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An Evolutionary Plan for Rapid Deployment of Reusable Launch Vehicles (RLVs)

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Abstract

Civil, military and commercial exploitation of space are all inhibited by the high costs and modest reliability of our present means of access to space. A new space launch vehicle architecture is necessary that will place us upon the proper path toward a space transportation system with airliner-like safety and reliability; operating for hundreds of round trip missions while requiring only minimal maintenance.

Attempts of the recent past, applying time and funds to hoped-for “technological breakthroughs” have not succeeded. In this paper, we report the results of an extended in-house systems engineering study, begun in 1995, to develop and field a conservative, multi-stage RLV architecture tailored to commercial markets, but also capable of satisfying, at each step of the way, the markets now emerging within both the military and civil sectors.

The results of this work have indicated that a small “technology demonstrator” system known as *StarBooster 2™* can be fielded very quickly and economically to address the very real problems of *learning how to best utilize such a system* (i.e., create the needed *Operational Technologies*).

Downstream application to near term markets can be served by this vehicle, generating income to aid in taking the next step: *StarBooster 30™*. Scale-up of this vehicle will then lead in turn to the *StarBooster 200™* system to serve the needs now filled by current expendable launch vehicles (ELV’s), including the *Titan IV-B*, and will provide an alternate means for humans to participate in space missions.

In the absence of *proven* new technologies offering much lower operations costs at acceptable risks and development costs, the *StarBooster™* system can then be scaled up once again to meet the needs of the *Space Shuttle* for a *Flyback Booster* and to serve the long-standing need for true “heavy lift” to enable renewal of human space exploration beyond low Earth orbit, including sustained return to the Moon, and economically important future space missions, perhaps including *Space Solar Power*, and further opening space travel to the general public.

The market opportunities to be discussed will, however, become real if and *only if* we soon embark upon a viable path leading to reusable space launch systems. Delay or further failures cannot be tolerated if we are to regain our space launch competitiveness with other nations. *StarBooster™* offers such a path.

Introduction

This paper discusses a conservative, evolutionary approach to achieving the space launch capabilities needed beyond those now available. This new initiative is not expected to displace the development of new technologies; it simply addresses a different problem: Providing the low cost, reliable access to space needed now, while awaiting full demonstration that the suggested new technologies may be realistically and practically applied to major development programs within budgetary and time constraints, with high confidence in their success.

Market Opportunities

The dominant source of revenue for present suppliers of launch services in the commercial markets is placement of large satellites into geostationary orbit (GEO). We believe this market will continue to grow, as both public and government demand for “bandwidth” continues to expand. There are, however, important and growing “niche” markets for smaller vehicles. These include sounding rockets and the emerging field of “micro-sats” and “nano-sats”.

Should NASA’s stated plans materialize to commercialize the servicing of the *International Space Station* (ISS), a new, lucrative and highly competitive market will arise.

Should the announced plans of the United States Air Force come to fruition to *maintain security* for the large space infrastructure upon which our modern society is now totally dependent, an even larger market will develop – not for launch services, but rather for the equipment, supplies and technical assistance needed by the “Blue Suit” crews operating this new national security capability.

We believe that future commercial markets will eventually arise for the deployment and maintenance of additional LEO infrastructure; some of these new facilities will inevitably be populated.

With the support of the United States Congress, NASA has emerging plans for a series of technology demonstration satellites supporting a later decision on commercial deployment of *Space Solar Power*. Thus, with these commercial, civil space and defense needs, we believe that a rich, “price elastic” market can be anticipated, sufficient for several concurrent, competitive reusable space launch vehicle approaches to succeed in the future space launch marketplace.

Design Guidelines

In deciding what is best to build, we must learn from both the successes and the failures of the past. We must not be seduced by “silver bullet” technology attempting to revolutionize this important aspect of transportation in one single giant leap. Such “breakthroughs” may appear, or again they may not, in the short time we have to improve our present capabilities and competitiveness. Evolution is the safer and more affordable approach that can, when properly applied, achieve revolutionary results.

