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VentureStar™...
Reaping The Benefits Of The X-33 Program

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Abstract

Major X-33 flight hardware has been delivered, and assembly of the vehicle is well underway in anticipation of its flight test program commencing in the summer of 1999. Attention has now turned to the operational *VentureStar™*, the first single-stage-to-orbit (SSTO) reusable launch vehicle. Activities are grouped under two broad categories: (1) vehicle development and (2) market/business planning, each of which is discussed. The mission concept is presented for direct payload delivery to the International Space Station and to low Earth orbit, as well as payload delivery with an upper stage to Geosynchronous Transfer Orbit (GTO) and other high energy orbits. System requirements include flight segment and ground segment. Vehicle system sizing and design status is provided including the application of X-33 traceability and lessons learned. Technology applications to the *VentureStar™* are described including the structure, propellant tanks, thermal protection system, aerodynamics, subsystems, payload bay and propulsion. Developing a market driven low cost launch services system for the 21st Century requires traditional and non-traditional ways of being able to forecast the evolution of the potential market. The challenge is balancing both the technical and financial assumptions of the market. This involves the need to provide a capability to meet market segments that in some cases are very speculative, while at the same time providing the financial community with a credible revenue stream. Furthermore, the market derived requirements need to be assessed so as not to impose unnecessary requirements on the vehicle design that add unreasonable cost to the development of the system, yet provides the right capabilities for new markets that could be triggered by dramatically lower space transportation prices.

Introduction

It has been widely recognized that the United States faces a critical national space transportation challenge in the coming years. America's costs for space access consume so many resources including budget, talent, and facilities, that insufficient resources remain to undertake the bold, aggressive and exploratory endeavors that the National Aeronautics and Space Administration (NASA) and our nation want and should be pursuing to advance our technologies and science. Many valid space missions, experiments, explorations, and commercial endeavors are not even planned simply due to high launch costs. To enable NASA to conduct better, faster, and cheaper programs in exploration, research, and science, and to enable the commercial sector to flourish in space endeavors, we must significantly reduce the cost of space access.

Background

NASA led an investigation during 1993 which has come be known as the Access to Space study. Three major alternatives, along with multiple sub-options, were addressed in the study as follows: (1) Retain and upgrade the Space Shuttle; (2) Develop a new expendable launch system with current technology; and (3) Develop a new Reusable Launch Vehicle (RLV) system using advanced technology. The study concluded that the most beneficial option is to develop and deploy a fully reusable, single-stage-to-orbit (SSTO) pure rocket launch vehicle fleet incorporating advanced technologies. The study thus recommended that the development of an advanced technology single-stage-to-orbit rocket vehicle become a NASA goal, and that a focused technology maturation and demonstration program be undertaken. In response to this recommendation, NASA undertook a ground-based technology effort and initiated planning for a series of flight demonstration projects, culminating in the selection on July 2, 1996 of

an industry team led by Lockheed Martin Skunk Works (LMSW) to build and flight test a sub-scale, high-fidelity flight demonstrator called the X-33. This partnership between NASA and industry is aimed at radical improvements in launch system cost and performance. Six parameters are being focused on: reusability, operability, reliability, safety, mass fraction, and affordability. The design and development of the X-33 flight vehicle and ground system will not be discussed in detail in this paper, but can be characterized as progressing satisfactorily in anticipation of initiating the flight test program in the summer of 1999. The goal of the X-33 demonstration program is to reduce the technical and programmatic risks sufficiently to enable a decision around the end of the decade to proceed with the private sector development of an operational RLV system which Lockheed-Martin calls *VentureStar*™.

Program Description

The X-33/*VentureStar*™ program is generally described in three phases. Phase I of the program refers to the period during which multiple, fundamentally different RLV concepts and associated sub-scale demonstrators were analyzed by competing industry teams. Phase II of the program commenced with the firm decision to proceed with the development and flight test of the X-33 vehicle and the selection of the LMSW team to lead the activity. As shown in Figure 1, the activities in preparation for the *VentureStar*™ are being conducted in parallel with the design, development and flight test of the X-33 vehicle.

These activities include the evolution of the *VentureStar*™ design to enable confidence that a viable concept for an operational RLV has been found, as well as the maturation and demonstration of key technologies through a ground-based activity. A sub-scale composite liquid oxygen tank will be built and tested to validate the design concept and demonstrate that the selected composite material is compatible with oxygen. Full-size components of the *VentureStar*™ linear aerospike engine will also be built and tested. Lessons being learned during the build and test of the X-33 are already being incorporated into the *VentureStar*™ systems definition. Major risks to the *VentureStar*™ have been identified, and reduction of these risks are being rigorously tracked in this timeframe. Marketing and business analysis and planning are also part of the Phase II program. All of these Phase II activities are focused on preparation for an end-of-the-decade decision to proceed into Phase III, the full-scale development, fight test and revenue service of the privately-financed and operated *VentureStar*™.

