 145" interior diameter is more than wide enough to envelope a Centaur upper stage and payload. Unlike the diagram in Figure 5 of the Lockheed L2000-7B, this sketch shows the dimensions of the fuselage at various points; we would expect the HSA to have similar dimensions.

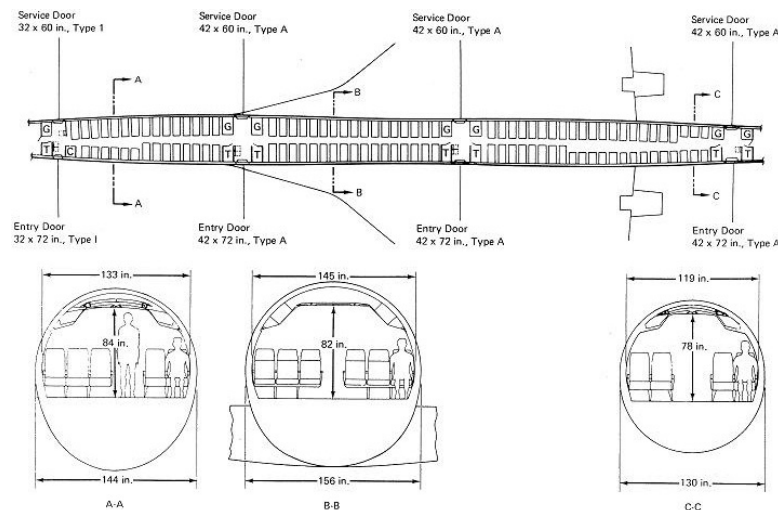
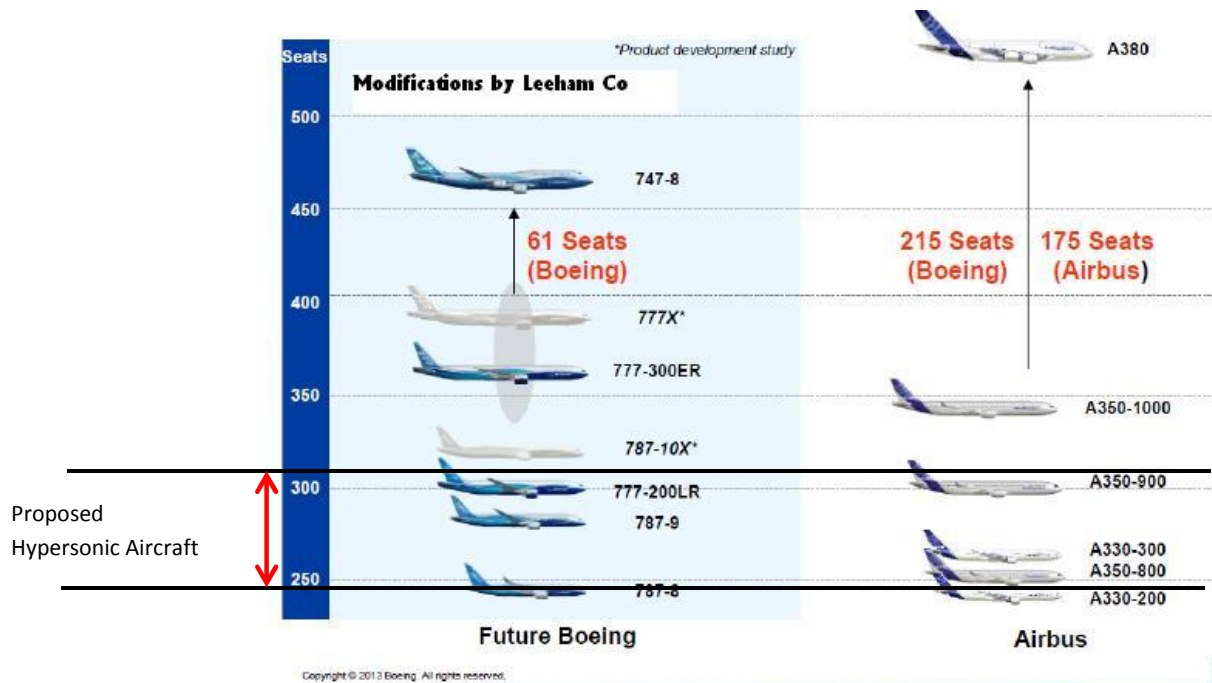


Figure 4-A. Interior Arrangement 298 Passengers

Figure 24: 270 to 300 passenger aircraft would compete with 787-x, 777-200LR, and some A350 aircraft. At a cruising speed of Mach 4.2 (as shown on Figure 3), our 1st generation aircraft will cover its 3,400 mile range in 2.1 hours from gate-to-gate (with 65 minutes at cruising speed) while the 777-200 will require 7.25 hours gate-to-gate to go the same 3,400 miles. The 2nd generation will cover 6,000 miles in 2.75 hours gate-to-gate while the 777-200 will require 12 hours.