The path we have chosen is to select the best of what is presently available, apply it in innovative ways to meet progressively larger demands, and to gain a foothold in the market; small at first, but growing ever larger. This path is founded upon several basic ideas:

First, a multi-stage system is now considered by most practitioners to be best orbit delivery system that can be done with existing or near term technologies. Efforts should be expended on simplifying the operational procedures and reducing the time required for maintenance and assembly rather than accepting further cost and schedule risks associated with the quest for single-stage-to-orbit approaches.

Second, kerosene fuel must be used for a reusable booster in preference to the higher performance hydrogen fuel, as an RLV booster must immediately enter the atmosphere and safely return to the launch site following the boost phase of the mission. Experience in attempting to incorporate the magnificent *Centaur* stage into the *Space Shuttle* demonstrated clearly that safe disposal of hydrogen was not likely during the brief time interval available from confirmation of the need to return to launch site to encountering the oxygen-laden atmosphere. This was not a deficiency of the *Centaur* stage, however, but rather of the very concept of placing this low density, highly flammable fuel inside a crewed vehicle requiring emergency return capability. A reusable booster must perform this difficult entry maneuver on every mission, not just in an emergency.

Third, the United States has largely neglected development of new rocket engines since the start of the *Space Shuttle Main Engine (SSME)* many years ago. Since achieving a new, warmer relationship with a former adversary, we find ourselves with the opportunity to employ a set of superior kerosene fuel engines developed elsewhere. We should use them without hesitation; protecting our economic interests by meticulous structuring of the purchases and their support.

Fourth, in spite of our technology advancement and the broad application of unprecedented computer power, designers have learned through repeated experience that our ability to accurately estimate, in advance, the dry mass of new rocket vehicles is limited. Growth of 25% and even more is not an uncommon occurrence. Consequently, Starcraft has specified an inert mass margin of 30% for all of the *StarBooster™* components that have not actually been weighed. This conservative measure not only protects against program failure, but it also provides project managers with the invaluable option of substituting a small growth in weight for the time and funds required to overcome a problem with no weight impact. Thus, programmatic as well as technical risk is reduced by this measure.

Fifth, many different vehicle recovery techniques have been suggested and some have been used. As intact recovery without concern over hidden damage is imperative for an RLV that must be rapidly readied for re-flight, it is our conviction that wheeled landing at a runway near the launch site, supported by wings, is the only prudent approach. To avoid the brakes, tire, and handling problems associated with higher landing speeds, we believe it is necessary to have sufficient wing area to land at 150 knots or less.

Sixth, *Space Shuttle Orbiter* experience has shown us that the external tile/blanket thermal protection is a feature requiring significant maintenance effort. Trajectory analysis has demonstrated that the “heat sink” approach to thermal protection is adequate for staging velocities up to Mach 6 for a reusable booster. This will permit almost the entire airplane to be built of aluminum alloys, with the use of more expensive high temperature metals confined to the nose and leading edges. Trajectories have shown that staging velocities above Mach 6 provide only marginal gains in payload for multi-stage systems.

Seventh, the range required for return to the launch site increases with staging velocity. Up to about Mach 3.3, the vehicle can glide back without power. Above that velocity, a set of air-breathing engines and jet fuel are necessary to return from the further down range beginning of return flight. We plan to use the “glide-back” approach initially, deferring the installation of air-breathing engines until adequate operational experience has been gained by gliding approach flight from lower Mach number staging.

Finally, it is the ambition of some in the U.S. aerospace community to simply build a better “*Shuttle Replacement*” – huge payload bay, multi-deck passenger compartment, remote manipulators –

all of the “bells and whistles” decided upon as necessary for project approval more than 25 years ago. But, these features have, quite necessarily, driven launch costs to an intolerable level for simple freight service – the *Space Shuttle* does much more.

Times are different today. We are now talking about commercial development of RLVs, albeit with significant government funding assistance. We now have a permanent space station in the *ISS*, complete with far more capable manipulator systems and human conveniences than has the *Space Shuttle*. We no longer have urgent need for a portable space station, supporting a crew of seven or more for a week or more. The *Shuttle* “return capability” has seen most of its use returning trash – a task better delegated to less expensive expendable entry systems.