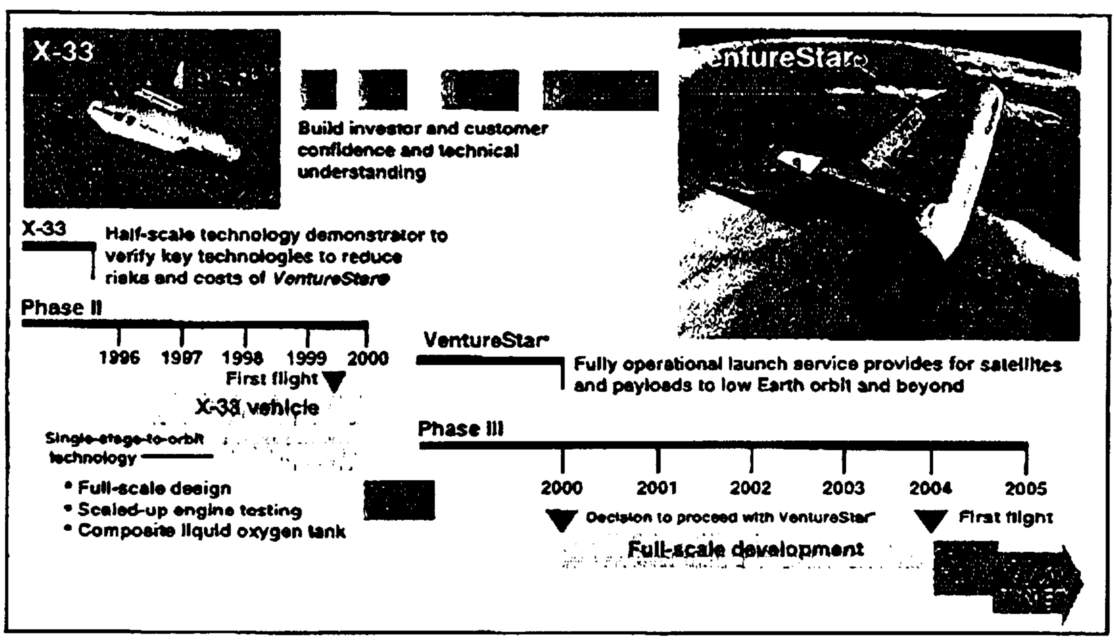


Figure 1 -- X-33/*VentureStar*™

Vehicle Description

The *VentureStar™* configuration depicted in Figure 2 is being matured in parallel with development and test of the X-33.

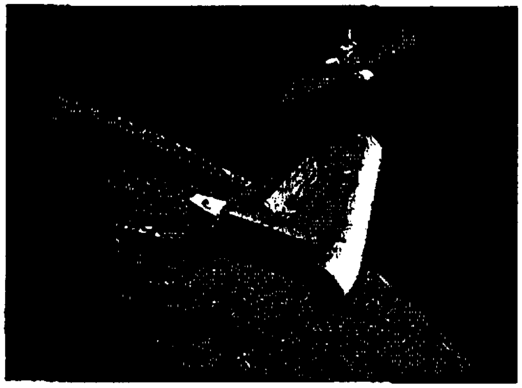


Figure 2 -- *VentureStar™*

Prior to their competitive selection to build the X-33, LMSW and their competitors developed conceptual designs of an operational RLV upon which to base their proposals for building the X-33 sub-scale demonstrator and with which to identify the technology risks which the program needed to reduce. Although the X-33 has been described as a 53% scale prototype of the *VentureStar™*, it was recognized from the outset that the operational RLV design would likely undergo significant modifications as a result of continuing design work and as a result of lessons learned from the X-33 experience. The current *VentureStar™* concept depicted in Figure 2 retains many of the features of the original conceptual design, but is significantly improved over the original concept. Further changes can be anticipated as the vehicle system design and sizing matures and the business plan evolves. However, even though specific design and configuration details have changed and will continue to change over the next year, the principal vehicle features remain unchanged.

Some of the significant vehicle features are shown in Figure 3. The basic shape of the vehicle is a lifting body in which the hypersonic lift-to-drag ratio needed to satisfy mission requirements is provided by the body shape itself. The relative large radii of curvature, flat bottom, and low planform loading have the combined effect of producing a somewhat less severe aeroheating environment as compared to other configuration options. This enables the use of a robust metallic thermal protection system (TPS), which also serves as the aeroshell, over both the leeward and windward sides of the vehicle. These materials (e.g., Inconel and titanium) are durable, can fly through rain, require no water-proofing, provide lightening protection to the composite structure beneath, and require minimal servicing between flights. Their mechanical attachment allows quick changeout of individual TPS panels if required. Hotter areas such as the nose, leading edges of the canted fins, etc. will still require refractory composites such as carbon-carbon (C/C) or carbon silicon-carbide (C/SiC).

