Starcraft Boosters, Inc.
The *StarBooster* System
A Cargo Aircraft for Space

October 27, 1999

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Part 1 – Table of Contents

StarBooster™ and all variations of the *StarBooster*™ name (eg. *StarBooster 200*™) are trademarks of Starcraft Booster, Inc.

Part 2 - Executive Summary

"The journey of a thousand miles begins with a single step."
-Chinese adage

The *StarBooster* Vision

On the path to opening up space to further exploration, travel, and widespread commercial development, Starcraft Boosters, Inc. has been committed, since its incorporation in 1996, to provide the most practical single step to begin the journey. We believe that the three most pressing goals that must be realized are an increase in reliability, a practical growth path to future mission requirements and a drastic reduction in space launch costs.

Starcraft Boosters, Inc. has a unique, proprietary concept that will achieve these goals. It is to transform an existing expendable space launch vehicle (ELV) first stage into a reusable first stage by housing it in a new, aluminum aircraft called *StarBooster*. Through use, inspection, maintenance and reuse, an existing stage can be evolved to provide an increase in reliability. Reusing this normally expended first stage reduces costs by allowing the preservation of more than 70% of the launch vehicle's dry mass. Single or dual *StarBooster*, when combined with different sets of existing and derived upper stages, can address a wide range of missions.

By initially focusing on creating a reusable booster, Starcraft is not developing a concept limited merely to a small range of missions and potential payloads. *StarBooster* is envisioned as being used to augment a variety of current launch vehicles and upper stages by multiplying their present payload capabilities compared to that when they are ground-launched.

This report presents an overview of the work completed since the company's inception. The majority of effort has been focused on one *StarBooster* configuration, the *StarBooster 200*. This vehicle employs an *Atlas III* derived rocket propulsion module and a set of upper stages called *StarCores* to place medium and intermediate payloads in their desired orbits. In addition, concepts are presented with the *StarCore* line of upper stages and with the *StarBird* and *Space Shuttle Orbiter* manned vehicles. This evolutionary architecture is an example of how *StarBoosters* can be grown and evolved into a complete space transportation system. Future applications as a *Liquid Flyback Booster (LFBB)* technology demonstrator for the *Space Shuttle*, for *International Space Station* supply and servicing, for future space tourism, and heavy lift for ambitious exploration missions are enabled by the flexibility of the *StarBooster* family of vehicles. However, the journey begins with a single step, which is the role of the *StarBooster* aircraft.

The *StarBooster* Aircraft

Figure 2-1. The *StarBooster* Aircraft.

A versatile vehicle, the *StarBooster* aircraft is designed for several modes of operation:

- Vertical rocket-powered launch and ascent.

- Separation from payloads at velocities up to Mach 6.
- Gliding hypersonic to supersonic to subsonic flight on a return trajectory toward the launch site.
- Turbofan-powered subsonic cruise for approach and runway landing.

A key feature of the *StarBooster* system is the clean separation of maintenance activities for the rocket-powered ascent propulsion system and the aircraft system used for the return and recovery of the booster. This separation allows the *StarBooster* rocket reusability development program to be separated from the aircraft and its integration/reuse issues. By utilizing proven booster and upper stages, development risk, costs and time to market can be minimized. Furthermore, we anticipate significant system operational improvements over existing expendable vehicles. Through the use of liquid propellant boosters, which permit parallel maintenance and interchangeability of the aircraft and rocket stage, launch delays and flight-to-flight turn-around time can be reduced.

Reductions in development cost and time, when coupled with a wealth of operational experience gained from repeated re-flight of the initial system, should accelerate the introduction of growth options, such as our concept for the *StarBooster* 750, presently envisioned as a candidate for NASA's *LFBB*.

Presently, two versions of the *StarBooster* aircraft are being concurrently designed as Starcraft Boosters, Inc.'s first reusable booster systems. They are seen as the first step in development, maximizing the use of Commercial Off-the-Shelf (COTS) technology. The *StarBooster 200* vehicle uses the *RD-180* powered first stage of the *Atlas III*. Its performance is presented in detail in Part 6 of this report. The *StarBooster 350* employs the *RD-170*, the "big brother" of the *RD-180*. Both of these engines are supported by Pratt & Whitney.

To date, the *StarBooster 200* vehicle concept has benefited from more detailed analysis work, which is primarily presented in this report. Although the *StarBooster 350* configuration is promising, additional systems level analyses are required. This activity is proposed for the next contract period.

StarBooster 200

The *StarBooster 200* vehicle concept was born when Lockheed Martin and Pratt and Whitney decided to collaborate on integrating the Russian-designed *RD-180* rocket engine into the *Atlas III* (formally *Atlas IIAR*) launch vehicle. Starcraft had earlier developed the *StarBooster 350* aircraft to accommodate the first stage of the *Zenit* launch vehicle. However, with the increasing number of ITAR restrictions imposed by the US State Department, an indigenous booster supplier was sought. It was fortuitous that the *Atlas III* stage became available at roughly the same time.

Starcraft Boosters, Inc. has developed a family of vehicles based on the *StarBooster 200* first stage to serve the commercial market. The smallest member of this family combines a *StarBooster 200* with an existing *Athena II* ELV to place 13,200 lb$_m$ (6,000 kg) into an easterly LEO orbit. Adding a second *StarBooster 200* to the system increases the LEO payload capability by 77% to 23,400 lb$_m$ (10,600 kg). Using a solid kick motor, this same configuration can place four metric tons (8,820 lb$_m$) into a Geosynchronous Transfer Orbit (GTO).

To address future intermediate and heavy lift launch needs, in particular the anticipated growth in demand for placing large (5.0 metric tons / 11,000 lb$_m$ and up) communication satellites in GTO, Starcraft Boosters has developed a unique combination of existing stages. *StarCore I* combines the first two stages of the *Athena II* vehicle with an existing single engine *Centaur* in order to deliver 6.4 metric tons (14,000 lb$_m$) to GTO. An alternate mission for the dual *StarBooster 200 / StarCore I* system may be future re-supply and/or reboost of the *International Space Station (ISS)*.

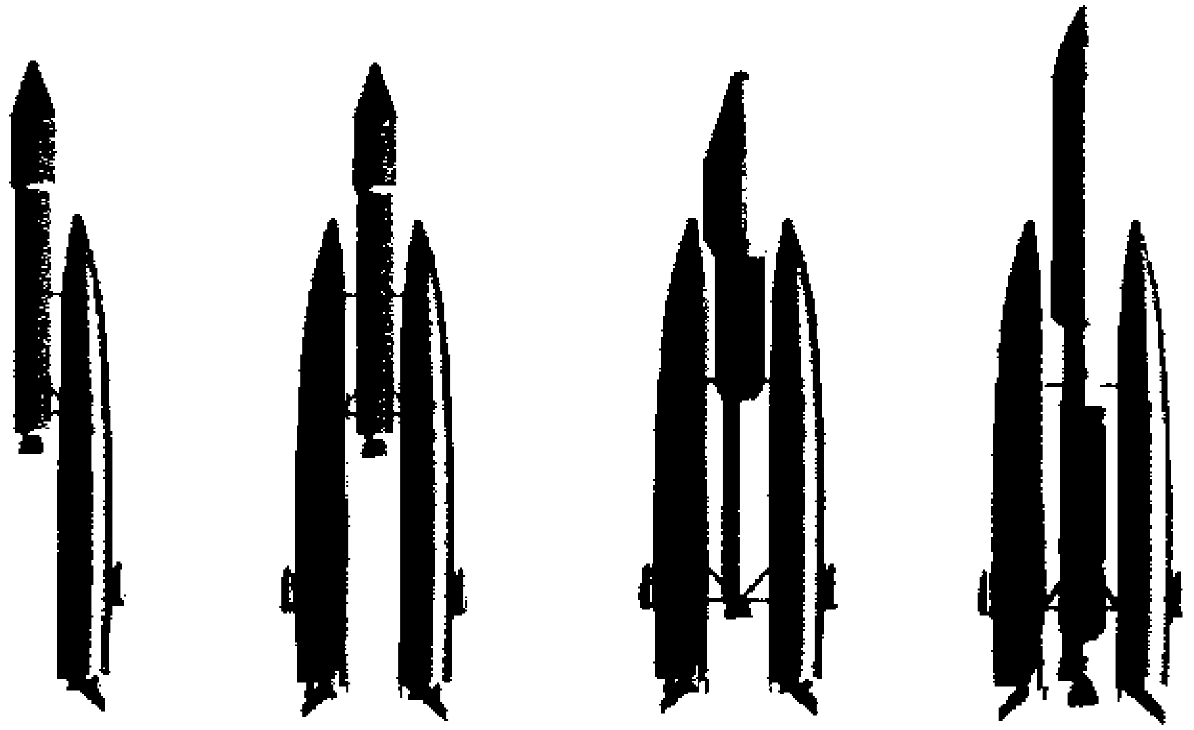


Figure 2-2. ***StarBooster*** **Family Configurations.**
From left to right: *StarBooster 200 / Athena II; Dual StarBooster 200 / Athena II; StarBooster 200 / StarCore I ; StarBooster 200 / StarCore II .*

StarBooster 350

The *StarBooster 350* vehicle is approximately 28% larger than the *StarBooster 200* and provides an alternate path for *StarBooster* development. This booster employs a Ukrainian *Zenit* first stage, which will be provided by Boeing. The *Zenit* first stage is powered by the world's most powerful liquid propellant rocket engine, the *RD-170.*

The family of existing or proposed upper stages for *StarBooster 350* is different. Although less detailed analyses have been performed, the LEO and GTO capabilities are impressive.

StarBooster 350 can also augment several current launch vehicles. For example, the *StarBooster 350* might triple the Pioneer *Pathfinder*'s payload to LEO. With nearly 2.5 times the total impulse of the *Ariane IV*'s solid rocket boosters, the *StarBooster 350* could replace these boosters and significantly increase this vehicle's payload. Likewise, *StarBooster 350* can double the payload capability of the Japanese *H-2* launch vehicle.

One interesting application of the *StarBooster 350* is to take advantage of the "peace dividend" and fly with surplus ICBM's as the "payload". Performance for the American *Titan II*, Ukrainian *Tsyklon*, Russian *Rokot*, and Russian *Ikar* have been analyzed and are significantly improved.

Another potential application is to replace the *Space Shuttle*'s solid rocket motors with dual *StarBooster 350*'s, and/or to use *StarBooster* to develop the technology for a larger *LFBB* to meet *RSRB* replacement requirements. A Shuttle using dual *StarBooster 350*'s could deliver 25,000 lb of payload to the *International Space Station*

(ISS). Although not useful for several of the *ISS* assembly missions, this lower STS payload capability would be useful for re-supply, crew rotation, and station re-boost missions. After an extensive "reliability by learning from reuse" cargo flight program, *StarBooster 350*'s would provide improvements in flight safety and ground processing timelines, and would meet or exceed the payload capability of the proposed Lockheed Martin *VentureStar* while transporting crew members in the current *Orbiter* cabin.

StarBooster Growth Options

The current and future applications and derivatives of *StarBooster* are quite broad. In the near term, one or two *StarBooster 200*'s could serve as liquid strap-on boosters for the *Atlas V* or *Delta IV* launch vehicles, replacing the solid rocket motors and additional "core stages" currently proposed, while increasing vehicle performance and reliability.

Starcraft Boosters has begun conceptualizing future *StarBooster* applications based on our approach of incremental development steps utilizing proven technologies and components. We believe that our concept of employing existing rocket stages as complete propulsion modules provides a low risk starting point for proceeding down a path for developing a family of reusable vehicles.

In the future, *StarBird* manned vehicles may pave the way for space tourism, and new reusable *StarCore* stages may enable a fully reusable launch system.

The most important aspect in a development process is to chart a course and begin the journey. We believe that developing a versatile low-cost airplane and utilizing existing, proven expendable booster stages will most efficiently yield a commercially viable space launch system. Furthermore, the *StarBooster* vehicle will build an industry knowledge base that can be used to expand our communal understanding of the design and operation of future, new technology reusable space systems.

Part 3 – Introduction

Starcraft Boosters has developed a different approach for lowering the cost of access to space. We propose developing a new aircraft that will house an existing expendable rocket stage. This vehicle, termed *StarBooster*, will be the first stage of a family of launch vehicles. By combining these elements, we believe we can reduce the cost and risk of fielding a new partially reusable launch system.

This report summarizes the work performed on the *StarBooster* concept since the company's inception in 1996. Detailed analyses are on-going and future reports will focus on the maturation of the vehicle and system design.

The *StarBooster* Approach

Starcraft Boosters, Inc. has closely watched the market developments of the last five years to chart the company's future course. The *StarBooster* concept is the result of careful consideration of industry trends and requirements.

We have observed that the expendable launch vehicle has been evolved and matured to the point of diminishing returns. If an operator is to achieve quantum improvements in cost and reliability then reusability must be introduced into the system. Furthermore, the commercial pathfinders for fully reusable launch systems, particularly Lockheed Martin with their *VentureStar* SSTO and Kistler Aerospace with their *K-1* TSTO, have met with significant technical and financial challenges. As a result, Starcraft Boosters has chosen a "middle of the road" approach whereby the company will focus upon a reusable booster, utilizing existing expendable stages to place the spacecraft payloads into their final destination orbits.

Starcraft Boosters believes that if it is to be a commercial success then it must strive for reusability while maximizing simplicity and minimizing time to market. To achieve these ends, the StarBooster vehicle ***will utilize existing liquid booster stages housed inside a new aircraft to provide for recovery on a conventional runway.*** We believe this approach will provide significant system cost and reliability improvements while enabling a low risk, low cost development / integration program.

Based on this philosophy as well as our understanding of the current launch market, future trends and requirements, Starcraft Boosters has developed the following set of design criteria for its new launch system.

1. A new, fully reusable booster is the first item to be developed. It will be mated to existing, proven, expendable upper stages in order to deliver payloads to orbit. Fully reusable second stages (i.e. *Orbiters*) will follow, but these will wait until the economic feasibility of the reusable booster is proven by frequent usage with existing upper stages.

2. The reusable booster's main propulsion system will employ a proven expendable booster stage. This will enhance reliability and assure rapid market acceptance. Prior successful flight experience as an expendable booster will be an important advantage for our first reusable booster.

3. The booster should be large enough to compete effectively with other launch vehicle systems, but no larger or more expensive than is necessary to meet commercial needs.

4. The fuel for this booster should be kerosene to assure flight safety beyond

that possible with a vehicle fueled with volatile hydrogen. Due to its small molecule size, hydrogen tends to leak, and a reusable booster must routinely and repeatedly experience the dynamic environment of reentry through the Earth's atmosphere.

5. The means of return for reuse should be a subsonic aircraft, which lands on a conventional runway on wheeled landing gear. Other, higher stress, recovery schemes may lead to serious concerns over the reliability of the recovered vehicle for safe re-flight.

6. The rocket stage should be readily removable from the aircraft to permit parallel and independent maintenance of these two different elements. This principle began to be employed fifty years ago by early jet aircraft, with a removable tail section, which permitted a thirty-minute to one-hour engine change. At that time, this was necessary due to the short life of then-available jet engines. With the rocket propulsion systems of today, it is needed for precisely the same reason. Once one hundred or more re-flights without off-vehicle maintenance has been achieved for rocket stages, integral propellant tank/fuselage arrangements may become preferable to reduce inert mass. Until then, we believe that the *Removable Propulsion Module (RPM)™* is essential to achieve acceptable turn-around for re-flight.

7. Efforts should be made to incorporate existing commercial rocket elements both in the reusable booster and in the upper stages. This approach will serve to minimize development costs. Amortization of these costs is a large determinant of the price that must be charged for launch services, and hence lowering these costs can be a major benefit to success in the marketplace.

8. The booster vehicle should not require a flight crew for commercial space missions in order to conserve inert weight, cost, and to avoid unnecessary risk of human life. It may, however, be capable of accepting a flight deck for early flight test, for use as an "*X-Plane*" carrier, for ferry flights and for other uses that may require the presence of a human crew.

9. The best state-of-the art for remotely piloted vehicles should be utilized for autonomous or nearly so flight operations. The best health maintenance and in-flight diagnostics systems should also be employed to reduce turn-around time and to enhance reliability and flight safety.

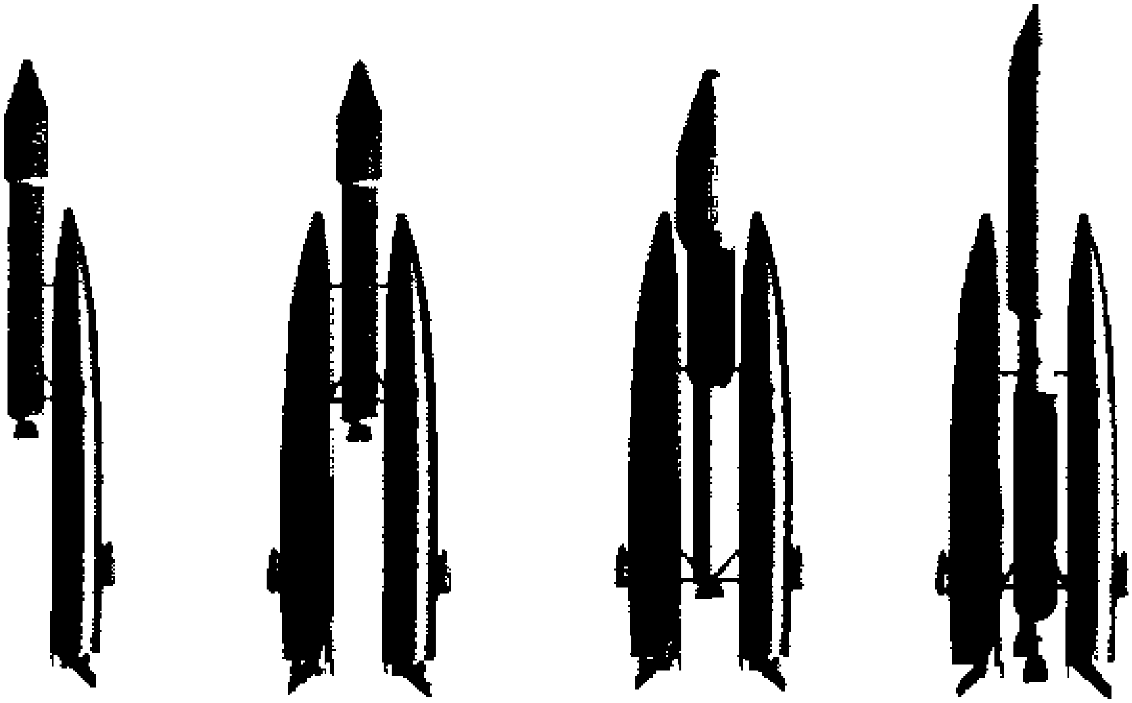
The *StarBooster 200* and *StarBooster 350* systems to be described in this report are based upon these requirements, and are the first members of the *StarBooster* family. They represent the first step on the path to attaining access to space more reliably and at lower cost. *StarBooster 200* and its features have been submitted to the U.S. Patent Office for international protection.

The *StarBooster* Family

The *StarBooster* family of vehicles is currently comprised of five interrelated elements:

- ***StarBooster 200 and StarBooster 350:*** Reusable booster vehicles based on existing engines and ELV booster stages.
- ***Existing ELV Stages:*** These are used to transport payloads from the *StarBooster* staging point (up to Mach 6.0, ~250,000 ft) to the desired orbit.
- ***StarCore I:*** An innovative combination of existing stages proposed to address specific commercial mission requirements.
- ***StarCore II:*** A partially reusable complex of cryogenic upper stages proposed to address specific Department of Defense and other "heavy lift" mission requirements.

- ***StarBird I:*** A new reusable upper stage (*Orbiter*) to address the Earth-to-orbit transportation of small numbers of people for NASA and as a pre-cursor to prospective future commercial industries - such as a space common carrier



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From left to right: ***StarBooster 200 / Athena II; Dual StarBooster 200 / Athena II; StarBooster 200 / StarCore I; StarBooster 200 / StarCore II.***

StarBooster Vehicle Configuration and System Performance

A versatile vehicle, the *StarBooster* aircraft is designed for several modes of operation:

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Reductions in development cost and time, when coupled with a wealth of operational experience gained from repeated re-flight of the initial system, should accelerate improvements in reliability and hasten the introduction of growth options, such as our concept for the *StarBooster 750*, presently envisioned as a candidate for NASA's *LFBB*.

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One interesting application of the *StarBooster 350* is to take advantage of the "peace dividend" and fly with surplus ICBM's as the "payload". Performance for the American *Titan II*, Ukrainian *Tsyklon*, Russian *Rokot*, and Russian *Ikar* has been analyzed and each is significantly improved compared to ground launch of the same vehicle.

Another potential application is to replace the *Space Shuttle*'s solid rocket motors with dual *StarBooster 350*'s, and/or to use *StarBooster* to develop *LFBB* technology to meet *RSRB* replacement requirements. A Shuttle using dual *StarBooster 350*'s could deliver 25,000 lb of payload to the *International Space Station (ISS)*. Although not useful for some *ISS* assembly missions, this lower STS payload capability would be useful for re-supply, crew rotation, and station re-boost missions. After a "reliability by learning from reuse" cargo flight program, *StarBooster 350*'s would provide improvements in flight safety and ground processing timelines, and meet or exceed the payload capability of the current next generation vehicle, the Lockheed Martin *VentureStar*.

***StarBooster* Growth Options**

The current and future applications and derivatives of *StarBooster* are quite broad. In the near term, one or two *StarBooster 200's* could serve as liquid strap-on boosters for the *Atlas V* or *Delta IV* launch vehicles, replacing the solid rocket motors currently proposed, while increasing vehicle performance and reliability.

Starcraft Boosters has begun conceptualizing future *StarBooster* applications based on our approach of incremental development steps utilizing proven technologies and components. We believe that our concept of employing existing rocket stages as complete propulsion modules provides a starting point for proceeding down a low risk path for developing a family of reusable vehicles.

In the future, growth versions of *StarBird* manned vehicles may pave the way for space tourism and new reusable *StarCore* stages may enable a fully reusable launch system.

The most important aspect in any development process is to chart a course and begin the journey. We estimate that developing the versatile low-cost *StarBooster* airplane and utilizing existing, proven expendable booster stages will yield a commercially viable space launch system. Furthermore, the *StarBooster* vehicle will build an industry knowledge base that can be used to expand our communal understanding of the design and operation of reusable space systems.

Part 4 – Regulatory Environment

"The United States space program is critical to achieving U.S. national security, scientific, technical, commercial, and foreign policy goals. Assuring reliable and affordable access to space through U.S. space transportation capabilities is a fundamental goal of the U.S. space program....

The Department of Defense (DoD) will be the lead agency for improvement and evolution of the current U.S. expendable launch vehicle (ELV) fleet, including appropriate technology development."

(National Space Transportation Policy, Office of Science and Technology Policy, August 5, 1994)

"U.S. Government agencies shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with commercial applications that preclude or deter commercial space activities except for reasons of national security or public safety. A space good or service is "commercially available" if it is currently offered commercially, or if it could be supplied commercially in response to a government service procurement request. "Feasible" means that such goods or services meet mission requirements in a cost-effective manner."