We need a means of getting our spacecraft into orbit reliably and economically, without these extraneous burdens imposed upon our new “space truck”.

We also need to transport small numbers of people to orbit, along with a modicum of equipment and supplies. This, however, is a totally separate design problem, best served by a separate, perhaps derivative development activity. The reusable booster can, of course, be an unmanned aerial vehicle used for both cargo and manned flight upper stage sets. “Man-rating” will be proven by initial redundancy, operational use and by effective evolution to high reliability rather than by endless mathematical modeling.

We must **not** place humans in a “can” inside a cargo bay – where there will be little hope for an effective crew escape system usable by all. All personnel should instead be placed in a single pressure vessel “crew escape module” and, yes, with a human pilot and co-pilot for passenger flights, both for human reassurance and for the judgment they will provide when things get “really sticky”.

The Evolutionary Architecture

*StarBooster*TM will begin life as a small technology demonstrator vehicle labeled *StarBooster 2*TM, with the number designating the approximate short tons of propellant capacity. From there, it will progress to an operational vehicle, *StarBooster 30*TM, about the size of an *F-15* fighter; then to *StarBooster 200*TM; the same size as a Boeing 737 airliner; and perhaps yet again to larger vehicles not yet well defined. Appropriate upper stage assemblies and payload fairings will be carried

side-mount to the airplane and launch missions will, in many cases, use two boosters per flight.

Upper stages will, whenever possible, be drawn from existing inventories. *StarBooster 2*TM will, following its technology demonstration program, be used operationally to augment the performance of existing sounding rockets and may be fitted with upper stages permitting payloads (*nanosats* and *microsats*) of a few tens of pounds to be placed into low orbit. As another example, the *Athena II* vehicle can be boosted by *StarBooster 200*TM to augment its performance by a factor of three with one *StarBooster (Delta II class)* and to about five times that of *Athena II* with two boosters (*Atlas II class*).

This dual booster configuration will also be fitted with a derivative upper stage called *StarCore I*TM to place modern “6-ton class” (to GTO) communications satellites at their destination. When *Titan IV-B* capability is needed, another, higher energy, derivative upper stage called *StarCore II*TM can be provided, boosted by two *StarBooster 200s*TM.

Alternate access to the *ISS* can be gained, with cargo carried in a nose-mounted module on *StarCore I*TM. Separate crew transfer flights can be provided by the reusable *StarBird I*TM powered by a single *SSME* and equipped with external hydrogen tanks to enable safe abort flight and to dramatically reduce the size and mass of this second stage so that a single *StarBooster 200*TM may launch it to *ISS* or polar orbits. This vehicle could also support a fledgling space tourist industry.

Future *StarBoosters*TM may use from one to five of the *RD-170* oxygen / kerosene rocket engines, presently the world’s most powerful rocket engine.

University Flight Tests

*StarBooster*TM design work had been underway for about three years when the NASA Langley Research Center indicated an interest in this approach. This interest extended to issuance of small grants to a visiting summer University Professor, Dr. Dianne DeTurris of the California Polytechnic Institute, San Luis Obispo.

Professor DeTurris has harnessed the impressive energies of the student Rocket Club to build and test fly glideback booster models similar to the *StarBooster*TM configuration. This program is now in its second year, and has flown three examples of a vehicle 9.5 feet in length.

Various models to date have demonstrated rocket-powered flight up to altitudes of 4,000 feet, transition to level flight and stable cruise flight. This program continues.



Figure 1 CalPoly 9.5' *StarBooster* No. 2

Wind Tunnel Tests

The NASA Langley Research Center is now completing wind tunnel models of a glideback booster configuration with plans for testing this summer from landing speeds to above Mach 4. These tests are expected to confirm the analytically derived stability / controllability and lift-drag characteristics over the flight envelope that are inputs to trajectory simulations predicting performance. These tests may include representative “payloads” and dual booster launch configurations. This information will help further configuration definition for the *StarBooster*TM architecture and will support additional computer simulations of glide-back flight.