Lightweight composite tanks and primary structure are key technologies to enable a SSTO type of vehicle. The graphite epoxy hydrogen and oxygen propellant tanks must also carry the vehicle loads, including the aerodynamic loads transmitted to the tanks by the TPS/aeroshell. These tanks have to be lightweight, leakproof and durable for hundreds of flights. Their

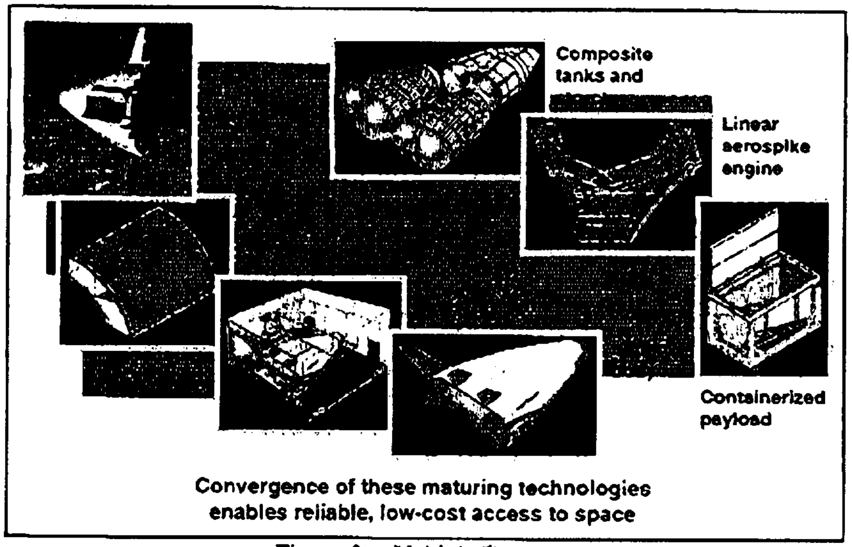


Figure 3 -- Vehicle Features

dimensions dictate the need for either the largest autoclave ever built or the use of some out-of-autoclave cure process such as e-beam curing. Their design and manufacture constitutes one of the greatest technology challenges to the program. Similarly, the thrust structure and other structural components will have to simultaneously be light, strong and durable.

Another key feature of the *VentureStar*™ is the use of a linear aerospike engine as illustrated in Figure 4. The linear aerospike engine for *VentureStar*™ has been designated the RS-2200. Propellants are liquid oxygen and liquid hydrogen. This engine concept has never flown before, but underwent extensive ground testing in the early 1970's.

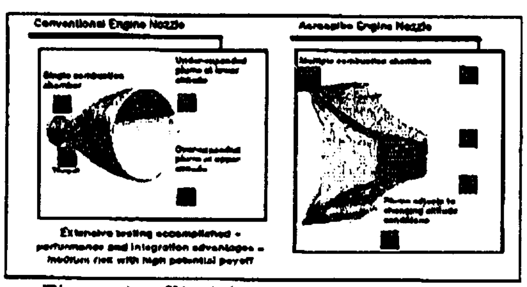


Figure 4 -- The Linear Aerospike Engine

In this concept, the plume from multiple combustion chambers expands against a ramp on one side and against the free stream on the other side. This has a significant performance advantage over the conventional bell engine design because of higher nozzle efficiency. A bell engine's exhaust plume, at sea level, is pinched by the high ambient atmospheric pressure, reducing the efficiency. As the vehicle rises, the conventional engine becomes efficient at its design altitude, but as the rocket ascends past its design altitude, the exhaust plume flares and again becomes inefficient, this time due to overexpansion. In contrast, the aerospike engine is inherently altitude compensating, with the plume continuously expanding in a near-optimum fashion. This engine concept offers several advantages including high mission-averaged specific impulse (I_{SP}), while allowing the use of a simple gas generator (open) cycle, shorter engine, no gimballing required for thrust vectoring, and modular component development.

The *VentureStar*™ system must feature aircraft-like operations, which necessitate the need for highly automated processing and a sophisticated vehicle health management (VHM) system. Typical turnaround times of the vehicle are envisioned to be on the order of a week, with a surge capability of only a few days when required. To achieve this kind of operational performance, the vehicle has to be designed to be operable from the start. Typically, launch vehicles in the past have been designed only to achieve the necessary flight performance, with operational considerations given little or no considerations during the design process. This vehicle system has to be designed to operate within a well-understood performance envelope such that, if no design limits were exceeded on a given flight, minimal processing is required before the vehicle is refueled and launched again.