(National Space Policy, National Science and Technology Council, September 19, 1996)

"With the number of space launches projected to grow to as many as 50 per year over the next decade, and with the prospect of at least a portion of them being on what we are referring to as hybrid vehicles - that is vehicles that operate as airplanes during part of their mission and as space vehicles during other parts - planning is well underway on how to manage this situation for both safety and efficiency."

(Remarks by Patricia Grace Smith, Associate Administrator for Commercial Space Transportation, Federal Aviation Administration, United States Department of Transportation, "SPACE AT THE CROSSROADS: MILITARY USES OF COMMERCIAL SPACE SERVICES CONFERENCE, U.S. SENATE HART OFFICE BUILDING, WASHINGTON, D.C., September 16, 1999)

Introduction and Summary

What policy, law and regulations have jurisdiction over the StarBooster? Why is this question important enough for Starcraft Boosters, Inc. to have studied it while the StarBooster is just a paper concept?

The StarBooster is a "hybrid vehicle," a reusable booster that takes off vertically as part of a space vehicle. But the StarBooster does not enter outer space. It separates from the upper stage in the atmosphere and then flies back to its landing site like an airplane.

Any commercially owned or operated StarBooster will be regulated as either an aircraft or as a launch vehicle even if it is used for NASA or DOD launches. The only way to avoid regulation is for the StarBooster to be owned by the government.

If the StarBooster is an airplane, the FAA must certify it. For example, the Pegasus launch vehicle uses an L-1011 aircraft, which is certified by the FAA. If the StarBooster is a reusable launch vehicle, then the FAA must issue a launch license authorizing its flight. This is not an academic question. Which regulatory regime controls the StarBooster will define important aspects of its engineering, design, financing and operation.

The Commercial Space Act of 1998 (CSA), Public Law 105-303, extends the licensing authority of the Secretary of Transportation under 49 U.S.C. Subtitle IX, chapter 701 (known as the Commercial Space Launch Act or CSLA), to reentry vehicle operators and the operation of reentry sites by a commercial or non-Federal entity. Under the CSA, the Secretary is authorized to license reentry of a reentry vehicle, including reusable launch vehicles, and the operation of reentry sites when those activities are conducted within the United States or by U.S. citizens abroad.

FAA draft rules that are not yet final define a "reentry vehicle" as a vehicle designed to return from Earth orbit or outer space to Earth substantially intact. A reusable launch vehicle that is designed to return from Earth orbit or outer space to Earth substantially intact is a reentry vehicle. The StarBooster is not a reentry vehicle under this definition because it does not return from orbit or outer space.

Under the proposed FAA rule a "reusable launch vehicle (RLV)" is a launch vehicle that is designed to return to Earth substantially intact and therefore may be launched more than one time **or that contains vehicle stages that may be recovered by a launch operator for future use in the operation of a substantially similar launch vehicle**. (Notice of proposed rulemaking [Docket No. FAA-1999-5535; Notice No. 99-04] RIN 2120-AG71, Commercial Space Transportation Reusable Launch Vehicle and Reentry Licensing.)

Under this proposed rule, the StarBooster would be a "Reusable Launch Vehicle." But it is uncertain if the draft rule would apply to the StarBooster "aircraft" as it flies hundreds of miles back to a landing site. The draft rule seems to have been written more in contemplation of the parachute recovery of conventional rocket stages, like the solid rocket boosters on the space shuttle.

I tried to clarify this issue by calling Ms. Laura Montgomery, a FAA attorney in the office of Commercial Space Transportation. Ms. Montgomery confirmed that it is now uncertain how a hybrid vehicle like StarBooster would be regulated. She suggested that it might be necessary for SBI to file a "Request for Interpretation Letter" that would cause the FAA to consider this matter and make a ruling. She told me that the ruling would take quite some time because this question is already under study in the FAA and may require additional rulemaking. This communication is continuing.

In order to understand what it means for the StarBooster to be regulated as a launch vehicle, it is necessary to understand how launch vehicles are licensed.

Regulation of Commercial Launch Vehicles

The Commercial Space Launch Act of 1984, as codified at 49 U.S.C. Subtitle IX--Commercial Space Transportation, ch. 701, Commercial Space Launch Activities, 49 U.S.C. §§ 70101-70121 (the Act), authorizes the Secretary of Transportation to oversee, license and regulate commercial launch activities and the operation of launch sites as carried out by U.S. citizens or within the United States. 49 U.S.C. §§ 70104, 70105. The Act directs the Secretary to exercise this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States, 49 U.S.C. § 70105, and to encourage, facilitate and promote commercial space launches by the private sector, 49 U.S.C. § 70103.

The FAA carries out the Secretary's responsibilities for licensing and regulating launches and the operation of launch sites. Prior to November 15, 1995, the Secretary's responsibilities were implemented by the Office of Commercial Space Transportation (the Office), which was located within the Office of the Secretary in the Department of Transportation. Now, the Associate Administrator for Commercial Space Transportation is part of DOT's Federal Aviation Administration. When this administrative change was effected, the Secretary delegated the statutory authority over the regulation of commercial space transportation to the Administrator of the Federal Aviation Administration, and the Administrator redelegated this authority to the Associate Administrator.

On August 4, 1994, President Clinton announced a new National Space Transportation Policy reaffirming the government's commitment to the commercial space transportation industry and the critical role of the Department of Transportation in encouraging and facilitating private sector launch activities. In 1996, President Clinton signed a National Space Policy, which recognized the Department of Transportation as the lead federal agency for regulatory guidance regarding commercial space transportation activities. The FAA's rules, by offering greater specificity and certainty regarding licensing requirements and the scope of a license, should assist the launch industry in its business and operational planning. This will facilitate the private sector's launch activities by increasing certainty and by easing its regulatory burden.

Background on the FAA's Commercial Launch Licensing History and Process

The FAA licenses commercial launches and the commercial operation of launch sites through 14 CFR Ch. III. In April 1988, when the then Office of Commercial Space Transportation first issued final regulations, no licensed launches had yet taken place. Accordingly, the Office established a flexible regime intended to be responsive to an emerging industry while at the same time ensuring public safety. The Office noted that it would "continue to evaluate and, when necessary, reshape its program in response to growth, innovation and diversity in this critically important industry." Commercial Space Transportation Licensing Regulations, 53 FR 11004,11006, (Apr. 4, 1988). Under the 1988 regulations the Office implemented a case-by-case approach for the evaluation of launch license applications. All commercial launches at the time took place from federal launch ranges.

In conjunction with information guidelines describing the Office's application process, the Office's regulations reflected the intent of Congress that the Office evaluate the policy aspects and safety of a proposed launch. The Office followed a case-by-case approach to performing these reviews, tailoring its information requests to the specifics of a given launch proposal.

Later, the Office took further steps designed to simplify the licensing process for launch operators with established safety records. For example, before issuing its final rules in 1988, the Office issued interim regulations, in which it had contemplated the possibility that "one license could cover a specified series of launches where the same safety resources [would] support identical or similar missions." Commercial Space Transportation Licensing Regulations; Interim Final Rule and Request for Comments,
51 FR 6870, 6872 (Feb. 26, 1986). In 1991, the Office implemented this option by instituting a launch operator license for similar launches carried out by a single licensee. The launch operator license currently authorizes a licensee to conduct any number of launches within defined parameters over the course of a two year period. The FAA has continued to apply a case by case analysis to licenses authorizing a single launch or to licenses authorizing a set of specifically identified launches.

The FAA, in accordance with 49 U.S.C. § 70112 and 14 CFR Ch. III, part 440, imposes financial responsibility requirements on a licensee commensurate with the scope of its license, pursuant to which a licensee is required either to purchase insurance to protect launch participants in the event of claims by third parties and to protect against damage to government property, or to otherwise demonstrate financial responsibility. In the event that there was a launch accident and third party claims arising out of that launch exceeded the financial responsibility required by the FAA, the Act contains procedures through which the government of the United States may pay those excess claims up to a statutory ceiling. See 49 U.S.C. § 70113. The possible payment of excess claims by the government for damages related to a particular launch is commonly referred to, albeit erroneously, as "indemnification" of the launch industry. The payment of excess claims constitutes, in fact, only a provisional agreement by the government of the United States, which is subject to conditions, including Congressional appropriation of funds.

Growth and Current Status of Launch Industry

The number of commercial space launches has steadily grown over the years since the first licensed commercial launch in 1989. As of October, 1999, over 110 licensed launches have taken place from five different federal launch ranges, from an aircraft in flight and from an offshore platform in the Pacific. Launch vehicles have included traditional orbital launch vehicles such as the Atlas, Titan and Delta, as well as suborbital vehicles such as the Starfire. New vehicles using traditional launch techniques include Lockheed Martin's Athena I and II, EER's Conestoga, Orbital Sciences Corporation's Taurus, and Boeing's Delta III. Unique vehicles such as the Pegasus are also included in this count. New launch vehicles are proposed every year. For example, the Pegasus air-launched rocket has been developed since the passage of the Act. The Act also regulates sea-launched rockets, Lockheed Martin's Atlas III and

Boeing's and Lockheed Martin's evolved expendable launch vehicles. A number of companies are proposing partially and fully reusable launch vehicles. Several companies are participating in partnership with the National Aeronautics and Space Administration (NASA) to develop X-33 and X-34 launch vehicles incorporating reusable and single-stage-to-orbit technology, which could result in vehicles for commercial use.

Currently, commercial launches take place from federal launch ranges operated by the Department of Defense and NASA. Launch operators bring launch vehicles to federal ranges such as Cape Canaveral Air Station, Vandenberg Air Force Base, White Sands Missile Range and Wallops Flight Facility, for launch. A launch operator obtains a number of services from a federal range, including radar, tracking and telemetry, flight termination and other launch services. Pursuant to an agreement between a federal launch range and a launch operator, the federal range has final authority over whether to allow a launch to proceed. A federal range operates pursuant to its own internal rules and procedures, and the launch operator must comply with those rules and procedures in addition to the requirements of the FAA.

The U.S. commercial space transportation industry faces strong international competition. Ariane, Europe's launch vehicle, continues to be the market leader, with other competition coming from China, Russia, and Ukraine. The U.S. industry still obtains a significant percentage of launch contracts, and over fifty commercial launches are planned within the next three years. AST projects over seventy commercial orbital launches within the next three years.

Additionally, U.S. participation in international ventures is increasing. For example, International Launch Services (ILS), comprised of Lockheed Martin Corporation, Khrunichev Enterprise and NPO Energia, markets Russia's Proton rockets and the U.S. Atlas. Another international partnership, Sea Launch Limited Partnership (Sea Launch), involves Boeing Commercial Space Company, S.P. Korolev Rocket and Space Corporation Energia, KB Yuzhnoye and PO Yuzhnoye Mashinostroitelny Zavod, and Kvaerner Moss Technologies a.s., which are U.S., Russian, Ukrainian and Norwegian companies, respectively. Sea Launch has launched two commercial rockets from a modified oil rig located in the Pacific Ocean. Orbital Sciences Corporation has conducted a launch outside the United States and envisions more.

Current Revisions to Licensing Regulations

With six years of experience in regulating the commercial launch industry, the DOT Office of Commercial Space Transportation initiated a process for standardizing its licensing regulations. When the Office first started its licensing program, the Office did not possess standardized rules or requirements. Accordingly, it evaluated each license application individually to ensure that a proposed launch would not jeopardize public health and safety, the safety of property, U.S. national security or foreign policy interests or international obligations of the United States. Over the course of time, and with the input of licensees and federal launch ranges, the FAA has evolved a standardized approach to licensing launches from federal launch ranges. Accordingly, the FAA now implements that approach through revisions to its regulations.

On October 13, 1994, in anticipation of issuing a notice of proposed rulemaking, the Office of Commercial Space Transportation, DOT, announced that it was holding a public meeting to obtain industry's views to assist the Office in developing an NPRM that would address specific requirements for launch and launch site operator licenses. Notice of Public Meeting, 59 FR 52020 (1994). The Office stated that it would streamline its launch licensing process by standardizing requirements and by codifying certain information requirements in its regulations. Id. The Office also advised the public that it would promulgate rules concerning licensing the operation of a launch site. Id. The FAA proposed to implement rules of general applicability for operation of a launch site through an additional notice of proposed rulemaking in order to foster certainty for this new industry as well. Id. The public meeting took place on October 27, and 28, 1994, and was attended by representatives of the commercial launch industry, payload companies, prospective commercial launch site operators, interested government agencies, both state and federal, and the public.

On March 19, 1997, the FAA released a notice of proposed rulemaking proposing to amend its licensing requirements. Commercial Space Transportation Licensing Regulations, Notice of Proposed Rulemaking (NPRM), 62 FR 13216 (Mar. 19, 1997). In the NPRM, the FAA proposed to narrow its definition of launch from "gate to gate," which resulted in the licensing of the launch related activities of a launch operator at a federal launch range prior to the arrival of the launch vehicle, to "vehicle at the gate," which encompasses only the launch operator's activities once its vehicle arrives. The NPRM proposed a launch license application process developed through its case by case license history, including the implementation of certain safety proposals recommended by the National Transportation Safety Board. The FAA also proposed to streamline and reorganize a variety of other licensing provisions. The comment period closed May 19, 1997. At the request of several launch operators, the FAA reopened the comment period until August 4, 1997, and received comments from a number of interested parties, including launch operators, a payload provider, a launch site operator and prospective reusable launch vehicle operators.

The Environmental Protection Agency commented on the FAA's environmental procedures. The launch operators who filed comments included Boeing Commercial Space Company, Lockheed Martin Corporation, McDonnell Douglas Aerospace, and Orbital Sciences Corporation. Reusable launch vehicle operators' views were represented by Kistler Aerospace Corporation, Rotary Rocket Company, and Space Access. Hughes Electronics, Spaceport Florida Authority, and the National Transportation Safety Board also filed comments. Comments focused on several major issues, with the proposed definition of launch eliciting the most attention. Foreign ownership of a license applicant also proved a topic of concern, as did issues surrounding the FAA's proposed risk threshold and various safety requirements. In light of the great variety of topics encompassed by this rulemaking, rather than devoting a single section to all of the comments, the FAA addressed the comments by subject matter throughout the preamble and section by section analysis in the relevant context.

On October 28, 1998, the Commercial Space Act of 1998 was signed into law. Among other things, it revised the definition of launch to include activities "involved in the preparation of a launch vehicle or payload for launch, when those activities take place at a launch site in the United States." P.L. 105-303 (1998), 49 U.S.C. 70102(3). The change affects this rulemaking's definition of launch by both confirming the more narrow application proposed in the NPRM and expanding the scope of launch to encompass launch vehicle preparatory activities occurring at any launch site in the United States, even when those activities take place at a launch site from which flight of the launch vehicle does not take place.

Launch License

The amendments to the FAA's launch licensing regulations address the definition of "launch," licensing requirements, including payload determinations and policy reviews, and information required from an applicant proposing to launch a vehicle employing established technology and procedures from a federal launch range. The FAA here changes its interpretation of the definition of "launch" and thus changes the scope of a launch license. Additionally, in contrast to what was originally proposed in the NPRM, which was to define with particularity the beginning of launch for purposes of those taking place from a federal launch range, the FAA will apply its proposed definition of launch to a launch taking place at any launch site located in the United States, whether that launch site is a federal launch range or not. Through this rulemaking the FAA is formalizing its practice of issuing two different types of launch licenses, a launch operator license pursuant to which a licensee may conduct any launches that fall within the broad parameters described in its license, and a launch-specific license, which allows a licensee to conduct only those launches enumerated in the license.

Proposed Requirements for RLV Mission License

Under currently proposed, but not yet adopted, FAA rules, in its RLV mission license application, an applicant must—

(a) Identify the model, type, and configuration of any RLV proposed for launch and reentry, or otherwise landing on Earth, by the applicant.

(b) Identify all vehicle systems, including structural, thermal, pneumatic, propulsion, electrical, and avionics and guidance systems used in the vehicle(s), and all propellants.

(c) Identify foreign ownership of the applicant as follows:

1. For a sole proprietorship or partnership, identify all foreign ownership;
2. For a corporation, identify any foreign ownership interests of 10% or more; and
3. For a joint venture, association, or other entity, identify any participating foreign entities.

(d) Identify proposed launch and reentry flight profile(s), including—

1. Launch and reentry site(s), including planned contingency abort locations, if any;

2. Flight trajectories, reentry trajectories, associated ground tracks, and instantaneous impact points for nominal operations, and contingency abort profiles, if any;

3. Sequence of planned events or maneuvers during the mission; and

For an orbital mission, the range of intermediate and final orbits of the vehicle and upper stages, if any, and their estimated orbital life times.

Part 5 - The *StarBooster* Family

The *StarBooster* family of vehicles is currently comprised of five interrelated elements:

- ***StarBooster 200*** and ***StarBooster 350:*** Reusable booster vehicles based on existing engines and ELV booster stages.
- ***Existing ELV Stages:*** These are used to transport payloads from the *StarBooster* staging point (up to Mach 6.0, ~250,000 ft) to the desired orbit.
- ***StarCore I:*** An innovative combination of existing stages proposed to address specific commercial mission requirements.
- ***StarCore II:*** A partially reusable complex of cryogenic upper stages proposed to address specific Department of Defense and other "heavy lift" mission requirements.
- ***StarBird I:*** A new reusable upper stage (*Orbiter*) to address the Earth-to-orbit transportation of people for NASA and prospective future commercial industries - such as a space common carrier.

The goal of Starcraft Boosters, Inc. is to integrate these five elements to create a low risk, highly reliable space transportation architecture with clear growth paths for the space missions of the future. The initial configurations proposed are based upon either the *StarBooster 200* or the *StarBooster 350* reusable space boosters.

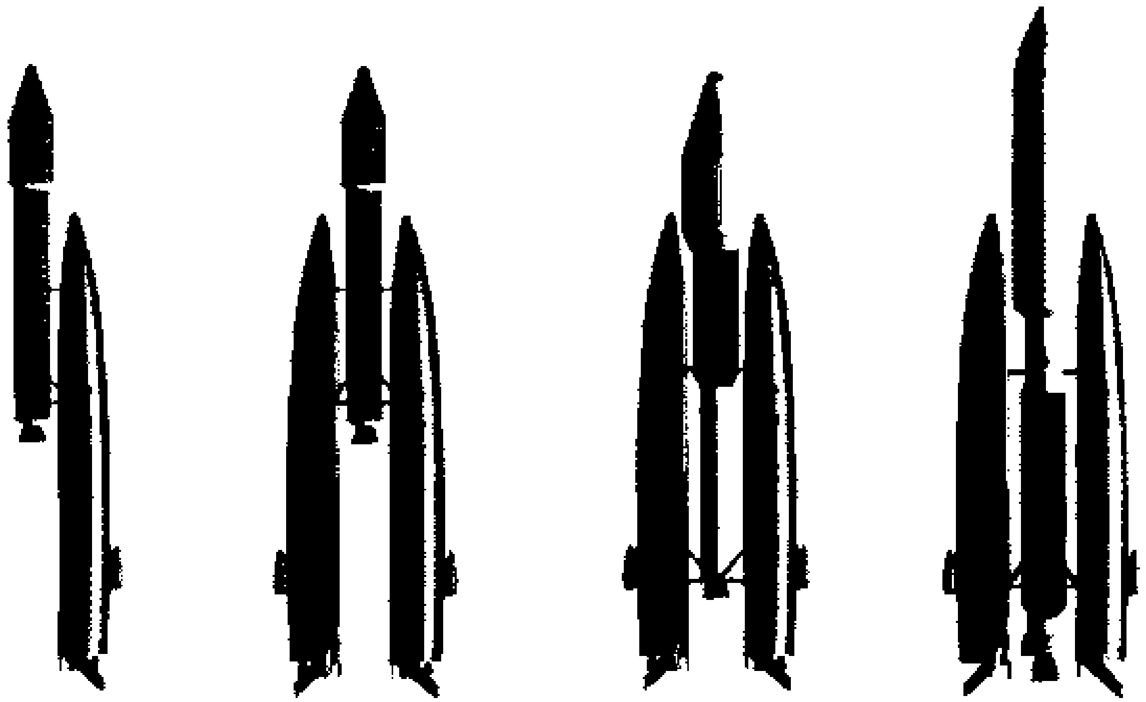

Figure 5-1. *StarBooster* Family Configurations.
From left to right: *StarBooster 200 / Athena II; Dual StarBooster 200 / Athena II; StarBooster 200 / StarCore I; StarBooster 200 / StarCore II.*

The *StarBooster 200* System

StarBooster is a program of aircraft development and adaptation of existing rocket vehicles. The *StarBooster 200* aircraft is designed to house and return the first stage of the new *Atlas III* launch vehicle, with its *RD-180* rocket engine. The airplane is roughly the size of the Boeing 737 airliner and has an expected dry mass near 70,000 lb$_m$ (32,000 kg). It contains approximately 200 US tons (400,000 lb$_m$/181,400 kg) of propellant, hence the designation *StarBooster 200.*

Figure 5-2. *StarBooster 200* Returning to Launch Site

StarBooster 200 is launched vertically under the rocket power of its internally mounted booster stage and delivers its expendable upper stages and payload to near Mach 5 at an altitude of approximately 150,000 ft (45 km). After separating from its payload, the vehicle, along with the spent *Atlas III* first stage still installed in the fuselage, proceeds on a return trajectory, decelerating as it descends in the atmosphere. After air starting its two turbofan engines, the vehicle cruises about 250 miles (400 km) back to the launch site at subsonic speed, and lands on its wheeled landing gear. For certain missions where the staging velocity can be limited to Mach 3.3, the *StarBooster* vehicle has the capability to use its wings to perform an un-powered Return to Launch Site (RTLS) maneuver. In these situations, the Air Breathing Propulsion System (ABES) can either be eliminated or used to further increase mission flexibility and reliability.

After the *StarBooster 200* lands on the runway, the aircraft and stage are then refurbished for re-flight. Due to the modularity of the design, the entire *Atlas III* first stage component can be removed from the vehicle and replaced with a new stage. This interchangeability of components is intended to decrease turn around time by allowing either the aircraft or the rocket stage to be maintained without having to ground the entire system. A sufficient number of rocket stages will be kept in inventory to facilitate this type of operation.

StarBooster 200 Vehicle Configuration

The *StarBooster 200* vehicle consists of a long cylindrical body with an aft delta wing and forward canards. Winglets provide lateral stability during atmospheric flight while an attitude control system is used to control the vehicle during exo-atmospheric flight.

StarBooster 200 has a body length of 123 ft (38 m) and a wingspan of 67 ft (21m). Approximately 66,000 lb$_m$ (30 metric tons) of the vehicle's 518,000 lb$_m$ (235 metric tons) gross mass is aircraft dry mass.

The vehicle's dry mass is split into three major parts: the aircraft, the air-breathing propulsion system (ABES) and the *Atlas III* first stage, referred to as the *Removable Propulsion Module (RPM)*. The aircraft has a calculated dry mass without ABES of 65,700 lb$_m$ (30 tons), including a 30% mass margin. For those missions staging above Mach 3.3, the ABES must be installed, increasing aircraft dry mass to 75,800 lb$_m$ (34 tons). The dry mass of the *Atlas III* first stage is estimated to be near 26,500 lb$_m$ (12 tons) with BECO "wet" mass of 30,260 lb$_m$ (13.7 tons). The *StarBooster 200* vehicle configuration is discussed in more detail in Part 6 of this report.