*StarBooster 2*TM

The *StarBooster Technology Demonstrator*TM vehicle will use three rocket engines of about 5,000 pounds vacuum thrust each and will have a loaded weight of about 8,600 pounds. Flight tests will begin with unpowered drop tests from an aircraft or helicopter; will extend to solo rocket-powered flight with partial and then full propellant loads to acquire the full flight

envelope through about Mach 2. With strap-on solid motor assist, flight tests up to Mach 3 may also be conducted, characteristic of the follow-on *StarBooster 30*TM vehicle. Mated tests with payloads to be used for operations will also be performed. No less than three flight vehicles will be provided for flight test, with at least two of these expected to later enter operations at Wallops Island to augment sounding rocket missions and then to place very small payloads (nanosats) into orbit.



Figure 2 *StarBooster 2*TM

*StarBooster 30*TM

Effectiveness of the *StarBooster*TM family is greatly enhanced in *StarBooster 30*TM by providing some 60,000 pounds of oxygen / kerosene propellants in a vehicle powered by an *RD-120* engine (modified for sea level start and incorporating thrust vector control).

Alternate engine sets may consist of four low cost 50,000-pound thrust pressure-fed engines under development at the Air Force Research Laboratory (AFRL). Both single and dual booster flight configurations are planned, beginning with expendable upper stages, progressing to the use of partially expended *StarBooster 30*TM propulsion modules as a

second stage and, later, to the use of a fully reusable third stage based upon a design produced by AFRL.

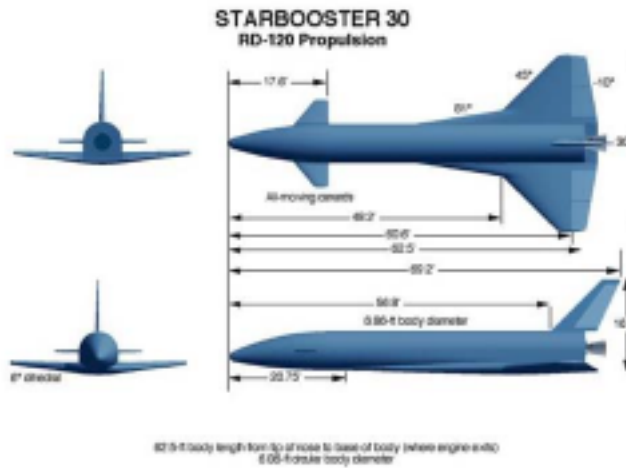


Figure 3 *StarBooster 30™* Dimensions

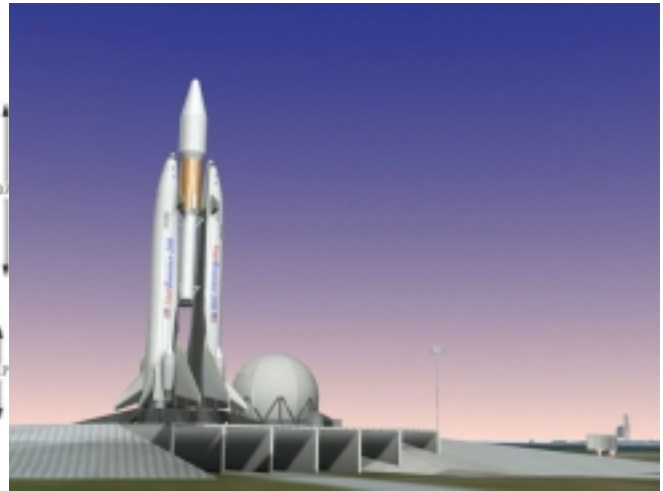


Figure 4 Dual *StarBooster 200™* with *StarCore I™* Launch Vehicle

StarBooster 200™

The commercial “workhorse”, *StarBooster200™*, will produce much greater payload capability than will the earlier, smaller versions. This fully reusable booster is approximately 130 feet in length, roughly the same size as a Boeing 737 airliner. The *Removable Propulsion Module (RPM™)* will be an adaptation of the first stage of the present *Atlas III* launch vehicle, which successfully flew on May 15, 2000. This powerful rocket stage, using *RD-180* propulsion, will be supported within the aeroshell by a flight-worthy replica of the ground handling “stretch fixture” which has long been in use to protect the *Atlas* against loss of pressurization.