<u>Operational Features</u>

The reusable SSTO concept offers a number of operational advantages when compared to conventional multi-stage expendable and partially reusable systems. As shown in Figure 5, there are no throw-away parts such as spent stages, interstages, or empty propellant tanks.

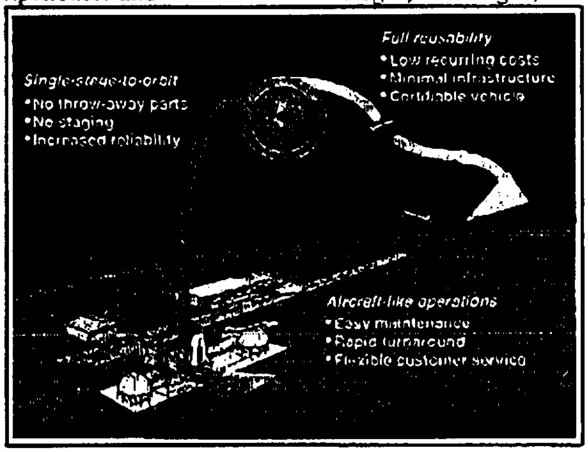


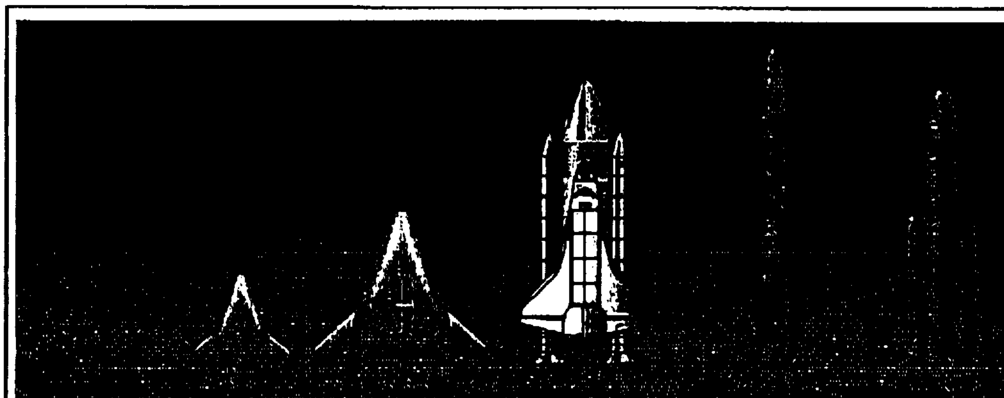
Figure 5 -- Breaking the Cost Barrier

Accordingly, there is no requirement to necessarily launch over open water or remote areas. However, prudent decisions will be made to ensure crew and public safety. There are no staging or propulsion events such as engine starts, each of which introduces another possibility of failure, thereby reducing reliability. The *VentureStar*™ system will be designed for significantly improved reliability over any other launch system in operation today, a requirement driven by the business consideration of not wanting to lose an expensive capital asset, either the vehicle or its valuable payload. An additional reason for high reliability is the recognition that, although initially *VentureStar*™ will deliver satellites and payloads, it will later carry humans to orbit. The system is being designed as a fully reusable system which can be serviced for low recurring costs, using minimal infrastructure and small work crews. A primary goal of the program is to produce a system with aircraft-like operations. The revenues to justify the investment cannot be generated with the vehicle spending extended periods on the ground. It must be capable of providing flexible service to the customer.

The modularized payload concept is a key element of having a highly operable vehicle. This enables payloads to be integrated into the mission module off-line from the vehicle processing. The goal is for this standard mission module vehicle interface to be as nearly identical as possible, regardless of the payload. This permits the payload to be quickly inserted for the next flight and for payloads to be capable of being changed out quickly, should this be become necessary. Of course the payload will have to be located such that the *VentureStar*™ can be trimmed, controlled and landed with or without the payload installed.

Vehicle Sizing

Vehicle sizing and delivery performance have not been finalized. Figure 6 displays the approximate size and performance compared to other current launch systems, as well as to the X-33 sub-scale demonstrator. The vehicle is expected to weigh approximately 2.6 million pounds at liftoff, of which about 90% is propellant. It will be capable of carrying in excess of 50,000 pounds to low Earth orbit when launched due east. This corresponds to 25,000 pounds to the International Space Station. Geostationary transfer orbits are achieved with the use of an upper stage. A dynamic payload envelope of 15 x 15 x 53 feet is planned.