The *Atlas III RD-180* engine provides a liftoff thrust-to-weight ratio of 1.20 or greater in series burn configurations (no supplemental thrust from payload rocket stages). With this configuration, 184,000 lb_m (83,500 kg) of *StarBooster 200* "throw weight" can be delivered to booster engine cutoff (BECO). The staging ideal velocity of 9,500 ft/s (2,900 m/s) corresponds to a relative velocity of approximately Mach 5.0, well within the Mach 6.0 thermal limitation of the vehicle's aluminum airframe.

The *StarBooster 200* will be an automated vehicle. After BECO and payload separation, the vehicle will proceed toward the launch site, as a glider when it can, under the power of its two Pratt & Whitney PW6000 turbofan engines mounted aside the body for staging velocities above Mach 3.3. 8,800 lb_f (39 kN) of thrust per engine is delivered at 15,000 feet (4.6 km) altitude. 10,200 lb_m (4.6 tons) of jet fuel is provided to support approximately 50 minutes of flight including engine start-up, 128 NM (240 km) of cruise return flight from the downrange re-entry point (derived by POST analyses), a 15-minute "go-around" allowance and 10% reserves.

In addition to the canard surfaces provided to help resolve the distinct and different control requirements of hypersonic flight and subsonic cruise, 600 lb_m (278 kg) of propellant has been allocated for the Attitude Control System (ACS) for exo-atmospheric flight. During rocket-powered ascent flight, the dual nozzle gimbaled rocket engine provides three-axis control.

StarBooster 200 Applications

The *StarBooster* vehicles are not intended to reach orbit. That is the function of the rockets and stages carried beneath its fuselage that transport communications satellites and other payloads destined for LEO, GTO, and GEO. *StarBooster* delivers these vehicles and payloads to a sub-orbital staging velocity and altitude from which the "upper stages" will continue the mission to orbit.

StarBooster and upper stage combinations that exceed the vehicle's ignition thrust to weight constraint of 1.2 can be accommodated by off-loading a portion of the Atlas III booster propellant, producing lower, but still useful, staging velocities. Another option is to use a "parallel burn" boost profile, where the first of the carried rocket stages is used to augment the lift-off thrust of the *StarBooster 200*'s engine.

Similarly, smaller payloads that would cause staging velocities above the Mach 6.0 "heat sink" limit of the vehicle's aluminum airframe may also be accommodated. This will be accomplished by tailoring the ascent trajectory to reduce heating loads and/or by off-loading a portion of the *StarBooster 200*'s propellant to produce lower staging velocities.

Over twenty candidate upper stage combinations have been examined for use with either single or dual *StarBooster 200* vehicles in order to increase the performance and cost-effectiveness of these. From these analyses three "upper stage" combinations have been selected to comprise the initial *StarBooster 200* system.

Single *StarBooster 200* with *Athena II*

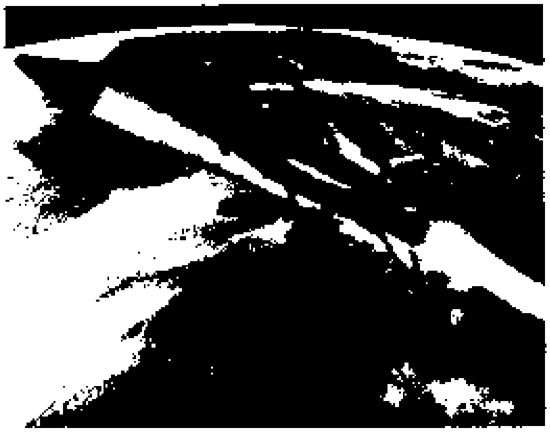

Figure 5-3. Single *StarBooster 200* with *Athena II*

The single *StarBooster 200 / Athena II* configuration utilizes a modified version of the existing Lockheed Martin *Athena II* solid rocket motor launch vehicle. This vehicle, with its two *Castor 120* motors (derived from the modern *Peacekeeper* ICBM), its *Orbus 21D* third stage, and a liquid propellant *Orbit Adjust Module (OAM)*, has a gross mass at liftoff of approximately 120 tons plus payload and is now capable of launching 1.65 metric tons (3,650 pounds) into low Earth orbit from Spaceport Florida.

When launched by a single *StarBooster 200*, the payload of the *Athena II* is increased to six tons to low Earth orbit (13,200 pounds) three and a half times that of the same vehicle when ground launched. A portion of the *StarBooster 200* propellants must be off-loaded to about 80% of capacity for this use in order to achieve the desired minimum thrust-to-weight ratio of 1.20 at lift-off.

Staging occurs at an altitude of 30 km with a velocity of approximately Mach 3.0. An issue yet to be examined is whether or not the control margin is adequate during boost phase flight.

Dual *StarBooster 200's* with *Athena II*

The second *StarBooster* system configuration consists of two *StarBooster 200's* combined with a modified *Athena II*. This "Dual *StarBooster 200*" configuration improves payload performance to almost five and one half times greater than that of a ground-launched *Athena II*, to about ten metric tons (23,400 lb_m / 10,600 kg) to LEO. With the addition of a *Star* series solid rocket motor, payloads approaching four metric tons (8,820 lb_m / 4,000 kg) may be delivered to GTO. This is in the payload class of the *Ariane IV*, *Atlas III*, and *Delta III*. This capability can address approximately 60% of the near term commercial GTO market.

In addition to the *Athena II*, dual *StarBooster 200's* could be combined with a variety of other current launch vehicles. Some consideration has been given to use of dual *StarBooster* launch of *Atlas II*, *Ariane V* (without its solid rocket boosters), and the inexpensive *Ikar II*, *Rokot*, *Start*, and *Tsyklon* vehicles derived from surplus Russian ICBM's.

Figure 5-4. Dual StarBooster 200's with Athena II

Parallel burn arrangements will be advantageous with other dual *StarBooster 200* launch configurations. In this arrangement, the launch vehicle or stage being carried is ignited simultaneously with the twin *StarBooster 200's*. One candidate vehicle for this mode of operation is the new *Delta IV* vehicle to be delivered by Boeing for the EELV program. Lockheed Martin's *EELV*, the Atlas V, and the future Japanese *H-2A* may also be good options for parallel burn launch by *StarBooster*.

Dual StarBooster 200's w/ StarCore I

For heavier payloads, particularly those destined for high energy orbits, the *Orbus 21D* and *OAM* may be removed from *Athena II* and replaced by the *Atlas III*'s high performance LO_2/LH_2 single engine *Centaur* stage and the *Atlas III* extended payload fairing (PLF) used to house larger sized payloads. This combination, conceived by Starcraft Boosters, Inc., is called *StarCore I*. A new conical interstage adapter will be required to attach *Centaur* to the smaller diameter *Castor 120* motor. Additional modifications include an altitude nozzle used for the *Athena II* first stage, and possibly additional over-wrap of the second stage case to accommodate the larger bending moments produced by *Centaur* and its larger payload and PLF. Dual *StarBooster 200's* will launch this new combination of existing elements.

Figure 5-5. Dual *StarBooster 200's* with *StarCore* I

The dual *StarBooster 200 / StarCore I* system has the ability to launch the large Geosynchronous communications satellites. At over six tons to GTO, its performance matches or exceeds that of other vehicles competing for this lucrative commercial market, including: *Ariane V, Sea Launch Zenit, Delta III, Proton / Breeze M*, and Atlas III.

StarBooster 200 Other Applications

An additional application for the dual *StarBooster 200 / StarCore I* system may be to re-supply the *International Space Station (ISS)* and to provide station reboost using *Centaur* residual propellants and its *RL-10* engine after achieving the orbit of and docking with *ISS*. A nose-mounted cargo carrier can provide both "dry" and "wet" cargo for the space station. Currently, cargo and carrier mass, not including the remaining *Centaur* propellants, cannot exceed 9.0 metric tons (20,000 lb_m) due to the structural limitations of the *Centaur*.

The *StarBooster 200* reusable booster system can also be used to provide various "air-launch" capabilities for a variety of vehicles. For example, a single *StarBooster 200* can "air-launch" a 65 metric ton payload at Mach 5. Two *StarBooster 200's* would increase this launch mass to near 130 metric tons. By adding two *Castor 120* SRMs to the system, 21.8 metric tons (48,200 lb_m) may be "air-launched" at Mach 19½. This capability may prove useful to NASA's *X-Plane* programs and to support USAF development of their future *Military Space Planes* or *Space Operations Vehicles*.

Figure 5-6. Conceptual USAF Space Plane

StarBooster 200 as a Liquid Flyback Booster Demonstrator

Recent NASA design efforts and wind tunnel testing on the *Liquid Flyback Booster (LFBB)* for the *Space Shuttle* (now called the *Reusable First Stage [RFS]* by NASA) have provided a rich legacy of experience on a system aerodynamically similar to *StarBooster*. Work is now underway on the *RFS* under contracts issued by NASA's Marshall Space Flight Center. A prime contract for the *LFBB* design effort was granted to the Lockheed Martin Michoud, Louisiana facility for the overall system; Michoud sub-contracted design work on the 100-ton empty weight *LFBB* aircraft to the Lockheed Martin Tactical Aircraft Division of Fort Worth, Texas.

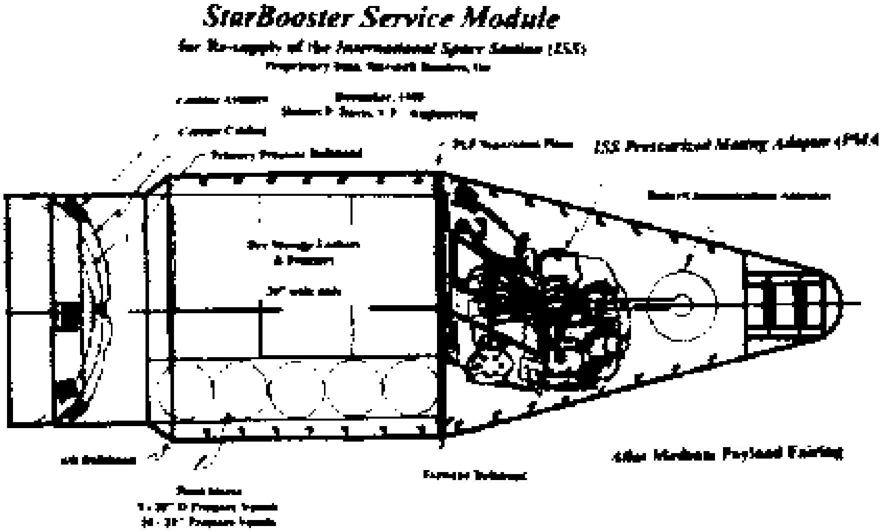

Figure 5-7. International Space Station support vehicle concept.

StarBooster preliminary design might use these same centers of expertise, adding work for Lockheed Martin facilities for adapting the *Athena II*, *Atlas III* and *Centaur* upper stage elements. Systems engineering and integration, site activation, and market analysis of the several candidate *StarBooster 200 / Athena II / StarCore I* configurations will also be needed, including those configurations which may assist the *EELVs*.

StarBooster 200 can initially benefit from recent NASA-funded *LFBB* (or *RFS*) research. In addition, flight operations of *StarBooster 200* and its suite of upper stages can soon provide extensive and valuable demonstration and operational experience with reusable boosters for NASA and DoD. The experience gained by dedicated, NASA-funded *StarBooster* flight tests can be greatly enhanced at small additional cost while *StarBooster* profitably serves the growing commercial space market. This body of flight experience will be extremely beneficial to NASA to support the large *RFS* when this full-scale flyback booster for the *Space Shuttle* is needed.

***StarBooster* 200 Summary**

The range of performance capabilities of the *StarBooster 200* system can address most of the commercial and governmental launch market requirements. Specific *StarBooster 200* system performance capabilities include: six metric tons to low Earth orbit (13,200 lb_m) with a single *StarBooster 200 / Athena II*, ten metric tons to LEO (23,400 lb_m) when dual *StarBooster 200's* are utilized, and near 4.0 metric tons (8,820 lb_m) to a geo-synchronous transfer orbit when a "kick motor" is added.

Upgrading *Athena II* to the *StarCore I* configuration with its capable *Centaur* stage opens a new realm of performance: 6.3 metric ton (14,000 lb_m) communications satellite plus apogee kick motor (AKM) to GTO; 3.3 tons (7,190 lb_m) to GEO without the need for an AKM; or 3.7 metric tons (8,150 lb_m) to GEO by using a spiral trajectory powered by an electric propulsion system.

The *StarBooster 200 / Athena II / StarCore I* system provides a versatile and capable set of building blocks on which the space program of the future may be built. This highly versatile system will provide reusable booster delivery to above Mach 5, SRM-augmented air-launch capability to Mach 19½, and completion of high-energy space missions with the use of the efficient *Centaur* stage. By extensive use of "off-the-shelf" components, this unequaled set of capabilities will be made available to customers at very affordable costs.

StarBooster 350 System

With the philosophy of designing an aircraft to fit around an existing expendable rocket stage, there are other LO_2 / Kerosene fuel vehicle possibilities for variations of the *StarBooster* vehicle.

StarBooster 350 accommodates the first stage of the Ukrainian *Zenit* launch vehicle as its *RPM*. The *Zenit* employs a single *RD-170* four chamber Russian engine, from which the two chamber *RD-180* was derived. Because of the larger *Zenit* stage, the dimensions of *StarBooster 350* are increased approximately 28% over those of *StarBooster 200*.

StarBooster 350 Vehicle Configuration

Similar to the *StarBooster* 200, the *StarBooster 350's* dry mass is split into two major parts: the aircraft and the *Zenit* first stage, referred to again as the *Removable Propulsion Module (RPM)*. The total vehicle dry mass is 136,520 lb_m (61,910 kg). The aircraft had, as of 1997 analyses, an estimated dry mass of 75,000 lbm (34,010 kg), and the dry mass of the *Zenit* first stage is 61,520 lb_m (27,900 kg).

StarBooster 350 can deliver 285,000 lb_m (129,250 kg) to BECO while staying within the Mach 6.0 limitation on its aluminum airframe. As is the case for *StarBooster 200*, more massive payloads can be accommodated by off-loading propellant or by using a parallel burn mission profile. Smaller payloads can be accommodated by tailoring the ascent profile to reduce aerodynamic heating or by off-loading propellant to produce staging velocities within the "heat sink" thermal protection system limits of *StarBooster*.

IMPORTANT NOTE REGARDING THIS REPORT:

An improved fidelity vehicle inert mass is under construction for StarBooster 350 and not available at the time of this report. This activities will be reported in later follow-on work. Thirty percent dry mass margins will continue to be used. The performance data cited below are thus based upon earlier work and must be considered to be somewhat optimistic based on our assumption that the weights will increase.

StarBooster 350 Applications

The *StarBooster 350* vehicle is roughly 28% larger than *StarBooster 200*, and therefore has a different, set of complementary companion vehicles and applications.

Unlike the *StarBooster 200* applications, single *StarBooster 350's* have been used in most of the 1997 performance estimates cited in this report. Adding an extra *StarBooster 350* will improve performance and eliminate concern over gimballing and control issues. This subject will be addressed in future work.

StarBooster 350 with *Zenit* Upper Stages

The first, most obvious set of upper stages to use with the *StarBooster* 350 are the *Zenit's* own upper stages. Due to the increased dry mass of the *StarBooster 350* aircraft and additional drag losses, the payload performance will be less than that of the *Zenit* alone, as expected. However, by reusing the *Zenit's* first stage, 79% of the expendable vehicle's dry mass is saved for reuse. Of great importance, detailed examination of its post-flight condition may be performed after each mission to accelerate development of a refined product possessing high reliability.

While the *Zenit* itself delivers 11,575 lb_m (5,250 kg) to GTO, the *StarBooster 350 / Zenit* combination will loft 9,700 lb_m (4,400 kg) to the same orbit, a performance loss of over 15%.

Figure 5-8. ***StarBooster 350*** **with Zenit upper stages.**

The commercial significance of conserving most of the vehicle hardware mass versus this loss in payload capability has yet to be determined. However, Starcraft Boosters believes that the opportunity to recover and inspect the flight hardware will off-set the economic penalties of reduced payload capability. Only after repeated re-use and inspection can operational trend data be gathered and analyzed to improve the booster life and reliability.

It should be noted that the Atlas III delivers 7,950 lb_m (3,610 kg) to GTO, 18% less than the *StarBooster 350 / Zenit* combination. Likewise, the *Delta II* 7925 places 4,060 lb_m (1,840 kg) to GTO, less than half that of the *StarBooster 350 / Zenit* combination. Customers frequently opt for the lower capability and cost of *Delta II* vehicles over larger boosters. A low-cost, highly reliable *StarBooster 350 / Zenit* could become an excellent competitor in this sector of the market.

StarBooster 350 with Pathfinder

The Pioneer Rocketplane *Pathfinder* partially reusable vehicle might encounter difficulty in accomplishing a key element required to enable their system: the in-flight transfer of liquid oxygen. Should that occur, *StarBooster 350* can launch a fully fueled version of the vehicle from the ground, eliminating the need for in-flight refueling, and simultaneously provide a three-fold increase in its payload. Furthermore, launch of *Pathfinder* with *StarBooster 350* might eliminate the need for a pilot onboard the *Pathfinder* vehicle to monitor in-flight refueling.

StarBooster 350 with Ariane IV and V

Ariane IV has been an extremely successful vehicle, capturing almost half of the global commercial space launch market. It has several versions that can launch between 4,520 lbm and 9,965 lbm (2,050 kg and 4,520 kg) to GTO. A pair of *StarBooster 350's* can provide almost 5.5 times the total impulse of four *Ariane Viking*-powered *Liquid Boosters*. Unlike the present *Ariane IV* boosters, *StarBooster 350* is totally reusable, once again permitting both decreased costs and evolution toward higher reliability. *StarBooster 350* can also be used in place of the *Ariane V* Solid Rocket Boosters, providing 50% more total impulse while increasing reliability and reducing cost.

StarBooster 350 with Japanese *H-2*

The premier product of the Japanese launch industry is the new *H-2* vehicle, a two-stage LO_2/LH_2 vehicle now boosted by a pair of solid rocket boosters (SRB's). It has a liftoff mass of 573,000 lb_m (260,000 kg), 310,000 lb_m (140,000 kg) or 54% of which are the solid rocket boosters.

Nominally, the H-2 can deliver 10.5 metric tons (23,000 lb_m) to LEO and four metric tons (8,800 lb_m) to GTO. When flown in a parallel burn configuration with dual *StarBooster 350s* substituting for its SRB's, its performance may be nearly doubled to 20 metric tons (44,000 lb_m) to LEO.

However, the *H-2*'s mass is below optimum for the *StarBooster 350*. This results in a BECO velocity that may be too high for the *StarBooster 350's* aluminum airframe. One method of dealing with this would be to determine that the *LE-7* main engine of the *H-2*'s first stage can be safely "air-started." In that case, the system could be burned as a series burn, igniting the *LE-7* after BECO. Another possibility is to merely offload some

StarBooster propellant, slightly decreasing the staging velocity and payload.

StarBooster 350 with Surplus ICBM's

One attractive option considered in recent years is to convert a portion of the world's intercontinental ballistic missile (ICBM) fleet into peaceful space launch vehicles. These vehicles are likely to be inexpensive, considering that they have already served their national defense needs. This conversion has recently been done with the American *Titan II*, Ukrainian *Tsyklon* (formerly *SS-9*) and Russian *Rokot* (formerly *SS-19*) missiles.

Russia has proposed the sale and ground launch of its *SS-18* ICBM, re-named *Ikar*. The *SS-18* has had a 97% success rate over 188 test flights. When ground-launched, *Ikar* can deliver payloads up to 9,300 lbm (4,200 kg) to LEO. In its current configuration it is incapable of placing payloads to GTO. This performance would be multiplied by launch with *StarBooster 350*. GTO would now be a possibility, with the *StarBooster 350 / Ikar* combination delivering over four metric tons (8,400 lb$_m$) to GTO. Estimated launched cost of the *Ikar* vehicle alone is below $10 million, making this combination very cost effective.

Figure 5-9. *StarBooster 350* deploying an Ikar vehicle.

The American *Titan II*, Ukrainian *Tsyklon*, and Russian *Rokot* have smaller payload capacities that may also be augmented with one or two *StarBooster 350's*. By itself, the *Titan II* can deliver 4,200 lb$_m$ (1,905 kg) to LEO. The *Tsyklon* is capable of 6,200 lb$_m$ to 7,900 lb$_m$ (2,800 kg to 3,600 kg) to LEO. Finally, the *Rokot* can lift 4,100 lb$_m$ (1,850 kg) to LEO.

Any of these former ICBM's could be boosted by the *StarBooster 350*, multiplying their performance and, for some, opening up new missions such as GTO deliveries. "Swords into plowshares" can, by the use of *StarBoosters*, become a cost-effective reality.

StarBooster 350 for the *Space Shuttle*

The *StarBooster 350* produces 237 million lbf-s (1,054 million N-s) of total impulse, 80% of the total impulse delivered by the *Space Shuttle's Revised Solid Rocket Motor (RSRM)* currently in service. Performance calculations (see Part 6) estimate that a dual *StarBooster 350* / Space Shuttle vehicle can deliver 26,000 lbm (11,800 kg) to ISS – a 20% loss in performance compared with the current capability. Although this performance is not adequate for early *ISS* missions requiring delivery of massive space station modules, it may hold promise for later re-supply, re-boost, and crew rotation missions.

When compared with the proposed *VentureStar* vehicle, with its payload capacity of only 25,000 lbm (11,340 kg) to *ISS*, not including crew or crew provisions, the dual *StarBooster 350* / Space Shuttle combination may emerge as a more attractive option to become the NASA *Crew Transfer Vehicle (CTV)*.

Clearly, *StarBooster 350*, used in one of its many possible launch configurations, is a contender for *ISS* servicing and crew rotation tasks, permitting continued use of major investments in the proven *Space Shuttle Orbiter* and *External Tank*. At the same time, *StarBooster* offers the possibility of improving flight safety and greatly reducing ground processing timelines through the use of the liquid oxygen/kerosene propulsion system of its boosters that are filled at the launch pad.

Figure 5-10. *StarBooster 350* with Space Shuttle Orbiter.

VAB operations would no longer be hampered by the presence of energetic solid propellants in the RSRM during vehicle buildup Mass to be transported to the launch pad by the MLPs would be greatly reduced, as *StarBooster* propellant loading would occur at the launch pad.

For use with the *Space Shuttle*, the *StarBooster 350* may require the addition of a wing fold feature to permit clearance with the *Orbiter* wing and will require the establishment of avionics and structural interfaces suited for use with the *Orbiter/ET*.

StarBooster 350 Summary
StarBooster 350 uses the powerful *Zenit* first stage to create a scaled-up version of the *StarBooster 200*. The possible existence of both series provides two choices for development and a dual development path that offers two size "classes" of boosters.

StarBooster 350 provides a potentially low-cost option for acquiring an existing booster stage. Due to ever-present political and financial uncertainty in the countries of the former Soviet Union, there may be future unforeseen difficulties with focusing *StarBooster*'s development on the *Zenit* vehicle. The existence of both vehicle lines provides the insurance of two viable options for booster development.