VI: Airport Operations:

1. What are the operations, maintenance, and propellant costs of a Subsonic vs Mach 2 engine vs one of the proposed flight schemes?
2. Some people think that the Concorde was a commercial failure because of its high maintenance cost due to flying at Mach 2. How would our vehicle be more of a commercial success than the Concorde?

Flight Operations Comparison: Based upon historical evidence, the operations and maintenance costs of a subsonic and Mach 2 vehicle would be fairly close to equal (say 20%) **IF they have a similar flight rate.** Fundamentally the Operations are the same and the Maintenance is not much more for Mach 2 once you operate it out of the very low flight rate scenario. As an example only 7 British Airline Concorde made 50,000 flights in 27.17 years or 5 flights per week per plane^{xii}. On the other hand, every day ~1,300 Boeing 777 aircraft are taking off^{xiii}.

Development Cost Amortization

1,852 Boeing 777 have been ordered^{xiv} and each cost an average of ~\$290M. Develop costs were stated as \$5.5B^{xv} or ~\$3M per Boeing 777 that has been ordered. If each aircraft makes only 1 flight per work day, the amortization of the development cost spread out over 10 years would amount to \$1,545 per flight. Since the Boeing 777 holds 400 passengers, the development cost would amount to less than \$4 per passenger.

On the other hand, the development cost of the Concorde was £1.134 billion in 1970 or £37.31B today, which equals \$57.31B in 2015 money. Spreading £1.134 billion over 50,000 flights for BA and 28,000 flights for Air France amounts to £14,538 per flight in 1976 money, which is approximately the cost of 2 or 3 seats aboard the 100 passenger aircraft. However, when the £1.134 billion was divided among the 2.5 million passengers, we see that the development cost amounts to no more than £454 (~\$900) per passenger. BA and Air France had their respective governments take care of the development cost so even this \$900 per passenger wasn't burdened by them. So in order to reduce the cost per aircraft, or per flight, or per passenger, we need to produce more than 1,000 aircraft that can hold 200 to 300 passengers and fly every day resulting in a development cost that doesn't affect the cost of the round-trip flight.

Propellant cost / flight will be a little different with the Mach 2 vehicle versus a subsonic vehicle unless a significantly different type of propulsion system than the afterburning turbojet utilized on the Concorde is employed. The Concorde spent most of its time cruising with no afterburner at higher altitudes than subsonic jets. The Concorde (with 1969 technology) consumed roughly 20% more fuel than a modern Boeing 777 with 1994 technology. One could speculate that improvements could be made to a modern Mach 2 engine to reduce the fuel consumption to a point that it would be cheaper and safer to fly than our technique with a rocket engine and long coast.

Why should our new supersonic aircraft be any more successful than the Concorde?

The real key to economic viability is the number of passengers the vehicle carries and the average price of a ticket. The Concorde carried roughly 100 passengers while a Boeing 777 carries roughly 400 passengers. Therefore a ticket on the Concorde would have to average 4-5 times that of a ticket on a 777. Is that a reasonable expectation for a Mach 2⁺ vehicle (with all "First Class" seating)? First Class tickets on a subsonic vehicle are 2X the cost of the average ticket and that people would be willing to pay another 2X to fly supersonically so it is not out of reach.

Three biggest problems with Concorde were:

1. That it only flew at Mach 2, which means it only saved 4 hours on a 7 hour trip via subsonic aircraft
2. Because it flew supersonic, it couldn't fly over land and,
3. It held only 100 passengers, which means its fix costs were higher than a 300 passenger aircraft.

We hope to fix all of these problems with our proposed aircraft because:

1. Our 1st generation flies at an average speed of Mach 4.2 (2nd generation at Mach 5.44), which hopefully will provide a savings in time that is more than the higher cost of the ticket.
2. Our aircraft flies at an altitude of more than 151,000 ft vs the 60,000 ft altitude for the Concorde; thus, we should fly high enough that a sonic boom can not be heard on ground and travel overland is permitted.
3. Our aircraft carries 300 passengers, which will divide the fix cost of travel to a point that a much larger fleet will be demanded.
4. By using an aircraft with a much larger MTOW (i.e., 675,000 lb vs 410,000 lb) our launch system can deliver 45 klb of useful mass to LEO vs less than 26 klbs with the Concorde sized aircraft with a standard non-reusable upper stage. But, as a result of using a much larger aircraft, we can create a totally reusable upper stage and still deliver at least 20,000 lb of useable payload to LEO with tremendous cost savings.