Weight	273K lb	2.6M lb	4.5M lb	1.6M lb	1.6M lb
Length	69 ft	144 ft	184 ft	188 ft	169 ft
LEO Payload (100 nm/28.5°	N/A	> 50,000 lb	51,000 lb	46,000 lb	39,600 lb
Bay size	N/A	15 x 53 ft	15 x 60 ft	13.5 x 48 ft	14.7 x 49.7 ft
Propulsion	2 J-2S aerospikes	7 RS2200 aerospikes	3 SSME bells + 2 solids	6 single-chamber liquids	1 bell + 2 solids

Figure 6 -- *VentureStar*™ Comparison

X-33 Contributions to *VentureStar*™

The X-33 development and flight test program help build credibility for *VentureStar*™ in several important ways. Before the vehicle manufacturing is even complete, lessons have already been learned which will be applied to the *VentureStar*™ design and manufacturing processes. Design improvements are in such areas as obtaining better structural efficiency, improving body pitching moments, improving transonic flow, improving control effectiveness, and moving the center of gravity forward. Potential improvements in manufacturing processes include thermal protection system attachment schemes and support structure. Examples of contributions expected from the flight test program include thermal performance and structural integrity of the thermal protection system, better understanding of flight environments, autonomous flight management from launch, entry, approach and landing through rollout and vehicle safing, and simplified ground operations.

Forecasting the Market

While the satellite side of the space industry has been experiencing dynamic and sweeping changes, the space transportation side has been evidencing evolutionary progress. The satellite builders, operators and service providers continue to push for dramatic cost reductions in space access, particularly with the new systems that require dozens of satellites to meet their operational capabilities.

Today, *VentureStar*™ has a unique opportunity. While the technologies for X-33 are validated, the design of the full scale vehicle is being matured. LMSW is striving for a new market-driven space transportation system for the 21st century. Figure 7 depicts the *VentueStar*® program design philosophy that focuses on discerning both the current and future market requirements, filters in the business requirements and is continually iterated with the technical design of the vehicle and system performance. As technically challenging as SSTO is, the system must also be built with the capacity for carrying sufficient payload to meet the projected market capture.

The NASA-Lockheed Martin X-33 Cooperative Agreement, under which the program is proceeding, has set forth multiple goals. In addition to achieving the technical validation of the concept through the X-33 flight test program, and demonstrating aircraft-like operations on the ground, NASA is striving to reduce the amount of technical risk on the development of the full scale system to enable private financing of the venture. To successfully obtain this financing, a business proposition must be developed that provides satisfactory returns to the investors. Secondly, since NASA is investing almost $1 billion in the X-33 Phase II program, they have identified three primary objectives: significantly reducing their future

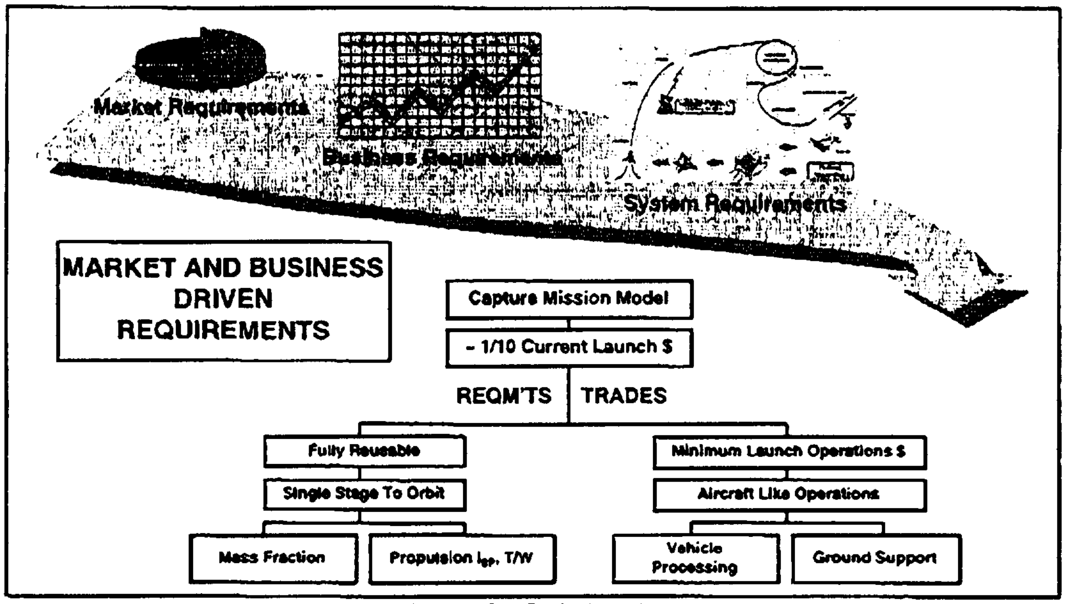


Figure 7 -- *VentureStar*™ is Requirements Driven

space transportations budget, specifically the costs for space station operations and logistics; regaining technology leadership; and expanding the overall space market both through growth of currently markets and enabling new markets.