Other Options for the *StarBooster RPM*

There are other available liquid oxygen/kerosene booster engines available on the global market that might be fitted to new propellant tank modules to perform the *RPM* function for other *StarBoosters*.

Notable among these is the *NK-33*, refurbished and adapted by Aerojet to be the primary propulsion engines for the forthcoming Kistler *K-1* launch vehicle. Thorough examination of all of the relevant possibilities, with varying numbers of candidate engines, will be necessary to compare their costs and benefits before a *StarBooster* "design freeze".

Should full-scale development of the Boeing/Rocketdyne *RS-76* engine be approved in the near future, this engine may provide a superior candidate of U.S. origin for use with the *StarBooster* fully reusable booster.

StarCore I

The use of *StarBooster* vehicles will greatly increase the capability of existing unmanned launchers and reduce the cost per unit mass delivered to orbit. Further gains will then depend on better upper stages. *StarCore I* is Starcraft Boosters' first "original" upper stage design. It is based on the existing *Athena II and Atlas III Centaur*, and is thus simply a reconfiguration of existing technology. It is intended to serve heavier payloads and the commercial geosynchronous satellite.

To create *StarCore I*, the Orbus 21D and *Orbit Adjust Module (OAM)* from the *Athena II* are removed and replaced with the *Atlas III*'s high performance LO_2/ LH_2 *Centaur* stage and extended payload fairing used to house larger sized payloads. A new conical interstage adapter is required to attach *Centaur* to the smaller diameter *Castor 120* motor. This new combination of existing elements is planned for launch by dual *StarBooster 200's* and may become a principal source of revenue to support other developments of the *StarBooster* system.

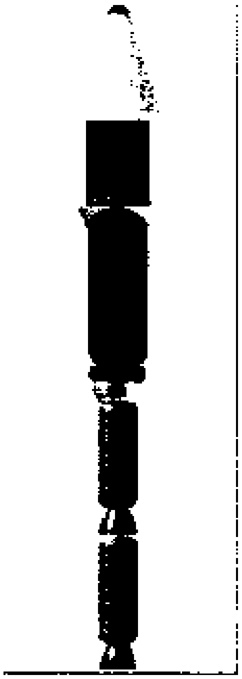

Figure 5-11. StarCore I vehicle configuration.

In keeping with the philosophy of Starcraft Boosters, Inc. to utilize as much existing technology as possible, *StarCore I* combines existing rocket stages in a new architecture. This will enable the *StarCore I*, when launched by dual *StarBooster 200's*, to compete in the commercial GEO market by launching 6 metric tons (13,200 lb_m) and greater satellites to GTO. This size class and orbit is considered to be the "sweet spot" in the current space launch market. This vehicle configuration will be competitive with *Ariane V, Sea Launch's Zenit-SL3, Proton / Breeze*, and *Atlas III*. Additionally, *StarCore I* could deliver up to 9 metric tons (19,800 lb_m) of cargo to the *International Space Station (ISS)* and have residual propellants remaining in *Centaur* to provide a significant reboost for the completed station.

StarCore II

Once experience is gained with *StarCore I*, the next step is another logical extension of present technology: *StarCore II*. The *StarCore II* vehicle is to be a partially recoverable second stage, regaining the value of re-use for the upper stage as the system continues to evolve. *StarCore II* will consist of a single *SSME* or *RD-0120* engine mounted to a liquid oxygen tank "core" with two side-mounted hydrogen fuel tanks. The payload capability of *StarCore II* with *Dual StarBooster 200*'s exceeds that of the *Titan IV*.

StarBird I

A possible future development beyond *StarCore I & II* is to "crewed" orbital vehicles, built on the same principles of cautious advance using known technology. *StarBird I* is expected to utilize the basic *StarBooster* shape and outer mold line, with a *Space Shuttle Main Engine (SSME)* or *RD-0120* as its main propulsion engine, fueled by two over-the-wing hydrogen drop tanks and a large oxygen tank placed in the fuselage in place of the *Atlas III* stage of StarBooster 200. Its nose section would be a simple winged crew transfer vehicle, which we have dubbed *StarReturn*, capable of carrying between 6 and 14 passengers, enough to evacuate *ISS* in an emergency. With pre-planning, this nose section could be developed early by NASA and sent to the *ISS* by an expendable launch vehicle to serve as the needed standby *ISS Crew Return Vehicle (CRV)*.

Later, this same spacecraft will become the crew cabin of *StarBird I* and carry out normal crew support and rotations for *ISS* when used as an integral part of *StarBird*. In normal operation as well as many emergency situations, *StarReturn* would remain an integral part of *StarBird I* for safe return to Earth. But, should an unrecoverable emergency arise during ascent, in orbit, or during entry, a dedicated rocket would separate *StarReturn* and propel it clear of hazards to land safely downrange with the crew and passengers.

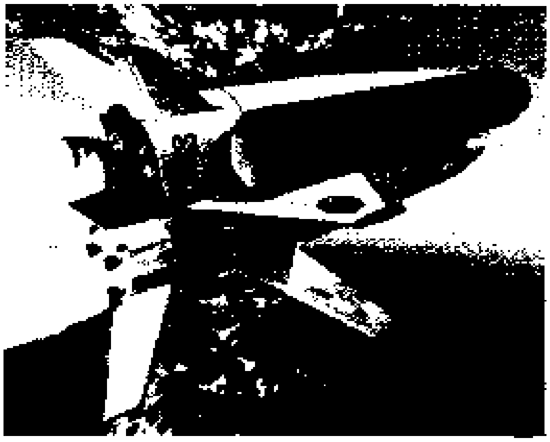

Figure 5-12. *StarCore I* Vehicle with *StarBooster 350*.

A *StarBooster I StarBird I* combination would launch vertically, belly-to-belly, and both stages will return via airplane-type landings. Only the *StarBird* drop tanks will be expended. Our long-range vision is to preserve these drop tanks, each the size of a *B-737* passenger cabin, in orbit for future in-space applications for evolutionary space architecture developments.

Future Enhancements

Starcraft Boosters, Inc. is dedicated to steadily increasing the capability of the *StarBooster*, *StarCore*, and *StarBird* family. As a result, conceptual work has already begun on the follow-on growth family of vehicles. Some of these configurations, alluded to in previous sections, will be outlined in further detail in follow-on work. At this time, only a rough sketch of these possibilities is to be provided.

StarBooster 750

StarBooster 750, as currently conceived, is designed to house 680 tons (1.5 million pounds) of oxygen/kerosene propellants and has dimensions approximately 29% larger than those of *StarBooster 350*, or 56% larger than those of *StarBooster 200*. The *RPM* for *StarBooster 750* is expected to have a diameter near 16 feet (4.8m) and will be powered by either four or five *RD-180* rocket engines, depending upon the outcome of future discussions on the effectiveness of "engine-out" capability (e.g., a spare rocket engine). *StarBooster 750* would build on experience derived from the *StarBooster 200* and may serve as a candidate for the *Liquid Propellant Flyback Booster (LFBB)* now contemplated for use with the present *Space Shuttle Orbiter* and *External Tank*.

StarBird II

StarBird II is a growth version of *StarBird* I that, with *StarBooster 750*, may be able to take a small crew and significant cargo to LEO, or if used for passengers, perhaps as many as 100 passengers per flight. *StarBird* II may use the mold line of *StarBooster 750*, use liquid hydrogen and liquid oxygen as propellants, and be powered by four SSME's. Again, the hydrogen is stored in external tanks for flight safety and to achieve roughly half the size of a vehicle carrying hydrogen fuel in the body.

StarBooster Sub-Scale Vehicles

Subscale booster vehicles identified by future work may prove to be a schedule and cost savings measure for development of the full scale *StarBooster* vehicle. As they will have boost capabilities in their own right, operational deployment of both a smaller and full-scale vehicle is a possibility. Future work on these options is planned once authoritative data on candidate hydrocarbon fuel stages becomes available or is generated.

Prospective Scenarios for Deployment

It is not possible for anyone to accurately define the future. However, "scenarios" of potential use for any proposed major investment can be useful as more than mere speculation. They can serve to clarify design requirements, broaden system engineering thought processes, improve the fidelity of cost estimates, and aid in effectively communicating attributes of the concept.

The *StarBooster* family is sufficiently versatile that a number of alternative scenarios can be formulated. What follows is an illustration of one possible sequence of employment of *StarBooster* over a time span of thirty years, beginning shortly after the turn of the century.

Phase I begins with development funded by a combination of private capital, government contributions, and "risk-sharing" by participating suppliers. Numerous problems are encountered and overcome along the way. After a span of three years from program initiation, qualification flight tests have been completed and three flight vehicles are successfully delivered to the *StarBooster* operator. Marketing efforts begun midway through development have acquired contracts to deliver six communications satellites per year for three years to GTO and to support an equal number of LEO deliveries. The upper stages flown as *StarBooster* payloads for these missions are contracted for and drawn from stocks of surplus military missiles.

Flight operations now begin. In parallel, an entrepreneur contracts for services with the operator of the *StarBoosters* fleet to offer space flight to the general public, achieving altitudes above 50 nmi (93 km) altitude but well short of orbital flight. A sister ship to *StarBooster*, using the same airframe, is fitted with passenger and crew accommodations, including view ports, and with a rocket propulsion system capable of maintaining the vehicle's attitude and velocity for the desired 1500 km range. This twin is launched by StarBooster two to five times per year beginning in year four. With revenues from commercial flight operations now available, development begins on a companion vehicle, a partially reusable upper stage, to significantly increase payload to orbit and to hold firm or decrease the operating costs produced by use of the stock of existing missiles. These activities collectively are identified as *Phase I*.

Phase II then begins. As these Phase I events unfold, NASA has completed the initial phase of *X-33* sub-orbital research flights. Additional technology development requirements indicates that further research will require extending the flight envelope beyond Mach 12 limit of the vehicle when ground launched. NASA contracts with the *StarBooster* operator to provide boost services for the *X-33* for six flights, with an option for twelve more, to achieve this major extension of its flight envelope and expand the fruits of *X-33* research. Similarly, *VentureStar* investors conclude similar augmentation is required for the follow-on SSTO, both to capture heavier payloads and to provide larger dry mass allowances for incorporating highly desirable design refinements.

These activities lead to *Phase III*, augmented human space flight, including ambitious NASA plans for return to the Moon and human expeditions to Mars.

Illustrative Scenario Phase 1

As a part of the development process, *StarBooster* is subjected to a rigorous flight test program. A dummy mass simulator of the *Zenit* or *Atlas III* first stage is installed in the *StarBooster* airplane, along with a tail cone for initial flights, and the subsonic flight envelope and handling characteristics are fully explored using runway takeoff under turbofan power. A four-month delay in testing is encountered while modifications are made to improve handling characteristics.

Once the subsonic flight characteristics of *StarBooster* have been confirmed by flight test to be acceptable, including autonomous cruise flight and landing, a series of solo vertical flight tests begin with vertical launch from the operational launch platform. These tests are rocket-powered by use of a partially filled *Atlas III* or *Zenit* first stage. Flight characteristics to the Mach 6.0 heat sink structural limit are explored by solo flight. Techniques are developed and proven by flight test for the post-payload-separation maneuvers. As the final step of development, a series of three vertical flight tests of the *StarBooster* Vehicle #1 are made with the full *Zenit* or *Atlas III* stage installed at propellant loads of 70%, 85% and 100% of capacity. For these missions, non-propulsive payloads are flown to simulate upper stages / payloads and space is offered to the scientific and commercial communities for use of this capability. Payload separation characteristics are refined and characterized. Autonomous return to launch site (RTLS) maneuvers and cruise / landing flight protocols are refined.

The initial operational application of *StarBooster* is to provide reliable, low cost delivery of four metric ton (8,800 lb_m / 4,000 kg) class communications satellites and their apogee kick motors to GTO. These missions originate from the launch site where the upper stages, surplus military missiles using hypergolic propellants, have been safely accommodated for a number of years. Revenue from these flights enables the *StarBooster* operator to achieve positive cash flow and to subsequently generate surplus revenue, some of which is returned to investors and some applied to highly focused research and development.

When the first operational *StarBooster* flight date is announced in the press, an entrepreneur approaches the *StarBooster* operator with a proposition: He will support all development costs for a passenger-carrying derivative of the *StarBooster* aircraft that will be *StarBooster's* payload. He will also indemnify the manufacturer and operator for developing and operating a system using *StarBooster* to put 50 passengers into space for landing 810 nmi (1500 km) downrange. Ticket price is $1 million. Six flights per year are quickly sold out for four years.

Meanwhile, Starcraft Boosters, Inc. has been developing a partially reusable cryogenic upper stage to replace the large military launch vehicles for GTO satellite placement. The *SSME* is selected as the vehicle's power plant. It is recovered for reuse in a ballistic entry body previously developed by Davis Aerospace Company.

Site selection, negotiations with government officials at the selected site, and facility design permit, in year eight, moving some operations with new flight vehicles to a new launch site favorably situated close to the Equator. Payload to GTO has now increased to ten metric tons (22,000 lb_m / 10,000 kg).

Illustrative Scenario Phase II

NASA, always supportive of space commercialization, has been monitoring these developments with great interest. NASA has been granted approval by Starcraft Boosters, Inc. and the *StarBooster* operator to place a six-person liaison office at the headquarters of each firm. Their purpose is to make available to these privately funded initiatives the technical and facility resources of the Agency under a Cooperative Agreement, as well as to gain first-hand insight into the development and flight experience. For all practical purposes, they become members of the *StarBooster* development team. Meanwhile, NASA and Lockheed/Martin continue development of the *X-33* and future research aircraft.

A series of funded studies are performed to determine the applicability of *StarBooster* to NASA's needs. From these studies emerge three initiatives: First, NASA contracts with the *StarBooster* operator to make ten cargo deliveries to the International Space Station (ISS), beginning at the rate of two per year in year four of *StarBooster* operations, with an option for twenty additional flights in the out-years. Military launch vehicles used for GTO flights, with the incorporation of modifications to the third stage to meet requirements for rendezvous with *ISS*, provide the upper stage functions for these missions.

Second, NASA contracts for six flights over two years with the *X-33* as *StarBooster's* payload, to more fully explore performance of its aerospike engine over the flight envelope of the future *VentureStar* SSTO. Other goals are to confirm the utility of the thermal protection systems planned for *VentureStar*, and to extend its mission to LEO science and technology experiments. The X-*33* is thus transformed from a ground-launched vehicle limited to Mach 12 flight into a vehicle with orbital capability with instruments as payload. Structural and propulsion system changes to the *X-33* are defined and implemented by NASA to permit a series burn launch. For these flights, the *X-33* will remain quiescent until *StarBooster* burnout and separation.

Third, Lockheed Martin and NASA decide that *VentureStar* can be more useful if its payload capability is increased by an augmentation system for some portion of its missions. *StarBooster* is included as one of the several candidate augmentation schemes and ultimately wins the competition to provide this service for four *VentureStar* flights per year for ten years.

Illustrative Scenario Phase III

These developments lead to the involvement of the Starcraft Boosters, Inc. engineering staff in funded studies of large international programs considering a return to the Moon and for human exploration of Mars; both of which are at this time under active review by high levels of government in the US, Europe, Japan, Russia, Ukraine, China, India, and others. There is now increased traffic into space provided by the new stable of lower cost and more reliable space launch vehicles, including *StarBooster* and its companion upper stages. Success with both the *X-33* government-funded program and the low-cost *StarBooster* private venture promise the essential lower costs for future access to space.

Both the US Congress and the Administration are now ready to hear serious proposals for significant participation and leadership by the United States in several space areas:

- Establishing a permanent human presence on the Moon.
- Developing the water resource near the Poles of the Moon into a large supply of propellants that may be easily placed into space from the reduced gravity of the lunar surface.
- Possible future human ventures to Mars and its moons, possibly departing from lunar orbit using the newly acquired propellant supply from the Moon.
- LEO and MEO demonstration of sub-scale but operational *Space Power Systems*.

For these ventures an upgrading of space transportation capabilities is required. First, the *Space Shuttle* will be replaced by a new system providing equivalent or better services. *VentureStar* is still some years away because of technology shortfalls to mandatory targets and difficulties in obtaining the investment capital to bring it into full service. A TSTO system using the fully reusable *StarBooster* as its first stage is given the go-ahead. An *Orbiter* vehicle with internal oxygen and external hydrogen tanks, powered by two or more advanced versions of the *SSME* is selected. As it's dry weight is less than half that of its predecessor, its development is affordable. It will deliver about 25 metric tons (55,000 lb_m / 25,000 kg) of net payload to LEO, roughly equivalent to earlier capability.

For supporting the large missions to the Moon and the much larger missions found needed to explore Mars, a significant *Heavy Lift Launch Vehicle (HLLV)* capability is required. This is on the order of 100 metric tons (220,000 lb_m) to LEO per flight, with stringent launch cost ceilings as an imperative. A growth version of *Ariane V* and a system proposed by a joint venture of Lockheed Martin and the Rocketdyne Division of Boeing, which makes use of modified *Space Shuttle External Tanks*, recoverable advanced *SSMEs*, and a new *Reusable Upper Stage*, compete for this role. Both of these candidates and the growth *Shuttle* vehicles select *StarBoosters* for the boost phase of flight.

With these prospects for increased flight rates, Starcraft Boosters, Inc funds development of a much improved and larger second generation *StarBooster*. This vehicle is named the *StarBooster 750*.

Vehicle Family Summary

We believe that the key to a bright future in space is to begin the application of reusable launch vehicles with the large booster stage: *StarBooster*. By following a conservative path, making best use of existing assets, and sizing systems that will assure acceptance in the commercial marketplace, we believe that the *StarBooster* family is the best path toward that future.

Should new technologies be proven which will serve these needs in a superior manner, the small sequential step approach we recommend for the *StarBooster / StarCore / StarBird* family can either adopt these new technologies or be displaced by them with minimal loss at any time in the development sequence.

When new technologies are proposed, their advocates always cite their striking virtues. In examining these proposed applications of advanced technologies, the question must always be asked: "Compared to what?" We propose to define the "What", which may be achieved quickly and economically with today's technologies and end items.

Part 6 - *StarBooster* Vehicle Overview

The purpose of this section is to provide the results and explanatory notes for the configuration selection, weight estimation, and performance assessments of the StarBooster vehicle system. These estimates are preliminary and serve as a progress report for our continuing studies.

The *StarBooster* Vehicle Concept

Our objective from the outset of this work was to develop a highly reliable winged space launch vehicle equipped with substantial rocket propulsion capability for providing others (customers) with the vital "boost" needed to make access to space easier and more affordable. *StarBooster* does not go into orbit; it enables others to do so more reliably and at a lower cost.

The path toward accomplishing this objective quickly became apparent -- *build an uncomplicated aircraft to house an existing, fully integrated and proven rocket stage.*

The *StarBooster* airplane is expected to be the "backbone" of a new, evolutionary Space Transportation Architecture. The initial goal is to develop either *StarBooster 200*, sized to house an *Atlas III* first stage, or *StarBooster 350* to house the first stage of the *Zenit* launch vehicle. The goal of *StarBooster* is to provide less expensive commercial space launch through the re-use of recovered booster stages. In doing so, it will also permit post-flight examination to progressively improve system reliability and demonstrate the technologies and operational features of reusable boosters for future applications.

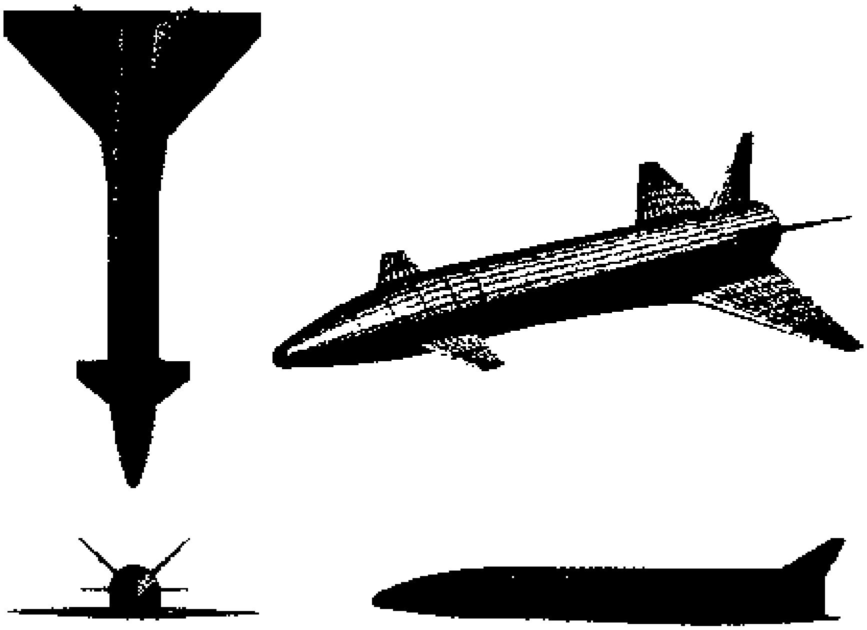

Figure 6-1. Starcraft Boosters, Inc. has developed a generic, versatile delta-wing vehicle configuration that will be used for each member of the *StarBooster* family.

The StarBooster Airplane

As the booster rocket stage is now available essentially "off-the-shelf", new development is focused on converting, by use of the aircraft, from an expendable to a fully reusable rocket vehicle. Thus, rather than attempting to force-fit the rocket body with wings, empennage, landing gear, turbine engines, and the other items uniquely required for aircraft flight, an early decision was made to provide a fuselage to house the rocket. De-coupling the two elements reduces the design complexity and changes necessary.

The second decision was to forego the improvements in packaging and aerodynamics resulting from variable geometry and use a simple, fixed straight (as shown for *StarBooster 350*) or delta wing (as now shown for *StarBooster 200*). A straight wing, if aerodynamic stability issues can be satisfactorily resolved, may reduce development, acquisition and maintenance costs and eliminate numerous potential failure sites. To both enhance flight safety and reduce costs of maintaining wheels and brakes, the wing size was established to permit landing speeds less than 180 miles per hour (300 km/hr), rather than the 240 miles per hour (400 km/hr) of the *Space Shuttle Orbiter*. No extensive lift augmentation devices are planned.

The third major design decision involved the means of safely handling the heat loads of ascent and descent flight. The heat sink approach was used instead of the externally applied tile and blanket concepts. The principal rationale is that "soft goods" on the vehicle exterior have been proven to be a major contributor to the intense manpower required to fly the *Space Shuttle Orbiter*. An aluminum structure, thickened as necessary to absorb the heat load without exceeding its 300 to 350 degree Fahrenheit (150 to 175 degree Celsius) temperature limit, will provide most of the thermal protection. Limited application of localized high temperature metal panels or ablative materials on leading edges and on the nose may prove to be economic. A benefit of this approach is that the thicker skin gages will permit an all-welded aluminum structure without the necessity of extensive, high precision 3-D skin routing or chem-milling to provide "weld lands" and lower weight. This is expected to be a major step in reducing manufacturing costs.

Finally, a "dual keel" fuselage structure was selected to permit flexibility in the placement of multiple hard points for belly-mounting a variety of prospective payloads. Such a structure also will provide support for the landing gear and the option of nose-mounting the twin turbofan engines.