StarBooster200™ will be used to boost several configurations of upper stages and payload fairings. One strong candidate for early use is the present *Athena II* solid rocket launch vehicle. An adaptation of this vehicle called *StarCore I™* substitutes the *Centaur* stage and payload fairing from *Atlas III* for the present *Orbus* upper stage solid rocket and payload fairing. Initial review of using *StarBooster 200™* to boost other large launch vehicles such as *Atlas V* indicates the potential for near-universal application.

With the added boost power of dual *StarBoosters™* (Figure 4), this architecture can support direct launch to geo-stationary orbit of over three metric tons net on-station payload mass for those satellites that are equipped with electric propulsion systems.

StarBird I

A companion *Orbiter* vehicle of similar plan form named *StarBird I™*, boosted by a single *StarBooster 200™*, shown in Figure 5, can provide an alternative to the *Space Shuttle* for human space flight. This project will be initiated only after the *StarBooster 200* fully reusable booster has proven its mettle successfully executing cargo missions. If we begin soon, this maturity can precede by a number of years the need date to replace today’s *Space Shuttle*.

StarBird I™ is powered by a single, advanced version of the SSME that is ignited for lift-off (parallel burn) along with the *StarBooster 200*. For flight safety and to greatly reduce body volume and hence inert mass, the hydrogen fuel is carried in expendable, external tanks mounted over the wings. Oxygen is carried in the main body, as is a crew escape module that may be used to carry some cargo as well as personnel.

Operational costs of the expendable tanks will be offset by the large reduction in vehicle size, resulting in huge savings of both development and acquisition costs – “front end” costs made much more valuable by the “cost of money”. These savings are supplemented by not providing a large payload bay. No large payload bay is now planned to be provided.

The unmanned vehicles in the *StarBooster™* family will perform the future large cargo placement function much better than can the human-carrying vehicle.



Figure 5 *StarBooster200TM & StarBird ITM*
Launch Configuration – Parallel Burn

StarBooster “X”

The initial work on *StarBoosterTM*, begun in 1995, was directed toward providing a replacement for the solid rocket boosters of the *Space Shuttle*, using twin *RD-170* rocket engines and almost one and a half million pounds of oxygen and kerosene propellants. It soon became evident that the limited market for this large a vehicle would render it difficult or impossible to generate the funds for its development until and unless another pressing need is established in addition to the use by the *Space Shuttle*.

StarBoosterTM was scaled down to 700,000 pounds of propellants, then to 400,000 pounds and subsequently, the evolutionary architecture described above was adopted.

StarBooster XTM will be necessary if the market develops for true “heavy lift”. This stimulus can come from civil space flight needs by NASA to return to the Moon, explore Mars and its moons, establish bases beyond low Earth orbit; in the commercial space market to carry revenue passengers, put *Space Solar Power* in place, plus untold other possible uses; and by military necessity to place much larger objects into space intact.

The Flight Test Program

Present plans are to conduct the initial technology demonstration flight tests of three *StarBooster 2TM* aircraft from Wallops Island, White Sands, or Edwards Air Force Base. Three aircraft are considered to be necessary to begin the flight test program, as loss of an aircraft in test should not be a reason to abandon the program. The needs of the flight test program, suitability of the range and the cooperative support offered would decide where this is to be accomplished.

Rocket-powered vertical flight test will begin with a small load of propellant, gradually increasing the propellant quantity loaded to extend the flight envelope to its full scope. A proof-of-concept flight to test staging dynamics will be accomplished with “dummy” upper stages, payload fairing and payload. Integration and test of the full “stack” will take place at the first operational site.

Subsequent operational use of *StarBooster 2TM* will be from Wallops Island and, if high inclination flights are also required, from Vandenberg Air Force Base.