The 1990's have been an extraordinary time of change for the relatively young space industry and in particular the commercial communications business. We have seen a dramatic reduction in the cost and cycle time of building satellites. The most significant aspect of this has been evident in the emergence of the use of small spacecraft in Low Earth Orbit (LEO) to satisfy telecommunications system needs. Concepts such as Iridium, Globalstar, Skybridge and others are offering constellations of satellites to meet global communications. This has highlighted the continuing need for large lift capability for deployment of these systems to reduce the time to market for these services.

In contrast to the small satellites for these LEO systems, recent forecasts continue to show the largest segment a growth for the geostationary market segment is in the "heavy" class or greater than 9,000 pounds. Discussions with satellite manufacturers continue to strive to put more transponder, power and fuel on the limited "real estate" in geosynchronous orbit.

1996 represented the first year that commercial space expenditures exceeded government expenditures. This trend continued to grow in 1997. The space telecommunications market is experiencing unprecedented growth and it is estimated that in the next ten years there could be 1500-2000 satellites delivered to space. The recent incident with the Galaxy Spacecraft shutting down millions of pagers and financial transtions only emphasizes that as the world increases its demand on space, so must the systems be robust enough to deal with failures.

Obviously, not all these proposed projects will become viable in the marketplace, and we've already seen several major mergers of projects to date. LMSW is currently in the process of translating the dynamics of the marketplace into a realistic projected flight rate for our business plan.

To date it appears that the space market has been relatively price inelastic in that the enormous growth that is currently occurring in telecommunications is happening despite the fact that space transportation prices have not significantly fallen. This probably has more to do with the fact that the rate of growth of communications services has experienced even greater growth than the satellite side. This is not to imply that the customers aren't looking for low space delivery prices. In fact, price does seem to be the critical factor in the selection of the launch system. This is meant only to underscore that the market is experiencing unprecedented growth without the concurrent reduction in launch prices.

There are a number of people who do believe that there is an elastic market when it comes to space business and the high cost of space access has kept many would-be entrepreneurs and businesses out of the market. Consequently, a challenge is how to build a space transport system to meet future space applications, without adding capabilities that significantly burden the financial side of the equation. Figure 8 shows current and potential market segments.

To obtain the financing needed, the business case must be based on a credible revenue stream in a reasonable timeframe. At the same time, a next generation space transporter must ensure that the design does not preclude the development of new space applications, systems and markets that a low cost system will enable.

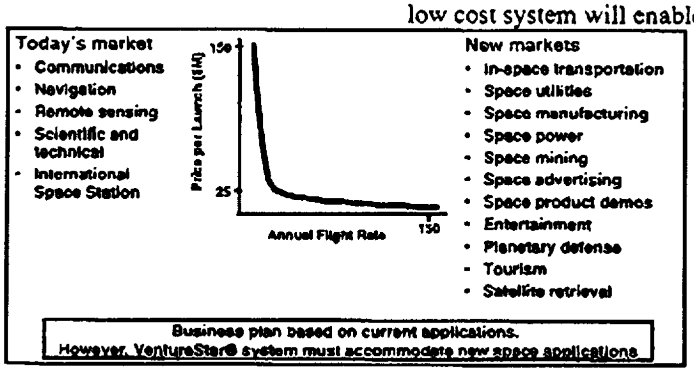


Figure 8 -- Space Market Segments

Operational Elements

As the dynamics of the market is shifting, so are the destinations of these new systems. In the past, if a company were launching commercial communication satellites the launch system only needed to deliver its customers to an equatorial geotransfer or geosynchronous orbit at 2,300 miles. Weather and remote sensing satellites have been traditionally polar orbits. The new Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) commercial communication systems that are being proposed today are being designed to operate at a variety of altitudes and inclinations. Figure 9 presents a look at the currently proposed systems and a forecast of potential systems that might be flown in the post 2004 timeframe and the inclinations at which these systems will operate.

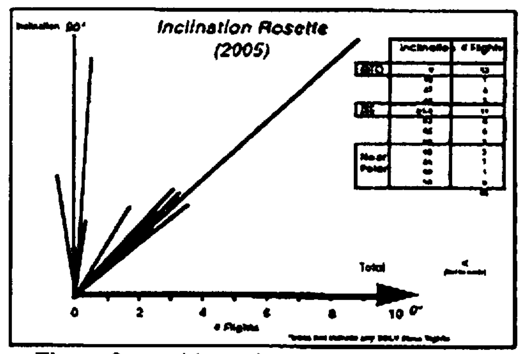


Figure 9 -- Addressable Market Inclination Rosette

This challenges the operations as a greater range of launch azimuths must be met than was previously required to serve the commercial space market.