Currently, the *StarBooster* vehicles do not have crew provisions except for early horizontal flight test. It is the philosophy of Starcraft Boosters to operate the operational *StarBooster* as a remotely piloted vehicle (RPV) with a significant degree of flight control autonomy by means of advanced Commercial Off-the-Shelf (COTS) on-board guidance, navigation, and flight management devices.

Present indications are that the same outer mold line may be used for the *StarBooster 200* and *StarBird I*. The same vehicle configuration will be scaled up to address the needs of the larger *StarBooster 350* and its growth variants, which include the *StarBooster 750* and *StarBird II*. The following subsections provide a brief overview of the different StarBooster family members.

StarBooster 200 Vehicle Configuration

StarBooster 200 has a body length of approximately 131 feet (40 meters), body diameter of 13.5 feet (4 meters) and a wingspan near 66 feet (20 meters). It has, without the *Atlas III* first stage, a dry mass near 70,000 pounds (31.5 metric tons), including a 30% dry mass margin. Two low bypass ratio turbo-fan engines to permit the vehicle to cruise near Mach 0.5 for the 240 to 300 mile (400 to 500 km) return flight. The fuselage cavity accommodates the *Atlas III* first stage, which has a diameter of ten feet

(3.05 m). This propulsion module is known as the *Removable Propulsion Module*, or *RPM*.

StarBooster 350 Vehicle Configuration
StarBooster 350 accommodates the first stage of the *Zenit* as its *RPM*. The *Zenit* vehicle has a diameter of 12.8 ft (3.9 m) and employs a single *RD-170* engine. Thus, the dimensions of *StarBooster 350* are approximately 28% larger than those of *StarBooster 200*. The *StarBooster 350* aircraft is 145.7 ft (44.4 m) long and has a wingspan of 78.1 ft (23.8 m), providing 1,400 square feet (130 m^2) of wing area. The aircraft is 35.1 ft (10.7 m) high on its landing gear.

Table 6-1. Comparison of the *StarBooster 350* vehicle to a Boeing 737-400.

	StarBooster 350 aircraft	Boeing 737-400
Inert weight	75,000 lbm	73,170 lbm
Landing weight	145,000 lbm	121,000 lbm
Vehicle length	145 ft	119.6 ft
Wing span	78 ft	94.8 ft
Wing area	1400 sq. ft	980 sq. ft
Cruise Mach	0.5 to 0.7	0.745
Landing	< 150 knots	< 137 knots
Engines	Two CFM-56-7	Two CFM-56-3C-1

The *StarBooster* Propulsion Module

After examining the technical and operational histories of available rocket vehicles, it was determined that the first stage of the CIS/Boeing (*Sea Launch*) *Zenit* space launch vehicle and the Lockheed Martin *Atlas III* were most suited to our purposes. These stages incorporate the most powerful LO_2/ RP-1 rocket engines currently in production, the *RD-170* and its smaller two chamber derivative, the *RD-180*.

***Atlas III* Expendable Launch Vehicle**
Ascent propulsion for the *StarBooster 200* vehicle is provided by the first stage of the Lockheed Martin *Atlas III* (formerly *Atlas IIAR*) launch vehicle. The *Atlas III* is the latest evolution in the highly successful *Atlas* series of launch vehicles derived originally from the *Atlas* ICBM. First launch of this vehicle is expected for late 1999 or early 2000.

The *Atlas III* first stage is powered by the *RD-180* LO_2/Kerosene engine, jointly developed by Russian NPO Energomash and American Pratt & Whitney. With its upgraded, single LO_2/LH_2 *RL-10* engine *Centaur* second stage, the expendable *Atlas III* can deliver payloads of 8,900 lb_m (4,040 kg) to GTO.

The *Atlas III* has a first stage length of 94.8 ft. (28.9 m), which fixes the length of the *StarBooster 200* 's internal fuselage cavity. The first stage has a diameter of 10.0-ft (3.05 m), plus protuberances.

The *RD-180* engine has a mass of 11,900 lb_m (5,390 kg). Taking that portion of the dry (inert) mass into account, the total stage dry mass is estimated to be 26,500 lb_m (12,000 kg). This produces an admirable propellant mass fraction just over 0.93. This estimate for dry mass is used in subsequent *StarBooster 200* performance calculations.

In order to minimize the vehicle's dry mass values (and produce higher propellant mass fractions), the *Atlas* family of rockets has traditionally used pressure stabilization in its thin-walled stainless steel propellant tanks. By maintaining a proper level of internal pressure at all times in the tanks, the resulting tensile force counteracts tank compressive and buckling loads due to both vehicle weight and external forces.

Although the *Atlas* family has been highly successful for over 500 missions, some observers perennially object to its use of pressure stabilization, since loss of internal pressure may result in structural collapse. They are particularly concerned with an erected, un-fueled vehicle with an expensive payload sitting on the launch pad.

Partly in response to this concern, the *Atlas V* vehicle proposed for the *EELV* program will use heavier, thicker walled aluminum propellant tanks that are capable of standing without internal pressure on the launch pad, even in high winds. However, this strength and security comes at the cost of increased vehicle inert mass, which negatively impacts performance.

For ground handling, the internally pressurized *Atlas* and *Centaur* stages have traditionally been attached to a "stretch fixture" which mechanically places the tank sidewalls in tension. *StarBooster 200* will use a similar strategy as an extra precaution for integrating the *Atlas III* first stage with the aircraft. Fore and aft attachments in the *StarBooster 200* aircraft will hold the stage in place, react thrust and other loads, and restore a tension load if needed.

Zenit Expendable Launch Vehicle

The *Zenit*, introduced in 1985, is a liquid-fueled launch vehicle that was the first completely new Soviet rocket in 20 years. Following the breakup of the Soviet Union, the launch vehicle became Ukrainian due to the location of its manufacturers, KB Yuzhnoye / PO Yuzhmash.

The *RD-170* family of engines has seen service in three programs. The *RD-170* powered *Zenit* first stage first flew in 1985 when four were used as the liquid strap-on boosters for the *Energia* heavy lift (100 ton payload class) vehicle. Four more were used to boost the first *Buran*, the short-lived Russian *Space Shuttle*. Producing 1.732 million pounds of thrust at lift-off, the *RD-170* engine can launch a vehicle with a gross mass of up to 1.4 million pounds, or 628 metric tons. As the *Zenit* first stage has a gross weight of 381 tons, 92% of which is oxygen and kerosene propellants, 247 tons can be devoted to support both the *StarBooster* aircraft, which houses the *Zenit* stage for return to the launch site, and its payload, or "throw weight" to end-of-boost.

The two-stage version, launched from Baikonur, can deliver 30,300 lb_m (13,740 kg) to LEO at a 51.6° inclination. The first stage has a diameter of 12.8-ft (3.9 m) and a length of 108 ft (32.9 m). Of its 781,010 lb_m (354.2 tons) mass, 61,520 lb_m (27.9 tons) is dry mass. This gives the stage a propellant mass fraction of 0.92

Recently, the Boeing-led *Sea Launch* joint venture has successfully accomplished the first and second launches of a new three stage version of this vehicle, the *Zenit-3SL*, from a movable-floating platform in the Pacific Ocean. With the addition of a Russian *Block DM* upper stage made by RSC Energia, this 3-stage vehicle is capable of placing 11,575 lb_m (5,250 kg) into GTO.

Aerodynamic Configuration and Flight Control

The purpose of *StarBooster* is to return the booster stage to the launch site for reuse. As a result, careful attention to aerodynamic design is required. The first imperative of this aerodynamic design is *survival*. A reusable booster with a high loss rate is no bargain. The vehicle must survive ascent flight under the thrust of the RD-170 or RD-180 engine, as well as ascent aerodynamic heating and loads. It will also experience maximum dynamic pressure near Mach 1 with the attendant complexities of pressure distribution and airflow. During supersonic and hypersonic flight, it will experience varying interference shock patterns. Variations in these patterns depend on the size, location, and configuration of the payload carried as well that differ over the broad range of ascent Mach numbers. Wind tunnel testing to supplement CFD will be necessary to predict aerodynamic loads.

Once ascent is complete, the payload must separate quickly and cleanly, with the *StarBooster* loads remaining within structural limits. By this point in the mission, dynamic pressure will have been greatly reduced but will still be tangible; above 100 psf.

The mass of the payload at separation will exceed that of the now empty *StarBooster* by a factor of up to 3.5:1. Aerodynamic control must be established and maintained for this critical maneuver, as lift forces will provide the principal separation impetus.

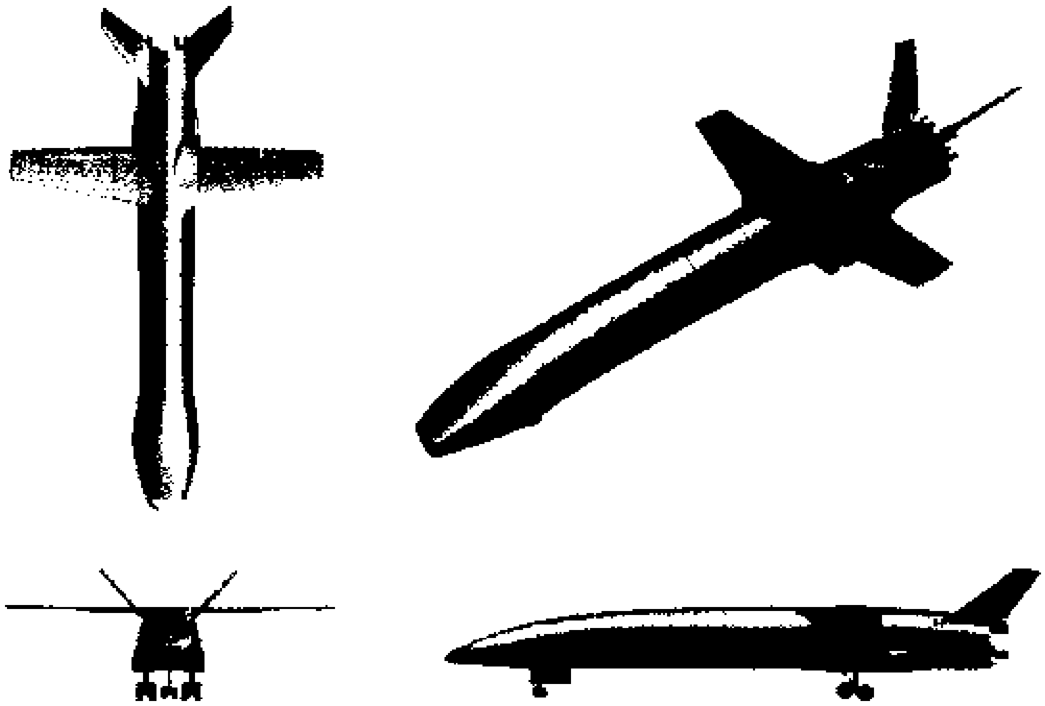

Figure 6-2. Early configurations of the *StarBooster 350* vehicle (pictured) employed a top mounted straight wing with the air breathing engines mounted in the nose.

Following separation, the unpowered *StarBooster* will decelerate and climb to limit downrange travel. In doing so, it will exit the sensible atmosphere and must, for the first time in the mission, establish and maintain attitude control through the use of small reaction control rocket engines. As it is oriented and descends from high altitude, it again encounters the atmosphere, experiences the heat loads of entry, regains effectiveness of the aerodynamic control surfaces, turns at supersonic velocity to a heading for return to the landing site and decelerates to subsonic velocity. At the highest permissible altitude, approximately 8 km, both the nose cap covering the inlet duct and the two turbofan exhaust duct covers are retracted and the turbofan engines are air-started. Descending cruise flight at Mach 0.4 to 0.5 for about one half hour brings the aircraft to the landing pattern for touchdown at near 300 m/sec (150 knots). Refurbishment for re-use can thus begin within a few hours of launch.

Wing loading for landing was chosen at 102 psf (500 kg/m^2) with a maximum lift coefficient of 1.4. Initial estimates indicate that 430 square feet (40 m^2) of exposed forward canard surface may be necessary for subsonic flight. Further analysis is required to balance the varied hypersonic and subsonic aerodynamic requirements.

Similarly, the tail volume must be critically examined to assure that adequate lateral stability and control authority are available throughout the aerodynamic flight regime.

The aft section or tails of all of the vehicles of the *StarBooster/StarBird* family will be equipped with "speed brake" surfaces and a horizontal body flap control surface provided for longitudinal axis (pitch) control. All three of these surfaces may be deployed aft to enhance their available control moments. The "speed brakes" may be differentially extended to increase directional (yaw) control. These features are termed the *Intelligent Aft Section*™. A drogue parachute, mounted in a pod on the top of the aft section, is included to assist the brakes in bringing the aircraft to a stop after landing.

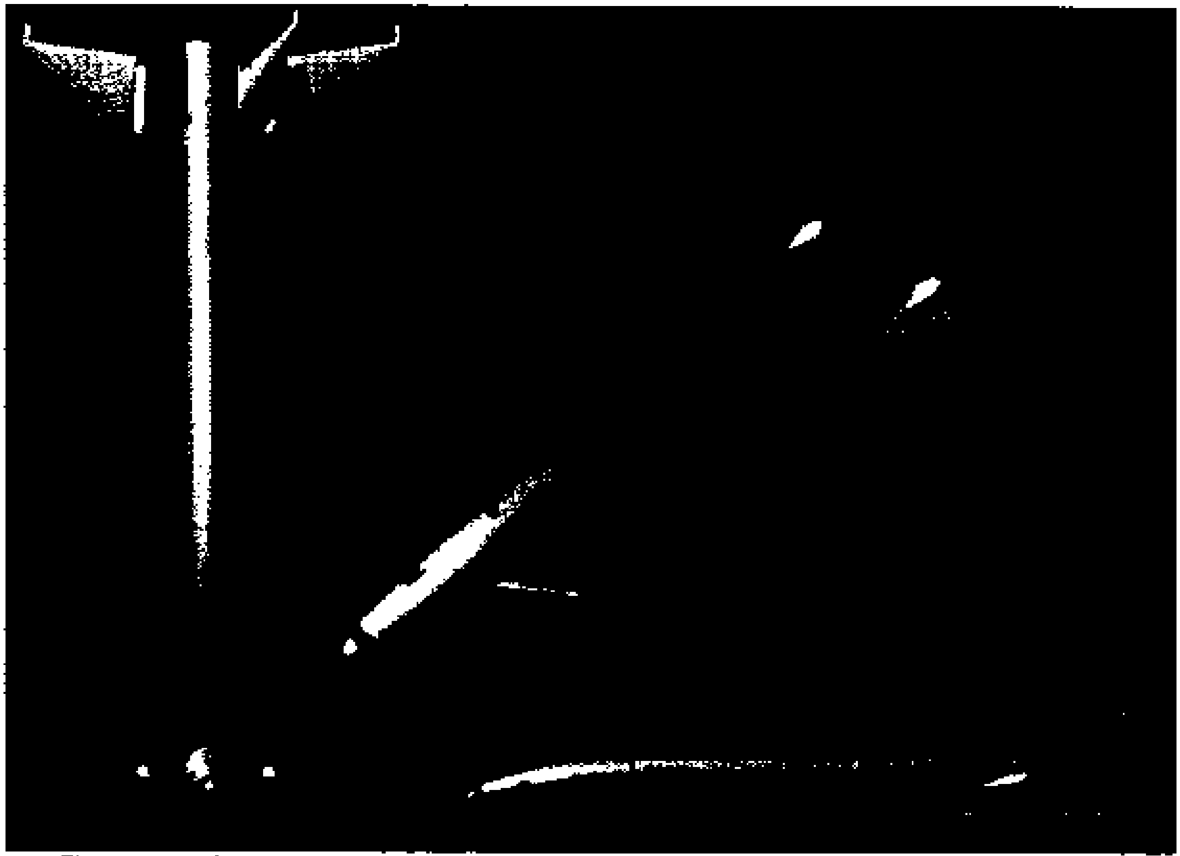

Figure 6-3. Current design studies for the *StarBooster 200* have shifted to a bottom-mounted delta wing. Further analysis is required before a final configuration is selected.

StarBooster 200 Wing Design

NASA's Langley Research Center (LaRC) is currently studying the *StarBooster 200*. The *StarBooster 200* mass estimate of September 10, 1999 indicated the following wing characteristics: 1,157 square feet of reference area provided for a 13.5% thick delta wing of aspect ratio 2.59. An ultimate safety factor of 1.4 was applied to an expected 2.5 normal load factor. "Best cruise" lift-to-drag ratio was estimated to be six at 15,000 feet altitude at 288 knots.

***StarBooster 350* Wing Design**
The aspect ratio chosen for the fixed straight wing is 4.3, with a taper ratio of 0.56 and a thickness ratio of 12% at the tip and 15% at the root. This configuration enables deep spars that provide the load bearing capability to accommodate the pull-up maneuver after payload separation. This configuration also enables large radius leading edges for reduced entry heating. The wing is positioned on the body to provide positive subsonic longitudinal stability. Subsonic L/D is estimated to be near 6.5:1.

Air-Breathing Propulsion

The first question that must be asked regarding air-breathing propulsion is: "Is it required?" The answer is not obvious. For ascent flight, NASA studies have shown that all-rocket propulsion is the superior choice. For return to the launch site, however, a number of NASA studies have indicated that "glide-back" to the launch site is possible, through trajectory shaping, if burnout of *StarBooster* is constrained to about Mach 3. A gliding return trajectory would eliminate the need for the heavy and expensive air breathing propulsion subsystem. Similarly, if launch occurs with a landing site available several hundred kilometers downrange, a "straight in" gliding approach is possible.

However, an assessment of parametric performance indicates the requirement to provide staging up to the heat sink limit, above Mach 5.5. In that case, the point at which gliding decent reduces altitude to ground level occurs further downrange, eliminating gliding return to launch site. If gliding return is made to a site that is now the appropriate distance downrange, the problem then becomes the return of the vehicle to the launch site for repeat flights. "Ferry kits" have been proposed in which an air-breathing propulsion system is added to the aircraft post-landing and is removed before the next rocket-powered ascent.

Another desire, although perhaps not an absolute requirement, is that the aircraft be able to "go around" from a missed approach and of self-ferry. These factors led to the conservative choice to equip the *StarBooster* with a removable air breathing propulsion system mounted near the vehicle center-of-gravity. In order to avoid unnecessary program costs and to avoid inert mass represented by the air breathing propulsion system and its fuel, current plans are to not require this system to be installed on missions staging at Mach 3.3 and below. This issue will need to be treated with some care in follow-on work.

Turbofan engines, rather than turbojets, were tentatively selected to gain a lower rate of fuel consumption. This does, however, increase frontal area and weight for the fan. Choosing the proper bypass ratio must be addressed with care in follow on work to produce an optimum overall system. As cruising range is limited to less than 200 nautical miles, higher fuel consumption may be the lesser of the two considerations.

The thrust level was selected to provide a thrust-to-weight ratio (T/W) near that of commercial airliners, assuring good takeoff and cruise performance. Tentatively, two *CFM56-7* series engines were selected for *StarBooster 350*, producing a sea level takeoff T/W of about 0.3, as compared to the *B737-600* airliner T/W of 0.316. 6.9 tons of jet fuel was provided, permitting operation of both engines at maximum sea level static thrust for about one hour. More careful review of trajectory analyses and fuel use in cruising flight should reduce the quantity of fuel required, which will reduce the inert mass of *StarBooster*.

Two engine locations have been considered. The engines for the *StarBooster 200* are mounted on the side of the fuselage near the center of gravity while for the *StarBooster 350* the engines are placed in the nose to offset the 26,000 lb (11,800 kg) mass of the *RD-170* rocket engine. The *StarBooster 350* turbofan engine exhausts do not exit parallel to the longitudinal axis, but rather 15 to 20 degrees outboard, so differential throttle may be employed during cruise and landing to augment lateral stability and control. This thrust axis offset is necessary to house the twin engines in the nose without resorting to deployment mechanisms. However, the thrust axis offset has been found to reduce effective thrust by 6% and prohibit single engine flight. With the short flight time and the reliability of current airliner engines such as the *CF56*, these penalties are considered preferable to complex engine deployment mechanisms or tail mounting of the engine, which would exacerbate the already difficult problem of properly positioning the airplane's center-of-gravity.

StarBird I Vehicle Configurations

Present indications are that the same outer mold line may be used for the *StarBird I* and *StarBooster* vehicles. *StarBird* propellants are liquid oxygen and liquid hydrogen used in one or two *SSMEs*. For flight safety and to dramatically downsize the *StarBird* vehicle (to reduce its costs), the volatile and low-density hydrogen is carried in above-wing external tanks. These tanks can be left on orbit for future applications but are nominally disposed of in the atmosphere prior to entry. As turbofan engines are not required for *StarBird I*, the engine attachment points on the fuselage sides of *StarBooster 200* are used to attach the hydrogen tank support trusses.

StarBird I for single StarBooster 350 launch

Figure 6-4. StarBird I vehicle configuration

In all cases, variable incidence canard surfaces are provided to attain the proper locations of center-of-pressure and center-of-gravity for both hypersonic flight and subsonic flight. For *StarBird I*, these canards serve an additional purpose in the case of StarReturn / *StarBird* separation.

All personnel are transported in the nose section of *StarBirds*. No payload bay for carrying passengers or cargo is provided. In the event of an unmanageable event on the launch pad or during ascent flight, the nose section may be separated from the remainder of the vehicle. This is accomplished by a separate rocket propulsion system, providing about 5 "g's" of acceleration for approximately five seconds to acquire safe clearance from the malfunctioning vehicle(s). The canard surfaces then become the wings of this emergency return craft, to permit safe entry and an emergency landing downrange. Floatation bags are provided for assuring a soft land landing and survival in the water for an extended interval. The terminal landing system may be a parafoil system similar to that selected by NASA for the *X-38* vehicle, to decrease both vertical (sink rate) and horizontal landing speeds to safe levels.

The aft section of all of the vehicles of the *StarBooster / StarBird* family will be equipped with a horizontal body flap control surface for longitudinal axis (pitch) control and may have two vertical "speed brake" surfaces. All three of these surfaces may be deployed aft to enhance their available control moments. Alternatively, should the present dual tailfin configuration be selected, the speed brake function may be provided by these surfaces. The "speed brakes" may be differentially extended to increase directional (yaw) control. These features are termed the *Intelligent Aft Section*™ (*IAS*).

Attitude Control Systems (ACS) are provided fore and aft on all vehicles. In addition *StarBird I* has an Orbit Maneuvering Propulsion System (OMS). Batteries will supply electrical power for the *StarBooster* vehicles. Fuel cell power plants will be required for *StarBird I*'s longer flight duration.

StarBooster Subsystems

During powered ascent, vehicle stability and control will be maintained by gimballing the main engine and, if required, utilizing the *StarBooster*'s aero-surfaces. After shutdown and separation, which occurs above 150,000 ft, the vehicle's Attitude Control Systems (ACS) will orient the vehicle. ACS thrusters are provided fore and aft on all vehicles.