StarBooster 30TM will also undergo a thorough flight test program using three aircraft, beginning with horizontal flight tests to prove out subsonic flight and the approach and landing techniques initially tested by *StarBooster 2TM*. As operational, rocket-powered flights of *StarBooster 30TM* will not require air-breathing engines, other means of gaining flight speed will be necessary for this phase of flight test. The *B-52* aircraft used for the *X-15* and subsequent test programs and other carrier aircraft will be investigated to serve the purposes of drop tests. Other means will also be investigated, including towing with a large cargo aircraft, and fitting *StarBooster 30TM* with temporary air-breathing engines.

StarBooster 200™ and subsequent flight test programs have not yet been defined, but are expected to follow much the same path as earlier vehicles. These are expected to be at much lower risk due to the extensive test and operational experience gained with its smaller siblings. Nonetheless, the practice of requiring three aircraft to begin flight test will be followed.

Operational Deployment

Deployment of the *StarBooster™* family will occur in stages. Each system provides a blueprint for the next. The support infrastructure needed for all booster systems is basically the same. These major elements are: launch pad, commodities farm, umbilical tower, cranes and/or mobile gantry, processing facilities, runway, hangar, transporters, ground support equipment, and launch range. This infrastructure exists at current spaceports in the United States. In the clean launch pad approach some items may be reduced or eliminated. With some construction and modifications to existing facilities, (size of the booster will dictate the necessary modifications), a *StarBooster™* system can quickly be readied for operation.

Current contractor support personnel and US Air Force Space Launch Squadrons, at reduced numbers, can provide the necessary skill and personnel needed to support launch operations of the *StarBooster™* system

Using the *Star Booster 30 (SB-30)™* as a model, and existing East or West coast spaceports as sites, a typical launch operation scenario follows for a DOD mission:

The refurbishment facilities store the boosters and *Removable Propulsion Modules (RPM)™*. Two hangars near the flight line are ideal for this work. All necessary maintenance actions on the *SB-30™* can be accomplished here. Processing for upper stages and payloads can be accomplished using other existing facilities at these locations.

The *SB-30™* is placed on hard stands and jacks for landing gear inspection and to facilitate roll transfer of the *RPM™*. The *RPM™* is placed on a transporter/trailer and backed to the aft section of the stabilized *SB-30™*. Leveling and stabilizing of the transporter will allow the emplacement of the *RPM* into the *SB-30™*, similar to the roll transfer operation of a *Minuteman* booster into a transporter-erector. Mechanical and electrical checks are accomplished and

the *SB-30™* is prepared for transport to the launch pad. An adaptive mating collar to seat the *StarBooster 30™* to the launch ring is attached.

SB-30™ is then moved to the launch pad by a transporter. The upper stages and satellite processing and integration will be accomplished at their respective processing facilities. The mated upper stages and payload components are prepared for transport to the pad by trailer. This can be performed simultaneously with *SB-30™* placement.

Upper stage and payload mating follow *SB-30™* emplacement. The modest empty weight of the “dry” *SB-30™* allows the use of a mobile crane for emplacement. A break-over system can be used to assist in emplacement. Final mechanical and electrical checks and testing are accomplished on the pad. Existing commodity farms or tanker trucks with kerosene and LO₂ fuel the vehicle. Final range safety and mission requirements are reviewed, countdown proceeds, and the *SB-30™* is launched.

Ground support does not end there. The *SB-30™* is a RLV and support personnel are pre-positioned to accomplish recovery of the *SB-30™*. The *SB-30™* returns to the site as an Unmanned Aerial Vehicle. The *SB-30™* is towed, using an available aircraft tug vehicle, to the refurbishment facilities (hangars). The *RPM* is removed so that separate processing and inspections operations may be accomplished. Replacement of the refurbished, empty *RPM™* into the *StarBooster* aircraft will begin the process of readying the *SB-30™* for another mission.

Rapid turnaround capability is inherent in the system. The time line for such an operation can occur within days of notification and payload arrival. Total preparation and launch actions can occur in less than one week. By placing *StarBooster™* vehicles in an “alert state”, pre-positioned on the pad in flight-ready configuration, response time may be significantly reduced. Even with no booster-siting alert, the total operation to prepare, configure, and launch *StarBooster™* is measured in units of days.