Spaceports

LMSW has recently begun the selection process for potential spaceports. A very streamlined approach to this to minimize operational costs and maximize turn-around time has been emphasized. The spaceport facilities will include one or two launch pads, a 10,000 foot runway, and fuel production plants, a translating shelter (similar to an aircraft hanger for vehicle processing), an off-line payload processing facility, and an operations control center and business operations center. At least at the initial site a facility for vehicle assembly will also be required. This approach will be validated with the X-33 flight demonstrator. Figure 10 is the conceptual design for a *VentureStar*™ spaceport.

Figure 10 -- *VentureStar*™ Spaceport Concept

Current plans call for the selection of two sites as it is not anticipated that the full scale *VentureStar*™ vehicle will be able to be transported on a carrier aircraft. Consequently, at least one alternate landing site will be identified from which a launch capability will also be needed.

The assessment of potential spaceports began in January of this year. In July 1998 a qualification package was released that provided the minimum technical requirements for consideration of a domestic spaceport. A critical factor in assessing potential spaceports is the impact or accessibility it will have to contributing to market share. *VentureStar*™ is on a path to have a preferred configuration by the end of this year, thereby enabling a site or sites selection by the end of 1999. The operational spaceport(s) will be needed to support *VentureStar*™ in 2004.

Runway-to-Pad-to-Orbit

In the early 1980's the French took a bold step forward with their decision to launch the Ariane launch vehicle from a remote facility in French Guyana. This approach provided both an extremely attractive launch site from the customer's perspective of payload to orbit, as well as a new approach to vehicle and payload processing. Modeled after the shipping industry, Arianespace created a containerized approach to enable efficient operations from a remote site. Twenty years later, it's time to again move forward.

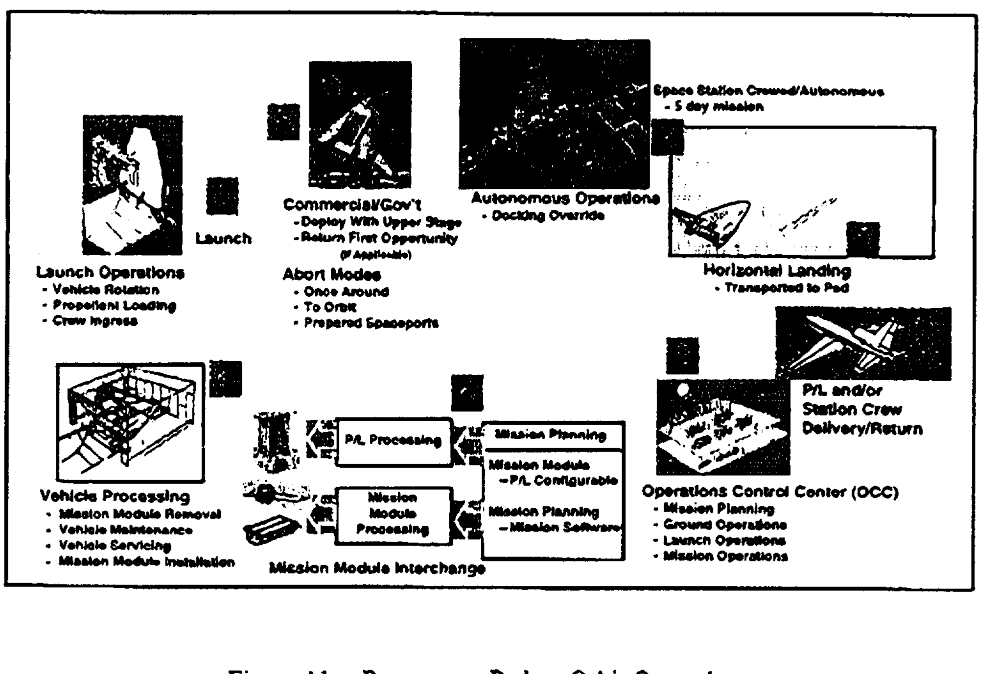


Figure 11 -- Runway-to-Pad-to-Orbit Operations

VentureStar™ operations are being designed to emulate the aircraft side of the business taking a full systems approach. Figure 11 represents *VentureStar's*® Operations Concept.

While routine maintenance is being performed on the vehicle, the payloads are being processed in a separate facility. All accommodations for the specific needs of the payloads (including upper stages) will be accommodated in the mission module and then the mission module will be a standard interface to the *VentureStar*™ system. Some mission modules may be customized for a particular use, such as ISS logistics or crew transfer. This module will then be installed in the vehicle approximately 24 hours before take off.