A number of advancements have been made recently in the area of "clean" ACS and OMS. GenCorp Aerojet has been developing a GO_2 / ethanol attitude control system for the Kistler *K-1* launch vehicle. They also supplied the GO_2 / GH_2 ACS for the *DC-XA* and the GO_2 / gaseous methane ACS for the *X-33* demonstrator vehicle. In addition, Aerojet is developing the 870 pound thrust LO_2 / ethanol Orbital Maneuvering Engine for the *K-1* upper stage. Starcraft Boosters intends to employ these new systems on the *StarBooster* and *StarBird* vehicles to both improve system performance (because of the higher specific impulses) and shorten the per flight operations costs resulting from the use of environmentally friendly propellant combinations.

Electrical power for the vehicles is to be supplied by batteries. Fuel cell power plants will be required for the *StarBirds*.

System Interdependence

System and subsystem interdependence is to be minimized. For example, the *Zenit* first stage systems will be used "as is" to the maximum extent possible to serve the needs of ascent flight. Most aircraft systems will be activated only after the rocket has been shut down. Design simplicity is paramount. As a design goal, for example, ascent flight control will be provided entirely by gimballing the *RD-170* or *RD-180* engine nozzles. The use of aircraft control surfaces will be employed during ascent flight only if persuasive evidence proves that it is necessary.

As another example, the *StarBooster* vehicles will have electrical energy supplied by batteries. Separate battery packs, one for the *Zenit* or *Atlas* stage and one for the aircraft, will supply electrical power for the time it takes (fifteen minutes or less) the aircraft to complete ascent flight, decelerate to subsonic flight and have the turbofan engines started. Once the air-breathing engines are operating, engine-driven alternators will supply all aircraft power for the return flight of less than one hour duration, while the rocket stage will continue to draw upon its battery pack for maintaining its low draw health monitoring and data recording sub-systems during return flight.

Configuration changes to the rocket stage are to be minimized, with implementation of only those design changes found to be absolutely imperative for repeated use and for safe operation.

Computer software will, to the extent possible, be maintained as separate entities for the rocket and the aircraft, with an overlay of rocket vehicle outputs provided to the aircraft for recording and for relaying telemetry. Maximum use of existing software will be a design goal. If the *Zenit* first stage now draws upon the *Zenit* upper stages or instrument unit for support, then accomodations will be provided for these items in the nose of the aircraft. *Zenit* operational autonomy will be preserved to the maximum extent possible. Thorough assessment of each configuration to be flown with *StarBooster* will be an operational imperative.

***StarBooster 200* Mass Properties Summary** **Sept. 10, 1999**

		Vehicle Mass		
Number	**Group/Element**	**Pounds**	**Kilograms**	
1.0	**Wing**	**6,737**	**3,055**	
2.0	**Fins and Canards**	**3,410**	**1,546**	
3.0	**Body**	**17,442**	**7,910**	
4.0	**Induced Env. Prot.**	**1,618**	**734**	
5.0	**Undercarriage**	**4,414**	**2,002**	
6.0	**Propulsion, main**	**0**	**0**	
7.0	**Propulsion, RCS**	**1,820**	**825**	
9.0	**Prime Power**	**1,134**	**514**	
10.0	**Electric conversion**	**4,337**	**1,967**	
11.0	**Hydraulics**	**0**	**0**	
12.0	**Control surface actuators**	**1,256**	**569**	
13.0	**Avionics**	**575**	**261**	
14.0	**Environmental control**	**2,421**	**1,098**	
15.0	**Payload provisions**	**3,500**	**1,587**	
16.0	**Range safety**	**300**	**136**	
17.0	**Ballast**	**0**	**0**	
18.0	**Auxiliary systems**	**200**	**91**	
	EMPTY W/O GROWTH	**50,637**	**22,919**	
19.0	**Growth allowance**	**15,161**	**6,876**	
	EMPTY W/ GROWTH	**65,798**	**29,795**	**StarBooster Only w/o Atlas or fluids**
20.0	**Personnel**	**0**	**0**	
21.0	**Payload**	**30,260**	**13,723**	**Atlas III MECO weight**
22.0	**Propulsion, ABES**	**10,133**	**4,595**	
23.0	**ABES propellant**	**10,182**	**4,618**	**Additive to dry mass when required**
24.0	**Residual & unusable fluids**	**292**	**132**	**(Vs > Mach 3.3)**
25.0	**Reserve fluids**	**50**	**23**	**75,831 lm w/ABES**
26.0	**Inflight losses**	**656**	**297**	
	ENTRY WEIGHT	**116,471**	**52,821**	
27.0	**Propellant, RCS**	**512**	**232**	
28.0	**Main propellants**	**400,700**	**181,723**	
	BLOW	**517,683**	**234,777**	
29.0	**Startup losses**	**6,096**	**2,765**	
	PRELAUNCH GROSS	**523,779**	**237,542**	**Mass Fraction = Wp ascent/BLOW**
	MECO WEIGHT	**116,983**	**53,054**	**MF = 0.774**
	CRUISE WEIGHT Start	**115,815**	**52,524**	
	LANDED WEIGHT	**109,023**	**49,443**	

Figure 6-5. *StarBooster 200* Mass Properties Overview.

Inert Mass Estimates and Comparisons

NASA's Langley Research Center has developed detailed weight statements for the *StarBooster 200* vehicle. A copy of this weight statement can be found in Appendix A. A top level summary of the weights has been provided in Figure 6-5.

Performance predictions for the *StarBooster 350* are based on a 1997 estimate of aircraft inert mass of 34 tons. This figure includes two *CFM56* turbofan engines and 6.9 tons of jet fuel, but does not including 34 tons for the *Zenit* first stage, which would give a total of 68 tons. Future work will re-address this matter.

StarBooster 200 Performance

This section provides an overview of the performance analysis work conducted on the *StarBooster 200* vehicle configuration. We will present both our initial parametric analyses as well as the results of recent POST analyses.

Figure 6-6 shows a parametric analysis of mass delivery to BECO for the *StarBooster 200*. It is important to notice the low sensitivity of *StarBooster 200* performance to dry weight of the aircraft. This, along with the 30% dry mass margin, provides additional certainty of *StarBooster* fulfilling its mission objectives.

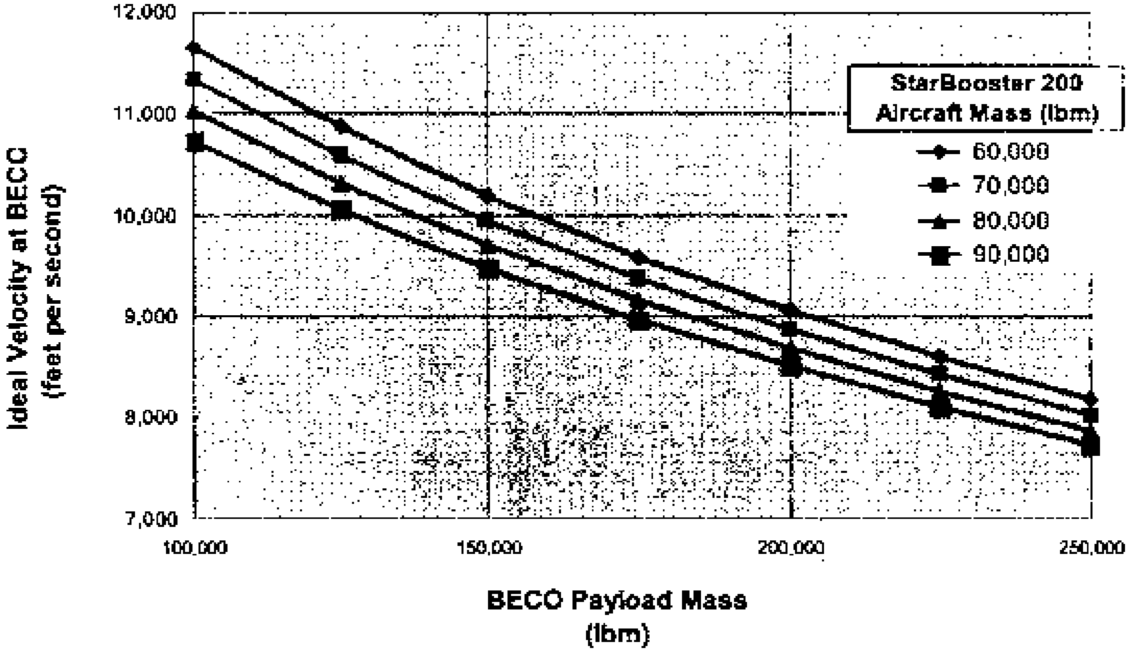

Figure 6-6. *StarBooster 200* Performance to BECO.

Single *StarBooster 200* with *Athena II*

The *StarBooster 200 / Athena II* configuration has been parametrically analyzed. Figure 6.7 plots payload performance as a function of system ideal velocity for a large range (35,000 lb to 65,000 lb) of aircraft dry mass. From this graph it is apparent that the delivered payload is relatively insensitive to aircraft weight growth. As mentioned earlier, this assures satisfactory performance even if dry mass greatly exceeds initial estimates.

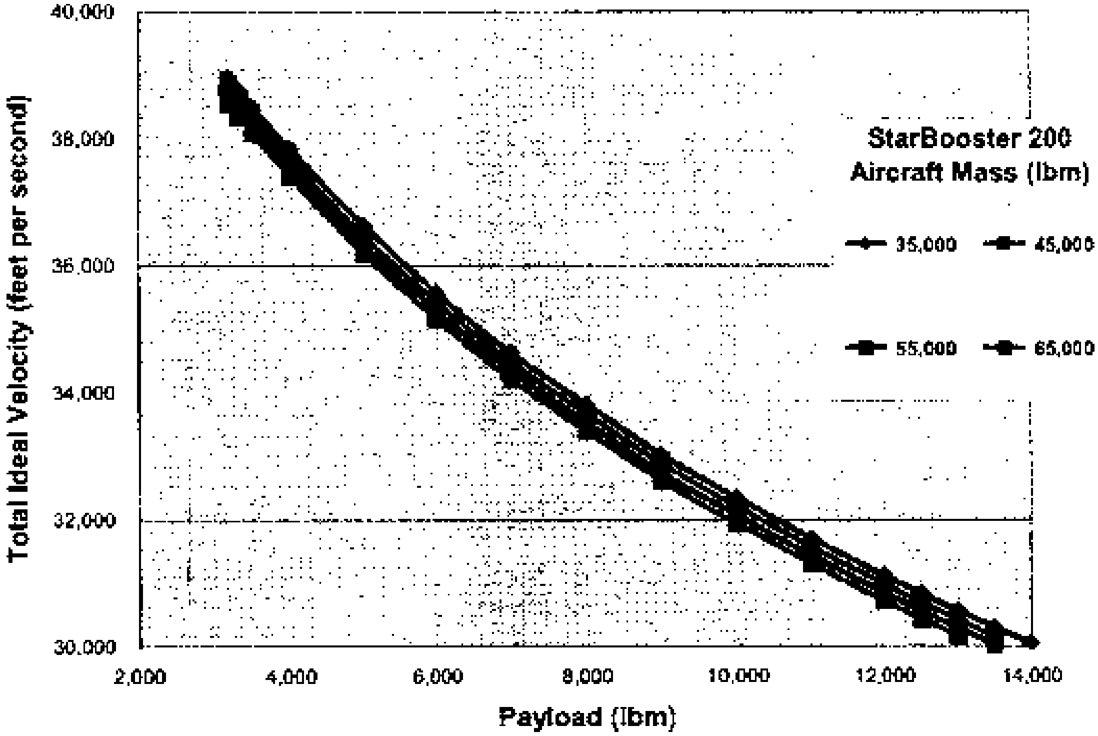

Figure 6-7. Single *StarBooster 200* with *Athena II* ideal performance.

Dual StarBooster 200* with *Athena II

The second configuration of the *StarBooster* system to be reviewed here consists of two *StarBooster 200's* combined with an *Athena II*. This "Dual *StarBooster*" configuration improves payload performance to almost five and one-half times greater than that of *Athena II* alone, boosting performance to over ten metric tons (23,400 lb$_m$ / 10,600 kg) to LEO. With the addition of a *Star* series solid rocket motor, payloads approaching four metric tons (8,820 lb$_m$ / 4,000 kg) may be delivered to GTO. This is in the same payload class as the *Ariane IV*, *Atlas II*, and *Delta III*. This capability can address 60% of the near term commercial GTO market.

Dual *StarBooster 200*'s permit the delivery of payload ensembles of up to 368,000 lb$_m$ (166,900 kg) to the staging velocity. As in the single *StarBooster* case, even larger payload ensembles are possible by off-loading some of the propellant.

Dual *StarBooster 200*'s with *StarCore I*

StarBooster 200 / StarCore I trajectory simulations have been performed by NASA's Langley Research Center using the industry standard POST simulation program. The results of these analyses can be viewed in the following section (see *StarBooster 200* Flight Profile). Langley's analyses indicate that the Dual *StarBooster 200 / StarCore I* configuration can place an 11.5 metric ton (25,600 lb$_m$ / 11,610 kg) payload into LEO, including 8.3 metric tons (18,300 lb$_m$) of propellant remaining in the *Centaur* stage. The remaining propellant is sufficient to circularize a 3.3 metric ton (7,190 lb$_m$) payload in GEO. Alternatively, the *Dual StarBooster 200 / StarCore I* configuration can deliver 6.3 metric ton (14,000 lb$_m$) payloads (i.e. communication satellite plus apogee kick motor) to GTO.

In addition to a traditional chemical rocket insertion scenario, the use of Electric Propulsion (EP) has been examined. In this application, the dual *StarBooster 200 / StarCore I* system delivers 5.3 metric tons (11,700 lb$_m$ / 5,310 kg) of payload to a highly elliptical orbit, with apogee above 28,080 NM (52,000 km) and an inclination of 26°. At apogee insertion, the *StarBooster* system has done its job. The two *StarBoosters* return to their launch site from their staging for reuse, while the upper stages are expended.

The communications satellite then uses its on-board storable propellant propulsion system at apogee to establish a 24-hour period orbit, inclined at 7 degrees, with periapsis above the Van Allen radiation belts. From there, the high specific impulse (generally >> 3,000 sec. Isp) electric propulsion system slowly adjusts the satellite's orbit to GEO in a spiraling trajectory. This method must take into account increased gravity losses due to very large burn times involved with the low thrust electric engines, and an increase in propellant tank size to hold the propellants consumed during orbital transfer. Considering these factors, the communications satellite net mass (dry mass plus station-keeping propellants) increases to 3.7 metric tons (8,150 lb$_m$).

Dual *StarBooster 200* with *StarBird I*

(to be supplied by future work)

StarBooster 200 Flight Profile

NASA's Langley Research Center has done a significant amount of work to define the ascent profile and vehicle loading conditions. The following plots graphically depict the ascent profile of a *Dual StarBooster 200 / StarCore I* launch. The critical launch events are characterized in Table 6-2.

Table 6-2. Critical *StarBooster 200 / StarCore I* Launch Events.

	Time (seconds)	Altitude (feet)	Relative Velocity (fps)	System Mass (lbm)
Ignition	-2	0	0	1,343,400
Liftoff	0	0	0	1,333,400
StarBooster 200 BECO	145	146,440	5,756	532,000
Castor 120 #1 Ignition	150	156,475	5,700	298,022
Castor 120 #1 Cutoff	233	287,256	9,000	190,676
Castor 120 #2 Ignition	233	287,256	9,000	178,927
Jettison Payload Fairing	260	325,870	10,770	138,536
Castor 120 #2 Cutoff	315	431,900	16,960	66,609
Centaur Ignition	344	492,580	16,850	54,901
Centaur MECO	810	607,614	24,213	31,844

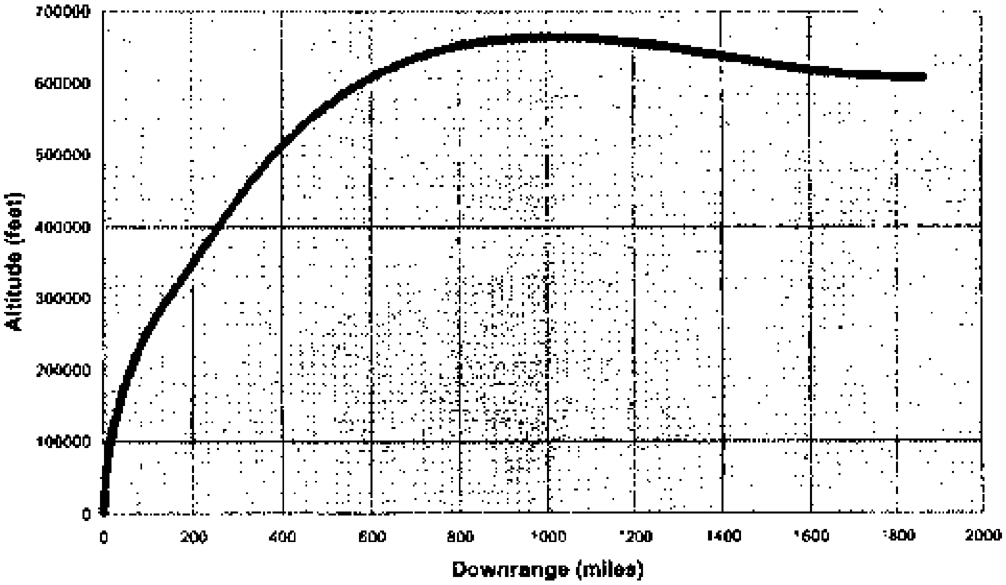

Figure 6-8. ***Dual StarBooster 200 / StarCore I*** **Ascent Profile (Altitude vs Downrange Distance)**

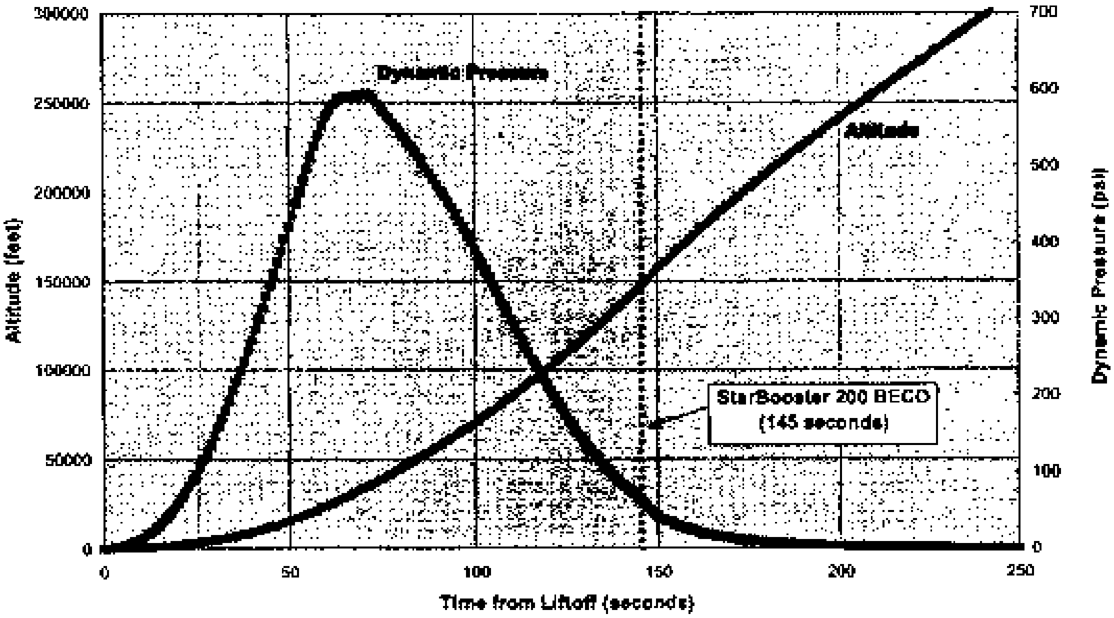

Figure 6-9. ***Dual StarBooster 200 / StarCore I*** **Ascent Profile (Altitude and Dynamic Pressure vs Time)**

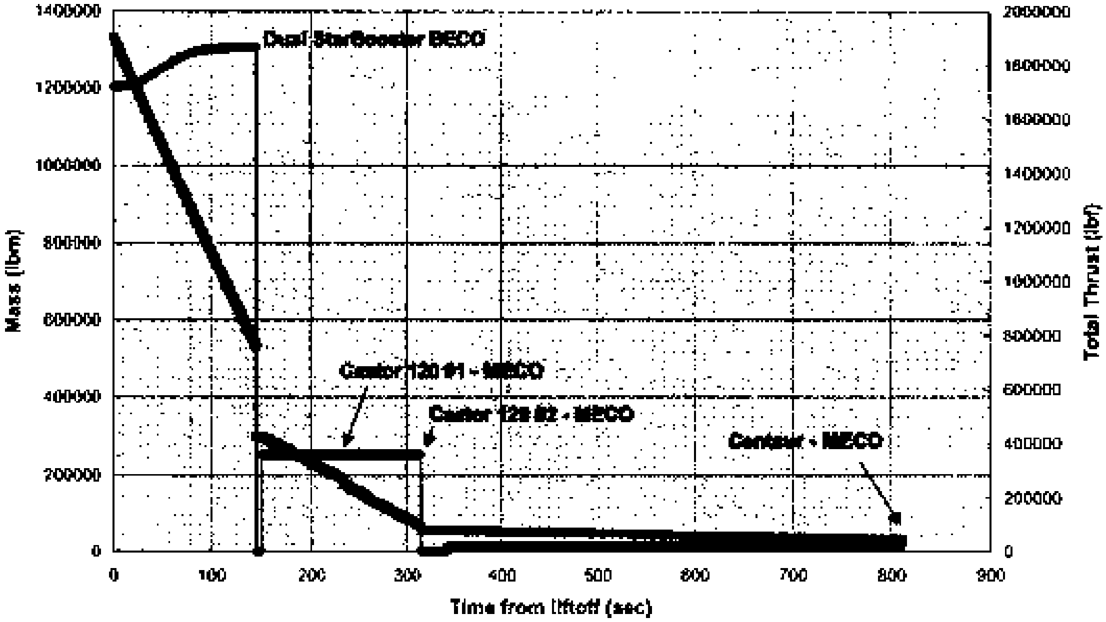

Figure 6-10. *Dual StarBooster 200 / StarCore I* Ascent Profile (Vehicle Thrust and Mass vs Time)

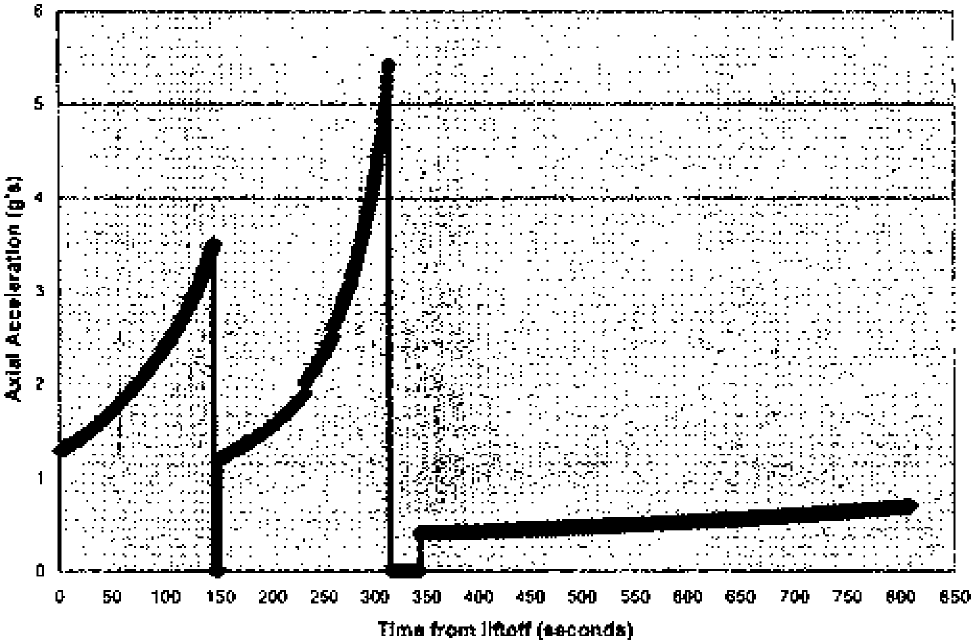

Figure 6-11. *Dual StarBooster 200 / StarCore I* Ascent Profile (Axial Acceleration vs Time)