Summary

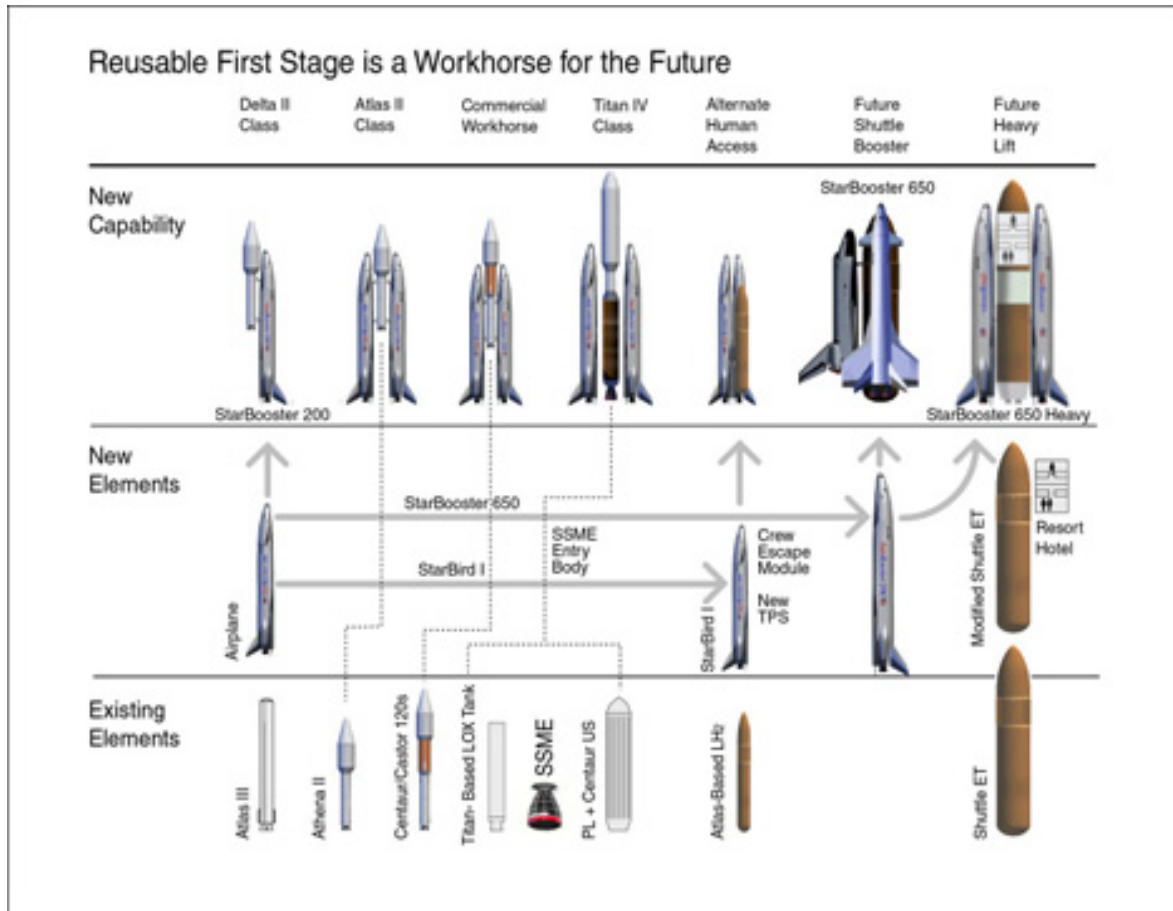


Figure 6 Future *StarBooster*TM Growth Path

Future opportunities for constructive and profitable application of the space environment await only a less expensive and more reliable means of gaining the vantage point of low Earth orbit. The evolutionary *StarBooster*TM architecture described above can be begun without further delay, providing an effective means of entering this path to the future.

In order to provide the needed services to meet national security needs and to successfully compete in the international launch services market, we must simply decide that we will begin - soon.

We can then apply our best efforts and our many available resources to gain the operational knowledge necessary to evolve to the high reliability and low operational costs required. These essential benefits will be made possible by routine, frequent application of an evolving, highly reliable, reusable launch system; one not requiring early application of highly speculative new technologies. *StarBooster* is such a system.