Due to the design of the mission module, late access to payloads of up to 2 hours before launch will be easily accommodated. The system has the capacity to prepare up to 40 payloads a year. The current nominal forecasted turnaround time for the vehicle is seven days, with a surge capability that will meet a three day or less turnaround time.

Figure 12 represents the typical turnaround time anticipated for *VentureStar*™.

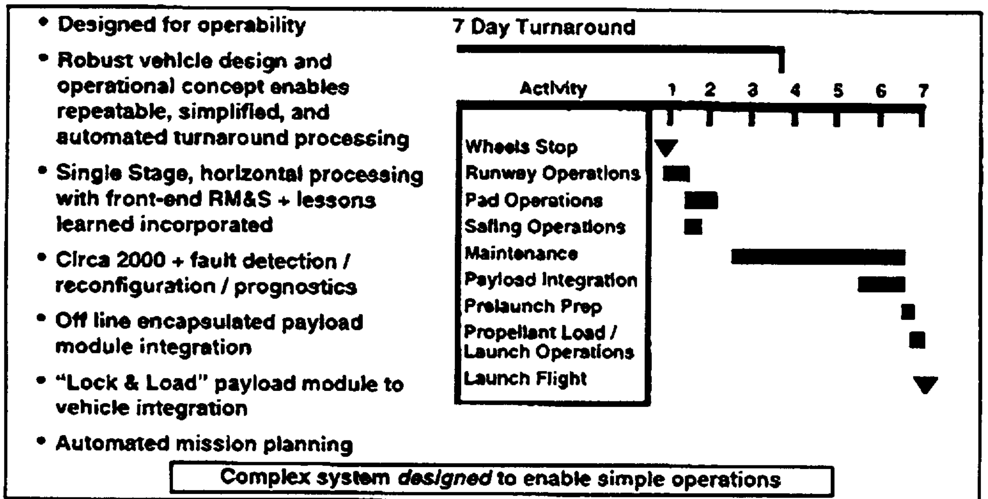


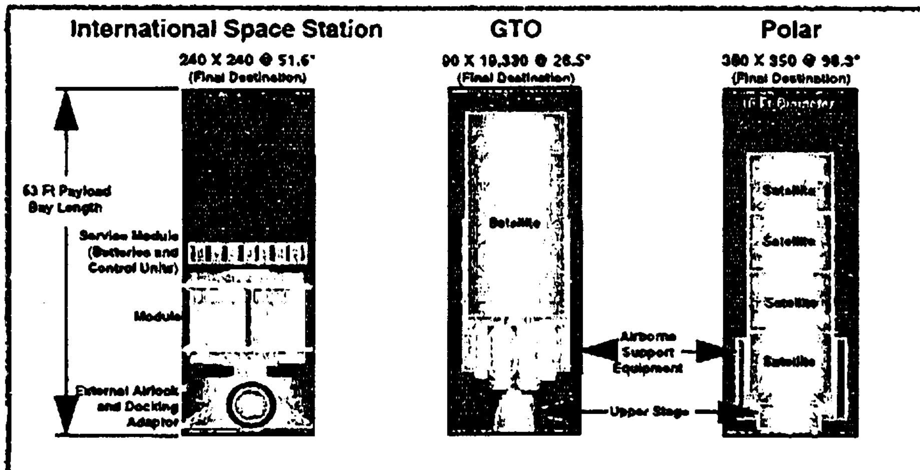
Figure 12 -- *VentureStar*™ Operations - 7 Day Turnaround

Understanding the needs of the payload customer community in terms of weight, volume, interface requirements, launch and landing environments and standard vs. optional services is a critical part of the system design effort. Figure 13 shows several representative payloads in the *VentureStar*™ payload bay.

X-33: Countdown to *VentureStar*™

Current plans call for a go-ahead decision for *VentureStar*™ at the beginning of 2000. The goal of *VentureStar*™ is to provide the next generation space transportation system. Dramatic reduction in the price per pound delivered to orbit coupled with operational flexibility afforded by rapid turnaround of the system, should have an enormous impact on space business in the future.

This is why X-33 flight test program is so pivotal. It will not only provide the requisite confidence in the technical feasibility of a fully reusable single-stage-to-orbit system, but performance on the X-33 program provides a benchmark to potential investors and customers that the vision for *VentureStar*™ is achieved.



	International Space Station	GTO	Polar
Mass to orbit (lbs)	25,000	18,000	11,200
Packaged length (ft)	~25	~51	~47
Packaged diameter (ft)	≤ 15	≤ 15	~13

Figure 13 -- *VentureStar*™ Payload Goals