We are considering loading LH2, LOX, or Liquid methane at an airport, how is this done safely, quickly (less than 30 minutes), and cheaply?

Highly qualified personnel would be in charge of loading LOX and liquid methane. No such fueling operations would be able to take place while there are people on board the aircraft, even though Jet fuel is sometimes loaded while passengers are on board.

We recognize that loading LOX on board an aircraft will make for a very hazardous situation. And we don't think it will be possible to conduct such operations close to the airport gates as is conducted today with jet fuel. Instead, we think LOX and all other propellants will be loaded on board the aircraft a great distance away (the other side of the airport). A trade study is needed to determine how to load the flight crew, passengers, and luggage on board the aircraft.

- One possibility is to send the flight crew and passengers out to the aircraft via a tram, bus, or some other means AFTER the aircraft is fully fueled and ready for take-off.
- Another possibility is to unload the passengers at the gate, tow the aircraft behind a blast wall and/or blast pit, then tow the aircraft to the gate, and finally load flight crew and passengers.

This inconvenience will only occur during take-offs. When the aircraft lands, it will only be powered by normal turbo-jet engines and can travel straight to a gate close to the terminal as is commonly done. However, the previous statement is only speculation and further study would be necessary to confirm in future papers.

It is also recognized that requiring a separate gate and/or terminal in order to fuel and board flight crew and passengers will not be convenient, popular, or cheap at most airports. But since only major airports will need long distant supersonic service, the requirement for an isolated departure gate may be within reason.

Our airplane could have rocket propulsion components:

- *The first concern is: The Space Shuttle required 6 months after landing before it could fly again, how could an airplane with a rocket engine and cryogenic tanks be made to fly within 30 minutes of landing?*

The component reliability must be raised to airline values to avoid parts replacement between flights and have an automatic functional systems verification system that gives you a green light before each flight. Avoid engine special start requirements such as the engine temperature start box, i.e., if pumps are a part of the tankage in a submerged

sump this will eliminate the operational problems. Many of these issues were thoroughly discussed and addressed within the OEPSS study papers with the author of the paper as the NASA-KSC study manager^{xvi}.

- *The second concern is: Rockets seem to ALWAYS have launch delays, why would our airplane not have delays (even while in flight) now that it has rocket propulsion?*

Again, having increased component reliability values would reduce the number of last minute problems during launch. In addition, two of the authors were involved with a NASA program referred to as Operational Efficient Propulsion System Study (OEPSS). Within OEPSS, we determined among other things that if we avoid engine special start requirements such as the engine temperature start box, i.e., if pumps are a part of the tankage in a submerged sump this will eliminate the operational problems. The McDonnell Douglas Delta Clipper Experimental (DC-X) rocket was able to land, be refueled, and launched again within 26 hours^{xvii}. Another example would be the Ascent Stage of the Lunar Module. Although the ascent stage had already been fully checked out on ground, when it came time for lift-off, a simple count-down was all that was needed.

VII: FLIGHT RELIABILITY WITH ROCKET PROPULSION COMPONENTS

1. **The first concern is: The Space Shuttle required 6 months after landing before it could fly again, how could an airplane with a rocket engine and cryogenic tanks be made to fly within 30 minutes of landing?**

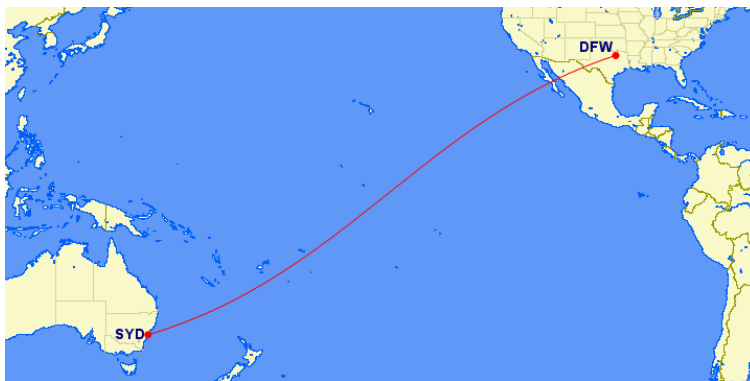
- The component reliability values must be increased to match airline values to avoid parts replacement between flights and have an automatic functional systems verification system that gives you a green light before each flight.