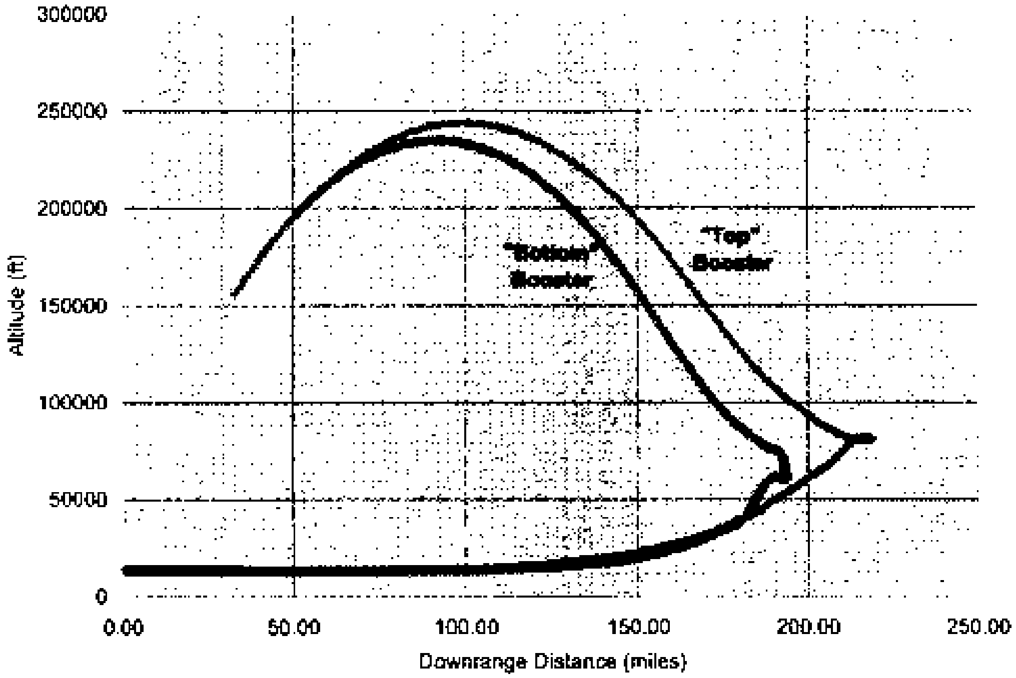

Figure 6-12. ***Dual StarBooster 200 / StarCore I – StarBooster*** **Return Profile (Downrange Distance vs. Altitude)**

StarBooster 350 Performance

Prior to 1997, a series of parametric performance analyses were conducted to identify potential "payloads" for the *StarBooster 350* vehicle, which was considered the "Baseline Configuration" at the time. This section provides an overview of the work that was conducted in an effort to highlight the breadth of system analysis that was performed. The following summarizes our top-level findings of the *StarBooster 350* performance.

1. The *StarBooster* can provide between 2.2 and 3.0 km/sec. of velocity to a complex of upper stages and payloads.
    a. The upper bound on "throw weight" at the lower velocity of 247 tons is determined by the thrust of the *RD-173* engine. Larger payloads may be launched provided the payload stage engine is used for liftoff (i.e., parallel burn). For the even larger payloads of the future, multiple *StarBoosters* may be employed.
    b. The lower bound on throw weight of 145 tons is to assure the thermal load limit for the "heat sink" *StarBooster* is not exceeded. Smaller payloads than these may be flown, provided that only a partial load of *StarBooster* propellants is provided and/or trajectory shaping is employed.
    c. A large number of existing rocket vehicles, when ground-launched, have gross weights between these boundaries. Those vehicles will be favored which avoid the use of amine-based fuels and nitrogen tetroxide oxidizer, both of which are toxic and, together, self-igniting. Vehicles using the more

hazardous propellants are best handled at facilities equipped for use of these propellants, with *StarBooster* accommodated there rather than at a new site.

2. Performance of the *StarBooster 350* is insensitive to aircraft and fuel weight. An increase of 25% in aircraft inert mass reduces "throw weight" mass less than ten tons, or about 5%. An increase of 50% reduces throw weight by about 15 tons, or less than 10%.

3. Considering velocity losses that occur during boost phase flight, the staging Mach number can be approximated. *StarBooster 350* is designed so burnout will occur between the boundaries of Mach 2.0 and 6.0. As a full load of propellants is burned in about 132 seconds, and deceleration to subsonic velocity after payload separation is rapid, dwell time in the high heating part of the trajectory is limited. This permits the heat sink thermal protection system to be used for a small increase in structural weight.

StarBooster 350 Performance Estimates, Methodology and Disclaimer

The performance estimates that follow were made using a "quick look" Microsoft Excel routine applying the ideal rocket equation. Vehicle characteristics were largely taken from the *International Reference Guide to Space Launch Systems*, AIAA, 2nd Edition. These estimates are thus very preliminary until confirmed or altered by future numeric integration ascent trajectory analyses using more authoritative mass properties and aerodynamic data. Where possible, the performance (net payload to the selected destination orbit from the designated launch site) of each vehicle was calculated to an ideal velocity that had been back-calculated from known payload, vehicle element mass properties, and engine specific impulse. Performance errors resulting from errors and omissions in treating mass properties and engine performance were thus at least partly nullified. In the case of the Russian *Ikar* launch vehicle, "reverse engineering" had to be applied to derive most of the stage mass properties, as Russia had not yet released these details on this relatively modern military missile. This process has clearly increased the uncertainty of the results.

Consequently, the payload numbers quoted below are to be taken as indicators rather than explicit claims. Based upon earlier work by this author that have had the benefit of follow-up trajectory analyses, future work can be expected to alter these numbers by 5% to 10%, but not usually by 25% or more.

Other qualifiers will also apply. Where the calculations suggest an increase in performance of an existing space launch vehicle from the use of the *StarBooster*, the reality of this increase will be dependent upon the vehicle structural and control properties. For example, the *Centaur* upper stage of the *Atlas* and *Titan* series is limited to near the present payload weight by compressive loads and bending moments applied to the pressure-stabilized propellant tank and primary structure. Thus, large payload increases enabled by launch of the vehicle by *StarBooster* cannot be confirmed until the structural capabilities required for such increases can be economically provided.

When addressing launch of the NASA *X-33* and Lockheed/Martin *VentureStar*, the availability of structural strong points for attachment of the *X-33* to *StarBooster* will become an issue. The present design activity does not, so far as is now known, include any requirement that it be mounted to another vehicle.

In spite of these limitations, the payload data given below is considered to be the best available (in 1997). As the *StarBooster* program progresses, predictions for payload delivered will improve.

StarBooster 350 with Zenit 3 Second and Third Stages

The most obvious way of applying the *StarBooster* is to use it in launching the GTO payload with the other two stages of the vehicle from which it was derived, the *Zenit 3*. The basic expendable *Zenit 3* is capable of placing 5.18 tons to GTO launched from Biakonur. With the added inert weight of the *StarBooster* aircraft, as well as the jet fuel to return to first stage to the launch site, and added drag losses, degradation of this payload is expected and inevitable.

In order to quantify this loss, the ideal velocity produced by the *Zenit 3* with the specified payload was computed, with assumptions used for flight performance reserves, unavailable propellants, etc. The result of these assumptions and the calculation was to produce a total ideal velocity of 11.6 km/sec. This number meets first-order "reasonableness tests", so it was used as the basis of estimating performance of the *Zenit 3* second and third stages with *StarBooster*. Also noted was that booster staging occurred at an ideal velocity of 3.63 km/sec. In addition, the thrust-to-mass ratio at second stage ignition of the *RD-120* engine was 0.82, lower than what might be desired for the reduced staging velocity.

Since the upper stages and payload are mounted to the belly of *StarBooster* rather than nose-mounted, additional aerodynamic drag will be experienced in ascent flight when compared to the expendable *Zenit*. Aerodynamic analyses and wind tunnel testing will be required to gain an authoritative value for this penalty. It was estimated, for calculation of GTO performance of the *Zenit* stages launched by *StarBooster*, that 200 meters per second additional drag losses were experienced. Such losses would be more than twice that of present *Zenit* drag losses in ascent flight.

Preliminary performance predicted by these analyses indicates a payload to GTO of 3.56 tons, a loss of 30%. This is perhaps overly pessimistic. This payload may not be adequate to capture the modern communications satellite payloads, which now begin near four tons. Second stage ignition now occurs at an ideal velocity of 3.23 km/sec. As the *StarBooster* heat sink TPS structure may not tolerate this high staging velocity, off-loading booster propellant may be required.

Because the *StarBooster 350 / Zenit* ensemble stages at a lower altitude and velocity than its expendable counterpart, the Zenit second and third stages will encounter greater gravity losses impacting payload further. As a result, heavier and / or higher performance upper stage combinations will be required to best utilize the capabilities of *StarBooster 350*. Various combinations of additional *Zenit* upper stages were tried to no avail. The low thrust of the second stage and expected high costs of additional stages make it unlikely these options will be satisfactory.

StarBooster 350 with *Ikar*

The *Ikar 2* launch vehicle was derived from the *SS-18* military ICBM. *Ikar 1* is essentially the military missile with the warhead replaced by a payload. *Ikar 2* replaces the small storable 3rd stage of the missile, which was used for targeting *MIRV* warheads, with the larger third stage of the *Tsyklon* launch vehicle, itself derived from an ICBM. This stage contains three tons of N_2O_4/UDMH propellants, has an inert mass of 1.6 tons, and produces 317 seconds of vacuum specific impulse.

The *International Reference Guide to Space Launch Systems*, AIAA, 2nd Edition, states that the gross mass of the *Ikar 2* launch vehicle is 212.9 tons, compared to 114.9 tons for the *Zenit 3* without its first stage. This will lead to a lower *StarBooster* staging velocity, removing concerns about heat sink limits. Other information provided includes payload capability of 4.2 tons for *Ikar 1* to 400 km, 46 degree circular (not GTO) orbit, a vehicle diameter of 3 m, length of 39.2 m and launch price of $6 to 8 millions. Contacts between Starcraft Boosters, Inc. and high-ranking officials in Russia indicate that hardware costs can be negotiated down to $5 million each or less. This price includes all three stages, guidance and other avionics, and the standard 2.7 meter diameter payload fairing.

As stage characteristics are not available, "reverse engineering" was performed to calculate the stage masses and engine specific impulse values. These were then applied, using the stated payload, to derive the ideal velocity to low Earth orbit. Taking into account the additional velocity required to establish the GTO orbit from LEO, the resultant 11.6 km/sec ideal velocity was used to the predict the GTO performance of *Ikar 2* with *StarBooster*. The calculated payload value of 4.5 tons is 77% that of the expendable *Zenit 3* payload from Biakonur and 118% that of the *Delta III*. This payload, almost 10,000 lbm, is considered adequate for capturing a share of the communications satellite market.

For this configuration, staging velocity was quite low, 2.02 km/sec, or below Mach 2.5. The *StarBooster* was flown with a 98% capacity propellant load to gain adequate thrust to weight at liftoff. This staging velocity offers a benign entry environment and may be ideal for beginning commercial flight operations.

Concern over *Ikar's* ability to take the increased payload mass provided by *StarBooster* is alleviated by the observation that the GTO payload is only 7% higher than the LEO payload of *Ikar 1*. A continuing concern, however, is that this vehicle uses N_2O_4/UDMH hypergolic propellants which are more hazardous to the environment and personnel than are kerosene or hydrogen propellants used in other rockets. Use of this propellant combination as an interim measure may become a commercial necessity, but early steps to replace it with less hazardous propellants are highly desirable.

***StarBooster 350* with Ariane**

Ariane 5 now uses a pair Europropulsion *P230* solid rocket boosters (SRBs). Each booster weighs 265 tons, has an inert mass of 35 tons and produces 273 seconds of vacuum I_{sp}. The pair produce approximately 14% more total impulse than a single *StarBooster*. The cryogenic *Ariane 5 core* stage is an outstanding modern design, weighing 170 tons, housing 155 tons of LO_2/LH_2 propellants, and with a dry mass of only 15 tons. The *Ariane 5* second stage uses 9.7 tons of N2O4/MMH propellants and has a dry weight of 1.2 tons, with vacuum I_{sp} of 324 sec. GTO payload is 6 to 6.8 tons, depending upon whether dual or single payloads are flown.

ESA's *Ariane 40* without SRBs may be a candidate *StarBooster 350* upper stage rather than *Ikar*. Performance analysis is planned but not yet completed for this configuration. Since *StarBooster 350* provides a total impulse nearly equal to that of ten of ESA's *L40* liquid strap-on boosters, a significant performance enhancement beyond the present *Ariane 44L* maximum of 4.9 tons can be expected.

To gain approval to launch *StarBooster 350* with *Ikar 2* or *Ariane 40* from Kourou, with follow-on application to the ESA standard and growth *Ariane 5* vehicles, a catalyst is needed. A future catastrophic failure of the *P230* SRB could be such a catalyst. With the recent track record of segmented *SRB*s, the probability of such a failure may be high.

Although Mr. Doug Heydon of Arianespace USA and Mr. Ian Pryke, an ESA Washington representative, have both been contacted recently for data on *Ariane*, the *StarBooster 350* concept has not yet been briefed to them.

***StarBooster 350* with other Space Launch Vehicles**

A number of other trial runs were made with other space launch vehicles, including the Lockheed/Martin *Athena II*. No useful results have yet been obtained. More effort, including trajectory shaping, use of partial propellant loads for *StarBooster 350*, and *RD-170* throttling may enable a favorable match with several additional candidate upper stage combinations. More will emerge from new work.

Of particular interest may be those vehicles using kerosene or hydrogen fuels rather than fuels which are amine-based. *Atlas* derivatives must, of course, be considered. These may not survive scrutiny because the limited load-carrying capability of the *Centaur* stage structure may negate the additional payload capability gained by use of *StarBooster*. A second criteria may prove to be equally important in ruling out this option: the $100 million costs of *Atlas* vehicles.

By leaving off all or part of its booster stage, *Soyuz*, a kerosene-fueled vehicle, may a candidate for flight with *StarBooster 350*. Each of the four strap-on booster modules of *Soyuz* weighs approximately 43 tons and have 27 million lbf-sec of total impulse. Eliminating two boosters and adding a *StarBooster* would increase total impulse by more than 75%. *Soyuz* engines may require extensive ground support equipment for safe ignition. If this is so, this might be the first occasion to use "parallel burn", in which both *StarBooster 350* and *Soyuz* engines are ignited on the launch pad, followed by throttling of the *Soyuz* boosters to conserve their propellants for use after separation from *StarBooster 350*. Parallel burn, as will be seen later, is one growth path for *StarBooster's* continued application over a very long productive life. The use of multiple boosters is the other.

Notable by its absence here is the use of *StarBooster 350* to launch the NASA *Space Shuttle*. This application is of strong interest to NASA and will require careful consideration. Since two *StarBooster 350*s provide only 80% of the total impulse of the *RSRM* pair, a decrease in performance can be expected. The wingspan of three of the present *StarBoosters* exceeds the available mounting space around the *Shuttle External Tank* without applying a shorter wing. "*Twin Zenit*" versions of *StarBooster 350* (*StarBooster 700*) are another possibility.

***StarBooster 350* with *StarCore* II**

There will be strong motivation to replace upper stages using amine fuels (UDMH, MMH and mixtures) with ones using fuels which are easier to handle and easier on the environment.

One possibility is to employ a partially reusable stage powered by a recoverable *SSME*. Davis Aerospace Company patented such a vehicle, *Consort*, in 1989. It employed a ballistic entry body to recover a single main engine, along with gimbal drive actuators, propulsion system components, and some stage avionics. A new expendable tank, 5 meters in diameter and 31 meters long, contained 186 tons of oxygen and hydrogen propellants. This tank employs modern structural design and fabrication techniques to achieve a low recurring cost, far below the cost-per-pound of the present *Space Shuttle ET*.

The *Consort* concept has been repackaged to create the *StarCore II* vehicle. Analyses were conducted using series burn, rather than parallel burn. In this configuration the net payload to LEO is 24 tons. Performance can be increased to 27 tons when advanced versions of the *SSME* are employed. The *SSME* does not have air-start capability at this time and thus cannot use the series burn approach. Acquiring this "air-start" capability was studied by Rocketdyne (now a part of Boeing) for NASA - Marshall and found to be very expensive. This topic must be re-examined. The approach of using a larger tank, parallel burn version with a single recoverable *SSME* (or Russian *RD-0120*) must also be reviewed.

The USAF *EELV* program may be another source for gaining more suitable upper stages. Developments will have to be watched carefully to determine the optimum path of departure from the initial surplus missile approach employed by *StarBooster 350*.

StarBooster 350 for Space Tourism

(to be supplied by future work)

StarBooster 350 with the NASA *X-33*

StarBooster 350 might be used to augment the performance of the *X-33* after its test objectives have been fulfilled. A caveat is that the *X-33*, with its outer skin panels suspended from the propellant tanks and inner structure on posts, does not appear to have hard points that allow attaching the *X-33* to the *StarBooster* for launch. Management approval to add these provisions with their "scar weight" to the *X-33* may be quite difficult to obtain, as the *X-33* is a very mass-critical vehicle.

A quick look at the performance of the *X-33 / StarBooster 350* combination indicates that a payload of 2.5 tons could be delivered to an Eastern Test Range (ETR) reference orbit. More work on this prospective opportunity may be required if NASA responds favorably to this suggestion.

StarBooster 350 with the *VentureStar* SSTO

If each one of *VentureStar's* ambitious objectives for engine weight, engine performance, airframe weight, and efficiency in flying the ascent trajectory is fulfilled, performance of this vehicle is expected to be 11.3 tons to the *ISS* and 18.1 tons to low altitude, due East launches from Kennedy Space Center. There are at least two reasons for considering boost augmentation of this vehicle, as advocated by a recent *Aeronautics and Astronautics* article by Dr. James Martin. The first reason is to gain additional payload for those missions that require it. The second reason is to provide a program insurance policy. Should the inert mass of the *VentureStar* consume the available mass margin, any further growth will deduct directly from payload. The predicted payload capability will be completely consumed if the *VentureStar* experiences weight growth similar to that experienced in other space programs. Present inert mass goals are necessarily very aggressive if SSTO is to be achieved.

This situation is being addressed by others using such means as attaching the payload to a small propulsive stage and releasing it in sub-orbit, in essence creating a TSTO. This technique may be effective from a performance standpoint, but consumes payload bay length as well as payload mass, and requires an additional guidance and control system with its software (unless the payload can be persuaded to guide itself). This technique also costs additional money, and introduces a new set of problems for return of the vehicle from a down-range recovery site to the launch facilities, and may therefore be of limited use.

Parallel burn of *VentureStar* with a single *StarBooster 350* and two sub-scale versions of *StarBooster* were examined in 1997 to address the problem of acquiring additional payload and/or program insurance at the outset of the mission, rather than near its end. The *RD-170* version yielded a staging velocity of 2.2 km/sec. with a payload of 33 tons. Versions with a smaller *StarBooster 200*, powered by an *RD-180* engine, results in a staging ideal velocity of 2.0 km/sec and almost 24 tons of payload. Either of these might become a welcome addition to the *VentureStar* fleet.

StarBooster 350 with the *Space Shuttle*

Data was obtained from NASA on the *STS-88* mission, the first mission to *ISS*. NASA predicted that the lift capability (payload plus management reserve) for *STS-88* is 32,526 lb_m (14,750 kg). Using this data, an ideal velocity requirement to *Orbiter* main engine cutoff was calculated to be 30,960 ft/s (9,440 m/s).

Figure 6-13 shows estimated *STS-88* performance using two *StarBooster 350's* in place of the *RSRM*s. Data series are shown for various estimates of aircraft dry mass from 65,000 lb_m (29,480 kg) to 105,000 lb_m (47,620 kg). The higher aircraft masses are now considered to be likely.

For the dual *StarBooster 350 / Space Shuttle* configuration, an estimated additional velocity loss of 250 ft/s (76 m/s) was assumed to account for increased gravity losses due to the lower liftoff thrust-to-weight ratio and increased drag losses of the dual *StarBooster 350* configuration. Taking this into account along with the predicted dry mass of the aircraft, lift capacity was estimated to be just below 26,000 lbm (11,800 kg) of cargo to the *ISS*. This is a 20% loss in performance vs. the current *Space Shuttle*.

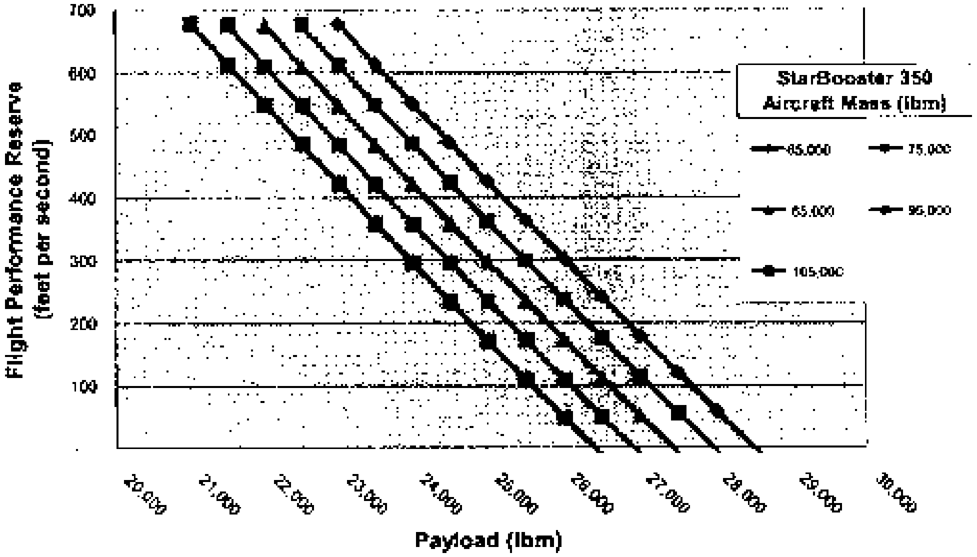

Figure 6-13. *Shuttle* Performance with *StarBooster 350*.

StarBooster 350* with a new *Space Shuttle Orbiter

Recent NASA planning events indicate that today's *Space Shuttle* may continue to operate until the year 2030. This plan is clearly driven by budget considerations and the desire to maintain unbroken human space flight in future years. This scenario may prove to overestimate the remaining life of this system, as it may be overcome by events, either favorable or unfavorable. Should national interest in human space flight be renewed, resources may become available to replace this system with one employing more modern technology.

Davis Aerospace Company developed for NASA an *Orbiter* concept in 1993/4, based upon work done for NASA by Mr. Fred Raymes and others of Grumman in the 1970s. The observation that the hydrogen tank is almost half the volume of vehicles housing this fuel internally, and that severe safety problems arise in a return-to-launch-site (RTLS) abort with hydrogen aboard and in providing a thorough inspection of these tanks before re-flight led to consideration of external mounting of expendable hydrogen tanks.

High performance military aircraft and the *X-15* have for decades seen fit to carry major portions of their fuel supplies in external, expendable tanks. As liquid hydrogen has a density requiring eleven times the volume per unit mass of kerosene, much larger design and operational incentives exist for using external hydrogen fuel tanks for space launch vehicles than have prompted aircraft designers to use this cost-saving technique.

The new *Orbiter* vehicle using two above-wing hydrogen tanks and two *SSMEs* was found in the early 1990's to have an inert mass of 47 tons including the two drop tanks, carrying 410 tons of propellant. When launched in parallel with a single *StarBooster 350*, liftoff mass was found to be 875 tons. Staging was predicted at 2.3 km/sec (near Mach 3) with a payload capability to the *ISS* of 24 tons carrying a 30% mass margin on both vehicles.

StarBooster 350* with a new *Heavy Lift Launch Vehicle

There are numerous opportunities for using the *StarBooster* to provide heavy lift launch services. Possible core stage building blocks may be the twin engine *Ariane 5* growth core with two *Vulcain* engines, *SSME*s provided with provisions for recovery and reuse with propellant tanks from modified *ET*s, *Energia*, growth versions of the *H-Vehicle*, the *EELV*, or new designs. One of the later configurations examined in the work reported here was built from three *StarBoosters* clustered around an in-line expendable *External Tank* with 839 tons, or 17% more propellant capacity than that used for today's *Space Shuttle*. Launch was parallel burn, with four current *SSMEs* mounted in the *Consort* dry recovery entry bodies studied and tested in the early 1990s by Davis Aerospace Company. Mr. Peter Wilhelm of the Naval Research Laboratory recently endorsed this recovery technique. A new feature of this most recent *HLLV* work was the addition of a new cryogenic propellant *Reusable Upper Stage (RUS)*, an early 1997 innovation of the Davis Aerospace Company. Detailed discussion of this upper stage concept is beyond the scope of this report.

This *RUS* carries 34 tons of propellants, is powered by one *RL10D* engine, recovers the entire stage except for its hydrogen tank, and may be modified to provide excellent trans-lunar transport and lunar landing vehicles.

Net payload of the three *StarBooster HLLV* indicated by early runs was 122 tons, but the staging velocity was above *StarBooster* TPS limits. Using two rather than three *StarBoosters*, or off-loading propellants will be required, which will result in a decrease in payload. What is important to note is that this vehicle, as others using *StarBooster*, is not sensitive to airplane weight. Specifically, only five percent of the payload is lost if the airplane and fuel weight double. This vehicle recovers more than 70% of its inert mass for reuse, including the high value elements.

Earlier *HLLV* runs made using *StarBoosters* without the benefit of the *RUS* were done but will not be reported here. Without the *RUS* interest in these results is minimal. The benefits of staging have once again become evident and may also provide for safer and easier rendezvous and docking at the *ISS*, as well as for disposal of the spent *ET*.

***StarBooster 350* Performance Synopsis**

The 1997 material presented above should be persuasive evidence of the capability and versatility of the *StarBooster 350*, using the proven *Zenit* first stage. We do not yet know which of the many available paths will prove to be the most effective for completing the task of payload insertion into the orbits of interest.

If we develop the *StarBooster* with sufficient versatility and prove its capabilities through a successful flight test program, it will be a major technical and financial triumph. Others will provide ideas, aggressive marketing and upper stages. We believe that launch system operators will compete for the right to purchase or use them.

In summary, the performance analyses indicate:

1. Performance of *StarBooster 350* with *Zenit* second and third stages is 3.56 tons to GTO, 30% less than the expendable *Zenit*.

2. Performance with *Ikar 2* is 4.5 tons, about 80% that of the expendable *Zenit*, but more than several competing systems.

3. *Ariane 5* performance, flown with two *StarBoosters* replacing the pair of *P230*

solid rocket boosters, indicates a performance increase of almost 30%. Staging velocity is too high, however, and some off-loading of *StarBooster* will be needed, with diminished performance. With planned *Ariane 5* growth cores, using two *Vulcain* engines, a better match may be obtained with two *StarBooster 350s*. The *Ariane 40* vehicle is another candidate *StarBooster 350* companion.

4. With a new partially reusable cryogenic upper stage using a single recoverable *SSME* and parallel burn, payload is 21 tons to the *ISS* and 30 tons if two *StarBooster 350s* are used. Use of a "kick stage" can increase this performance and ease proximity operations in the vicinity of the *ISS* by presenting a much smaller envelope within these confined quarters.

5. If the *X-33* meets its objectives, launch with a single *StarBooster 350* can extend its flight envelope from Mach 15 to low orbit, delivering over two tons of payload.

6. If the *VentureStar* SSTO is built and fulfills its objectives, the use of a *StarBooster 350* to assist its launch can approximately double its payload and/or add to the available inert mass margin.

7. A new external hydrogen tank *Orbiter* with two *SSME*s can place 24 tons to *ISS* using one *StarBooster 350* for liftoff.

8. Many alternative configurations for the *Heavy Lift Launch Vehicle (HLLV)* may be provided when needed using two, three or four reusable *StarBoosters*, with payloads to and beyond those of the *Apollo* era *Saturn V*.

9. Attractive sub-scale variants of *StarBooster* using the *RD-180* and *RD-190* derivative engines may be built, either as substitutes for or, more likely, as predecessors of and companions to *StarBooster*.

10. Other vehicles, such as *Soyuz* with only two strap-on boosters, are prospective candidates and will need review.

Part 7 – Conclusions

Starcraft Boosters, Inc. has explained its rationale, outlined its approach and laid the foundation for developing the *StarBooster*-based space launch system. We believe that the low risk, high payoff approach of developing a new airplane to house and recover an existing rocket booster stage does two important things. First, it provides an ideal first step on the road to reusability in the commercial arena, providing for repeated inspection and refinement of both the rocket propulsion module and the airplane. Second, the *StarBooster* approach represents a program limited to aircraft development and system integration – not requiring the development of an all-new rocket plane. As a result, financial and technical risks have been significantly reduced to increase the appeal of the *StarBooster* system for both government and private sector investment.

This report has summarized the *StarBooster* development logic and the systems level analyses that were conducted in the process of developing the current concept. Some refinement is required before a preliminary design effort can be initiated. However, with the aid of many people and organizations, including those of NASA's Langley Research Center, the *StarBooster* system is taking shape and the design is evolving towards a core family of vehicles that can address commercial, military, and civil space launch needs. These vehicles are built almost entirely from existing components derived from presently operational vehicles. As a result, creating the *StarBooster* family is largely an integration effort, not a major development program.

The *StarBooster* configurations discussed here, which include the *Atlas III*-powered *StarBooster 200* and the *Zenit*-powered *StarBooster 350*, have applications outside the commercial markets. These vehicles are versatile to the point that they can be adapted to meet the medium to heavy lift requirements of NASA, the United States Air Force and even those of the National Reconnaissance Office. Finally, *StarBooster 350* can serve as a *Liquid Flyback Booster* demonstrator for NASA and even serve as operational reusable boosters on *Shuttle* servicing missions that require only 25,000 lb of payload to *ISS*. It should be noted that 25,000 lb to ISS is equivalent to the capability of the proposed *VentureStar* vehicle. Finally, future derivatives of the *StarBooster* family have been postulated in this report to permit open-ended growth for new applications. These growth systems will require further refinement by work to be done in the future.

Starcraft Boosters believes that the most important aspect in a development process is to chart a course and begin the journey. We believe that developing the versatile low-cost *StarBooster* airplane and utilizing existing, proven expendable booster stages will most efficiently yield a commercially viable space launch system. Furthermore, we are confident that this vehicle will build a knowledge base that can be used to expand our understanding of the design and operation of future reusable space launch systems.

Part 8 – Recommendations

The purpose of this section is to highlight plans for future work as well as propose possible areas of synergy with NASA.

Future Technical Activities

The primary goal of the *StarBooster* Design Team is to further refine the system concept. For the *StarBooster 200* vehicle this will involve continuation of the design work currently being performed both in-house and by NASA's Langley Research Center. The vehicle planform will be analyzed to locate the air-breathing engine nacelles and solidify the aero-surface configuration. Vehicle weights will be updated and fed into the POST 3-DOF (Degree of Freedom) analyses to refine performance estimates and to identify any vehicle flight control issues. Subsystem schematics will be developed to establish the baseline for future weight and cost analyses.

The *StarBooster 350* configuration also requires more conceptual development and analysis. The first task will be to develop a vehicle weight statement and update early performance estimates. The second task will be to modify the basic *StarBooster* planform to address the unique packaging requirements of the *Zenit* booster stage.

Once the vehicle concepts have reached a sufficient and equal level of technical maturity, the *StarBooster* cost models will be updated and the business model revised.

Additional work will focus on the development and refinement of the vehicle operations concepts. In parallel, top-level Interface Control Documents (ICDs) will be created to document the primary system interfaces including: *StarBooster 200* to *Atlas III* first stage, *StarBooster 350* to *Zenit* first stage, *StarBooster* vehicles to Launch Facilities, and *StarBooster* vehicles to the upper stage ensembles.

Possible Areas of Synergy

Considering the current technical and financial challenges encountered by the Lockheed Martin *VentureStar* and Kistler *K-1* launch vehicle development programs, it may be a long time before a fully reusable launch system is available to NASA or the commercial markets. As a result, a partially reusable system, especially one that focuses on providing reusable boosters, may be an ideal near term alternative. Starcraft Boosters believes that *StarBooster*, when operated with current ELVs (such as the *Athena II*) or near term EELV's (such as the *Atlas V* or *Delta IV*) can provide NASA and other government agencies with higher reliability and lower cost access to orbit.

It is our opinion that it is in NASA's best interest to analyze the cost savings and safety improvement capabilities of the *StarBooster* system and to address how it can fulfill NASA's future requirements. Because it is early in the *StarBooster* development program, it is relatively inexpensive to incorporate specific customer requirements. Once the *StarBooster* system design evolves past the Preliminary Design Phase, it will become increasingly costly to adapt the system to meet specific NASA needs.

Near Term Engineering Efforts

- Refine the *StarBooster 200* configuration concept.
    - Continue design trades
    - Develop subsystem schematics
    - Refine vehicle plan form
    - Refine vehicle weights
    - Update vehicle performance
- Refine the *StarBooster 350* configuration concept
    - Develop subsystem schematics
    - Refine vehicle planform – determine if engines are located forward or aft
    - Develop vehicle weights
    - Develop detailed vehicle performance
- Develop system cost model
- Develop and / or refine operations concept
- Establish preliminary ICDs between the main components:
    - *StarBooster 200 / Atlas III*
    - *StarBooster 350 / Zenit*
    - *StarBooster* Vehicles / Launch Facilities
    - *StarBooster* Vehicles / Upper Stages
    - *StarBooster* Vehicles / Human Space Flight

Possible Future Work with NASA

Phase II Effort (continuation of this work) - November, 1999 and continuing

- Operational Analyses - - flight, ground operations definitions & timelines, facilities selection & interactions, preliminary definition of ground support equipment (GSE)
- Initial *StarBooster* Selection - 200 vs. 350 vs. new
- Preliminary Design Statements of Work
- *StarBooster* "X" (selected version) Preliminary Design (largely contracted)

Phase III Effort - Mission Application Studies Jan. 2000- Dec. 2000

- *StarBooster* Flight Test & Certification Planning
- *StarBird* Crew Cabin as NASA *CRV*
- Low Earth Orbit 5 ton class
- Low Earth Orbit 10 ton class
- Low Earth Orbit – near-polar heavy lift
- Geo-stationary Transfer Insertion 3 ton class
- Geo-stationary Transfer Insertion 6 ton class
- Geo-stationary Circular Insertion 3 ton class
- *ISS* Servicing and Re-boost

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- Geo-stationary Circular Insertion heavy class
- Lunar & Planetary Missions
- "*X-Plane*" Air Drop Utilization
- Military Mission applications (several)

Future Growth Paths

- *StarBooster 750* Class (1.5 million lbm of propellant)
- *StarBird II* Class (75-100 passenger Class)
- *StarBooster 1500* Class (Space Power Demonstration) and related systems

Part 9
Appendix A – StarBooster 200 Detailed Weight Statement

Number	Group/Element	Weight	C.G. Position	Product	Input Parameters	Values	Comment
1.0	**Wing**	**8,111**					
1.1	Exposed wing surface	6,737	0.903	6084	Ultimate safety factor	1.4	Aluminum wing
					Load factor	2.5	
					Exposed wing area, ft^2	1,167	
					Landed weight, lb	109,023	
					Aspect ratio	2.587	Exposed area
					Taper ratio ct/cr	0.1754	Exposed wing
					t/c	0.135	
1.2	Carry-through	695	0.903	628	Ultimate safety factor	1.4	
					Load factor	2.5	
					Landed weight, lb	109,023	
					Carry thru width, ft	13.5	
					Structural span, ft	64.06	
					Aspect ratio	2.5874	
					Taper ratio ct/cr	0.1754	
					Wingspan, ft	53.81	Exposed wingspan
					t/c	0.135	
					Root chord, ft	35.39	Exposed wing
					rrc	0.0000166	rho/sigma, aluminum
					Geometry parameter	1.14	
1.3	Wing-body fairing	356	0.665	237	Wing fairing unit weight	4	Titanium
					Wing fairing surface area	89	Glove only
1.4	Leading edge increment	323	0.843	272	Leading edge area both wings	209.7	Total both wings
					Titanium-aluminum delta	1.54	Weight delta lb/ft^2
2.0	**Fins and Canards**	**3,410**					
2.1	V-Tail fins	2,400	0.989	2375	V-Tail fin planform area, ft^2	152.65	One fin, titanium
					Number of fins	2	
					Unit weight of fins, lb/ft2	5	
2.2	Canards	1,009	0.250	252	Total canard area, ft^2	140	2 canards
					Unit weight of canards, lb/ft^2	7.21	Rene 41
3.0	**Body**	**17,442**					
3.1	Fuel tank	0			Atlas tank is used		n/a
3.2	Fuel tank insulation	0			Carried below		
3.3	Oxygen tank	0			Atlas tank is used		
3.4	Oxygen tank insulation	0			Carried below		
3.5	Atlas insulation	606	0.586	355	Unit weight of insulation	0.2	500°F radiating
					Atlas tank surface area, ft^2	3030.7	Prevents boiloff
3.6	Basic heat sink structure	13,615					
3.6.1	Primary shell	13,320	0.576	7671	Unit weight of body, lb/ft^2	2.75	Aluminum
					Total body wetted area, ft^2	4,843.63	
3.6.2	Nose area increment	295	0.052	15	Titanium-aluminum delta	1.54	Titanium increment
					Nose area, ft^2	191.45	
3.7	Aeroshell Thrust Structur	1,500					
3.7.1		1,000	0.969	969	Rear frame interface	1000	Atlas interface
3.7.2		500	0.288	144	Front frame interface	500	Atlas interface
3.8	Secondary structure	1,721					
3.8.1	Keel, doors, cutouts	969	0.576	558	Design coefficient, lbs/ft^2	0.2	includes keel structure
					Total body wetted area, ft^2	4,843.63	
3.8.2	Body flap	243	1.016	247	Unit weight of body flap	4	Titanium
					Body flap area, ft^2	60.75	
3.8.3	Speedbrakes	0	0.000	0	Unit weight of speed brake, lb/ft^2	3	Heat sink aluminum

STARBOOSTER

3.8.3	Speedbrakes (see tailfins)		0	0.000	0	Unit weight of speed brake, lb/ft^2	3	Heat sink aluminum
						Speedbrake area, ft^2	95.34	
						Number of speedbrakes	2	
3.8.4	Engine fairing (old versio		0	0.000	0	Area of fairing over engines, ft^2	0	Composite
						Unit weight of fairing, lb/ft^2	0	Dorsal fairing
3.8.5	Wing tanks for ABES		509	0.911	464	Wingtank coefficient	0.05	Wet wing sealing
						Total ABES fuel	10182	
4.0	**Induced Env. Prot.**	**1,618**						
4.1	Fuselage		0	0.000	0	None - heat sink booster		
4.2	Wing and Fins		0	0.000	0	Titanium structures & heat sink		
4.3	Internal insulation		334					
4.3.1	Nose area		214	0.183	39	Nose area, ft^2	1,069.01	Up to break
						Unit weight of insulation	0.2	500°F radiating
4.3.2	Equipment bays		60	0.209	13	Equipment bay area	300	Landing gear, misc
						Unit weight of insulation	0.2	
4.3.3	Wing tanks		60	0.911	55	Wing tank area	300	Estimated
						Unit weight of insulation	0.2	
4.4	Purge, vent, drain		1,284	0.628	807	Body length, ft	123	
						Exposed wing span	53.81	
5.0	**Undercarriage**	**4,414**						
5.1	Nose gear		709	0.246	174	Unit weight of nose gear, lb/lb	0.0065	
						Landed weight, lb	109,023	
5.2	Main gear		3,705	0.851	3154	Unit weight of main gear, lb/lb	0.033986	
						Landed weight, lb	109,023	
6.0	**Propulsion, main**	**0**						
6.1	Main engines		0	0.000	0	Atlas III (see below)	0	
7.0	**Propulsion, RCS**	**1,820**						
7.1	Forward thrusters		112	0.105	12	Number of vernier thrusters	6	
						Number of primary thrusters	9	
						Wt vernier thruster for baseline	5.3	
						Wt primary thruster for baseline	22	
						Entry weight, lb	116,471	
						Entry baseline weight (IHOT),lb	240,000	
7.2	Rear thrusters		223	0.969	216	Number of vernier thrusters	12	
						Number of primary thrusters	18	
						Wt vernier thruster for baseline	5.3	
						Wt primary thruster for baseline	22	
						Entry weight, lb	116,471	
						Entry baseline weight (IHOT),lb	240,000	
7.3	Propellant tanks		176	0.183	32	Tank constant, lb/ft^3	0.34	
						RCS propellant, usable	413	
						RCS propellant reserve & residuals	103.25	
7.4	Lines, manifolds, regulat		1,106	0.650	719	Baseline weight, lb	1304	IHOT
						Reference length baseline, ft	145	IHOT
						Vehicle length, ft	123	
7.5	Valves		178	0.650	116	Baseline weight, lb	367	
						Baseline entry weight, lb	240,000	IHOT
						Entry weight, lb	116,471	

7.6	Helium tanks		26	0.183	5	Helium pressure system constant	1.12	
						RCS propellant, usable	413	
						RCS propellant reserve & residual	103.25	
						Bulk density of RCS propellant	22.6	lb/ft^3
8.0	**OMS**	0		0.000	0	No OMS on booster		
9.0	**Prime Power**	1,134						
	Batteries		1,134	0.052	59	Rechargeable AgZn batteries	2720	[illegible] x HL-20 x scale factor
						Scale factor	4.17	
10.0	**Electric conversion**	4,337						
	ECD		4,337	0.420	1822	Constant % of entry weight	0.03724	
						Entry weight	116,471	
11.0	**Hydraulics**	0		0.000	0	No hydraulics		
12.0	**Control surface actuato**	1,256						
12.1	Elevons		656	0.953	529	Entry weight constant	0.0048	
12.2	V-Tail fins		397	0.958	380	Entry weight constant	0.0017	
12.3	Body flap		148	0.990	147	Based on STS-scaled for area		
12.4	Speed brakes		0	0.000	0	Differential rudders used	2.049	
12.5	Canards		155	0.236	37	Area ratio canards/body flap	1.046	
13.0	**Avionics**	575						
			575	0.300	173	X-34 Avionics		
14.0	**Environmental control**	2,421						
			2,421	0.500	1210	Constant % of entry weight	0.021	
						Entry weight	116,471	
15.0	**Payload provisions**	3,500		0.628	1885	Forward, rear Athena attachments	3000	
				0.947	471	*Atlas* mods to attach to aeroshell	500	
16.0	**Range safety**	300		0.500	150	Destruct system		
17.0	**Ballast**	0		0.000	0	None required at this time		
18.0	**Auxiliary systems**	200		0.969	194	Drogue chute	200	
	EMPTY W/O GROWTH	**50,537**		**0.646**	**32659**	CG Location		
19.0	**Growth allowance**	15,161				30 % of dry		
	EMPTY W/ GROWTH	**65,698**		**0.646**	**42470**	***StarBooster* Only w/o *Atlas* or fluids**		
20.0	**Personnel**	0				None		
21.0	**Payload**	30,260		0.874	26456	**Atlas IIA MECO weight**		
22.0	**Propulsion, ABES**	10,133						
22.1	ABES Engines		7,200	0.848	6107	Number of engines	2	
						Unit weight of engine, lb	3600	ABES
								PW6000
22.2	Propellant feed system		780	0.848	662	Boost pumps and lines w/30% margi	DC-9	TSFC = 56
								Thrust 15Kft = 6800 lbs
22.3	Engine mounts & cowin		2,153	0.848	1826	Fairings & Pylons w/30% margin	7200	23 % of engine weight
23.0	**ABES propellant**	10,182		0.864	8796			
24.0	**Residual & unusable fl**	292						

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24.0	**Residual & unusable fl**	**292**					
24.1	RCS		50	0.183	9		
24.2	Subsystems		242	0.209	51		
25.0	**Reserve fluids**	**60**					
25.1	RCS		50	0.183	9		
26.0	**Inflight losses**	**656**					
26.1	Evaportator water supply		625	0.209	131	Constant % of entry weight	0.0054
						Entry weight	116,471
26.2	Helium supply		31	0.183	6		
	ENTRY WEIGHT		**116,471**	**0.743**	**86,481**	**CG ON ENTRY**	
27.0	**Propellant, RCS**	**512**					
			512	0.183	94	Constant % of entry weight	0.0044
28.0	**Main propellants**	**400,700**				ATLAS III propellants	
	GLOW		**517,683**				
29.0	**Startup losses**	**6,096**					
	PRELAUNCH GROSS		**523,779**				
	MECO WEIGHT		**116,983**				
	CRUISE WEIGHT Start		**115,815**				
	LANDED WEIGHT		**109,023**				
	WING AREA		**1,677**			**sq ft**	
	NO JET ENGINE CASE						
	GLOW		497,368				
	MECO WEIGHT		96,668				

AERO	
L/D = 6	6
Drag=Lift/6	
Drag=Weight/6	19,497
Thrust = Drag	19,497
Cd	0.0651
Cl	0.3906
Density 15000	0.0014962
Velocity (ft/sec	486
Velocity (kts)	288
Range (nm)	128
Cruise time (hr	0.444
Startup time	0.05
Go-around	0.25
Total	0.744
10 % margin	0.074
Total cruise time	0.819
TSFC	0.56
Fuel	8,941
Thrust @ 15K	8,800
W/S	65