2. **The second concern is: Rockets seem to ALWAYS have launch delays, why would our airplane not have delays (even while in flight) now that it has rocket propulsion? What are some examples of rockets that were launched fairly quickly?**

- Again, having increased component reliability values would reduce the number of last minute problems during launch. In addition, two of the authors were involved with a NASA program referred to as Operational Efficient Propulsion System Study (OEPSS). Within OEPSS, we determined among other things that if we avoid engine special start requirements such as the engine temperature start box, i.e., if pumps are a part of the tankage in a submerged sump this will eliminate the operational problems.
- The McDonnell Douglas Delta Clipper Experimental (DC-X) rocket was able to land, be refueled, and launched again within 26 hours^{xviii}.
- Another example would be the Ascent Stage of the Lunar Module. Although the ascent stage had already been fully checked out on ground, when it came time for lift-off, a simple count-down was all that was needed.

3. **Flight reliability**

Which has a higher flight reliability; a rocket engine that only needs to operate for 335 seconds then allowing the aircraft to glide for 70 minutes or a 4-engine aircraft that must operate over open ocean for 16 hours per flight, such as Qantas flight 7 shown in the figure to the right? We have designed our aircraft so that the passenger compartments are self-sufficient and can be jettisoned if anything happens to the aircraft. Any problem with any other modern jet and all of the passengers will share the same fate.



Compare the proposed system with the Andrews Space Peregrine reusable launch vehicle

It seems only obvious that we must compare the proposed vehicle to the Andrews Space Peregrine Reusable Launch Vehicle^{xix}. The Peregrine is an excellent design and we share many similar features of using air breathing engines on an aircraft to propel the aircraft and upper stage to some high speed, high altitude condition where Lox/Kerosene rocket engines boost the aircraft to some high Mach number and high altitude until the upper stage is deployed. We also share the same feature of using the same air breathing engines to provide a powered landing for the aircraft at the end of the missions. That is where the similarities end.

1. Our system focuses on dual use of the aircraft while the Peregrine is single purpose. As a result:
 - o Our aircraft can be utilized 6 times per day for passenger services and once per night for ETO missions
 - o The Peregrine can only be utilized to carry the 28 commercial missions per year; resulting in much higher fixed cost per mission.
2. Our aircraft is derived from existing aircraft (or at least existing prototypes of aircraft); the Peregrine appears to be a totally original designed aircraft, which could mean more development cost
3. Our system uses 3 times more thrust from the air breathing engines. We can only assume our aircraft has 3 times Maximum Take-Off Weight, which means our upper stage can be at least 3 times more massive.
4. Our upper stage is deployed from a payload bay while the Peregrine is deployed from a bomb bay. It is unknown if one deployment system is better than the other.
5. Our flat fuselage design will accommodate changes in the Cargo Bay Module for oversized and odd size payloads; the Peregrine bomb bay dimensions wouldn't appear to be easily changed.
6. Our system emphasizes LOX-LH2 upper stage (and LOX-LH2 aircraft rocket engines for the 2nd generation) while the Peregrine currently shows only solid rocket propulsion for the upper stage.
7. Because our system can deliver a much larger total mass to orbit, it only makes sense that some of that orbital capability be used for a reusable upper stage while still delivering a minimum of 10 tons of useful payload to orbit. Since the Peregrine is 1/3 the size and uses less efficient solid propellants for the upper stage, it's very doubtful if such an upper stage system could ever be within an order of magnitude in cost per pound of our reusable system.

What are the strategic military advantages of having a civilian PTP-HSA with ETO capability?

Why is the proposed system important to the US military? If the proposed aircraft can be operated at a profit as a commercial passenger service aircraft for the 1st class, business, and premium economy passengers, then there should be no reason why a very large fleet of such aircraft is not deployed across the USA as well as USA friendly nations. Since any and every one the proposed aircraft can be used for Earth-To-Orbit missions, then on any given day a thousand missions could take place to remove thousands of enemy satellites as well as launch thousands of missions for replacement satellites. One any given day, the fleet of a thousand aircraft could be used to fulfill the requirements of SUSTAIN (Small Unit Space Transport and Insertion)^{xx} or project Hot Eagle^{xxi}.

Because passenger flights would be very short (~2.5 hours gate-to-gate), there would be little need to serve meals; thus reducing costs. In similar reasoning, when the cost of getting into orbit has been dramatically reduced while the availability of getting into orbit has skyrocketed, it would only make sense that the required reliability of satellites would dramatically fall along with their cost. Why spend \$million on satellite reliability when you can easily replace your satellite?

MARS MISSION ON ANY GIVEN DAY

On any given day, a mission to Mars would be possible at a fraction of the cost for launch operations; instead of launching 10-100 ton SLS rockets, we could launch 100-10 ton payloads to LEO with our fleet of aircraft. If we consider the 2nd generation HSA with a totally reusable upper stage; as stated before, the HSA can bring in \$1.2M per shift in revenue so the cost of using the HSA during the off shift to launch ETO mission shouldn't be more expensive since propellant is only needed once instead of 3 times. In similar manner, a totally reusable upper stage should have a marginal cost that is one tenth as much as the cost of a Centaur, which is approximate \$28M each. Therefore, the total cost of launching 10 tons of useful payload into LEO should be between \$4M and \$12M or roughly \$200 to \$600/lb.

VIII: CONCLUSION

It is our desire that we have provided ample evidence to prove that there is some merit to an aircraft that is propelled by a rocket engine to very high Mach numbers and very high altitude to achieve great average speed and reduced costs. This paper should provide convincing evidence that such an aircraft would be extremely competitive in the commercial passenger mid-range Point-To-Point markets. We hope that we also proved that if the aircraft has a modular design (for safety) that it could be converted into a “flyback booster” for Earth-To-Orbit launch operations at extremely little expense and no impact to daily PTP passenger service.

Very recently, Boeing forecast the demand for 38,050 new airplanes valued at \$5.6 Trillion over the next 20 years^{xxii}. Now is the time for a new supersonic aircraft to be developed to meet this demand. Now is the time to develop an Earth-To-Orbit supersonic air launcher that can finally move us away from missile technology to a totally reusable ETO system. We hope that you agree that only because the aircraft is designed for the gigantic commercial PTP passenger market, that there is finally a financial rationale for developing a supersonic air launcher for ETO market.

The next step with this concept is for the aviation industry to take a closer look, fund an in-depth study, and conduct experiments to prove the concept so that aviation takes its next logical step. Otherwise, passenger service will be stuck at sub-sonic speeds for many years to come, but most importantly, the cost of going into space and the envision of thousands of visitors per year to a space hotel will not be practical with the current foreseeable evolution of missile derived launch systems.

ⁱ Douglas Thorpe, Russ Rhodes, John Robinson, “Affordability Advantages in Integrating the Aircraft and Space Launch Operations”, 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Atlanta, Georgia, 30 July-1August, 2012, AIAA 2012-4155

ⁱⁱ Douglas Thorpe, Russ Rhodes, John Robinson, “Affordability Advantages in Integrating the Aircraft and Space Launch Operations2”, 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland, Ohio, 28-30 July 2014, AIAA 2014-3651

ⁱⁱⁱ <http://www.transtats.bts.gov/>

^{iv} http://en.wikipedia.org/wiki/List_of_space_travelers_by_name

^v http://en.wikipedia.org/wiki/Boeing_2707

^{vi} <http://www.globalsecurity.org/military/systems/aircraft/b2707-design.htm>

^{vii} http://en.wikipedia.org/wiki/Tupolev_Tu-144

^{viii} <http://imgbuddy.com/boeing-2707-mockup.asp>

^{ix} <http://www.pbs.org/wgbh/nova/space/anatomy-concorde.html>

^x <http://up-ship.com/blog/?p=1012>

^{xi} <http://www.telegraph.co.uk/news/aviation/10400354/Graphic-Concorde-10-years-on.html>

^{xii} <http://www.britishairways.com/en-us/information/about-ba/history-and-heritage/celebrating-concorde>

^{xiii} http://www.boeingblogs.com/randy/archives/2011/09/all_in_a_days_work.html

^{xiv} <http://active.boeing.com/commercial/orders/displaystandardreport.cfm?cboCurrentModel=777&optReportType=AllModels&cboAllModel=777&ViewReportF=View+Report>

^{xv} <http://www.globalsecurity.org/military/systems/aircraft/b777.htm>

^{xvi} <http://science.ksc.nasa.gov/shuttle/nexgen/OEPSS.htm>

^{xvii} <http://www.hq.nasa.gov/office/pao/History/x-33/dc-xa.htm>

^{xviii} <http://www.hq.nasa.gov/office/pao/History/x-33/dc-xa.htm>

^{xix} www.youtube.com/watch?v=Ew953pOZX

^{xx} <http://defensetech.org/2005/09/19/marines-in-spaaaaaace/>

^{xxi} <http://www.thespacereview.com/article/563/2>

^{xxii} <http://www.traveldailynews.com/news/article/66615/boeing-forecasts-demand-for-38-050>