SPACE STATION ACCESS WITH *VentureStar*™

Walt Faulconer and Don Randolph
Lockheed Martin Astronautics, Reusable Launch Systems
P. O. Box 179 MS DC3005
Denver, CO 80201
(303) 971-9778
walt.faulconer@lmco.com
http://www.venturestar.com

Abstract

The *VentureStar*™ reusable launch vehicle (RLV) will dramatically reduce the cost of access to the International Space Station (ISS). It will begin servicing the ISS starting in mid-2004 and become the primary space transportation provider by 2006. This paper discusses the ongoing development of *VentureStar*, Space Transportation System (STS) to *VentureStar* transition plans, and how *VentureStar* will service the space station.

INTRODUCTION

In 2004 a new era in space transportation will begin that will open new markets, enable the United States to regain its leadership role in space launch, and provide preeminent space transportation for civil, commercial and Department of Defense (DOD) customers in the 21st century. The new, fully reusable, Single Stage to Orbit (SSTO) *VentureStar* system (shown in Figure 1) will drastically reduce the cost of access to space and to the ISS.

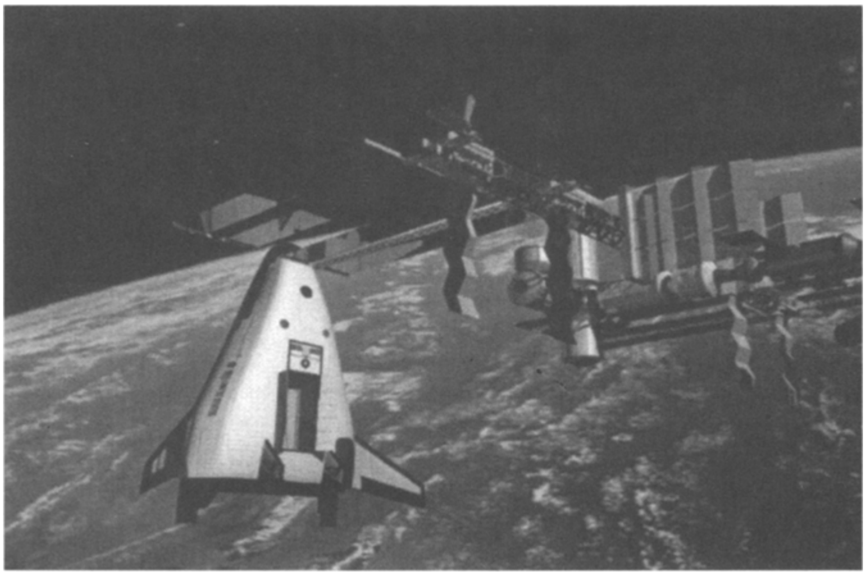

FIGURE 1. The *VentureStar* Will Fly Directly to the Space Station.

As compared with the existing market of expendable based launch vehicles, *VentureStar* will provide an order of magnitude improvement in cost to orbit. The goal of realizing launch costs of $2205 per kg or less can be realized by utilizing a totally reusable system, using a single stage to orbit vehicle and implementing "aircraft" like operations.

The current RLV program consists of three phases, as shown in Figure 2. (Baumgartner 1997)

Phase I: Contracts were awarded to Lockheed Martin, McDonnell Douglas, and Rockwell International in 1995 to develop an operational RLV concept, a X-33 preliminary design, and validate key SSTO technologies.

CP420, *Space Technology and Applications International Forum-1998*
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DOE CONF-980103 © 1998 The American Institute of Physics 1-56396-747-2/98/$10.00

Phase II: Lockheed Martin was awarded Phase II on 1 July 1996. Phase II, currently in progress, has three elements with a period of performance from 1 July 1996 to 31 December 1999:

1. Design, fabricate, and fly an X-33 SSTO demonstrator to validate inflight technologies
2. Ground test those SSTO technologies which cannot be flown on the X-33
3. Continue design and business development of the operational *VentureStar* System.

Phase III: *VentureStar* System full scale operational development is scheduled to begin 1 January 2000. *VentureStar* revenue service is scheduled to start mid-2004.

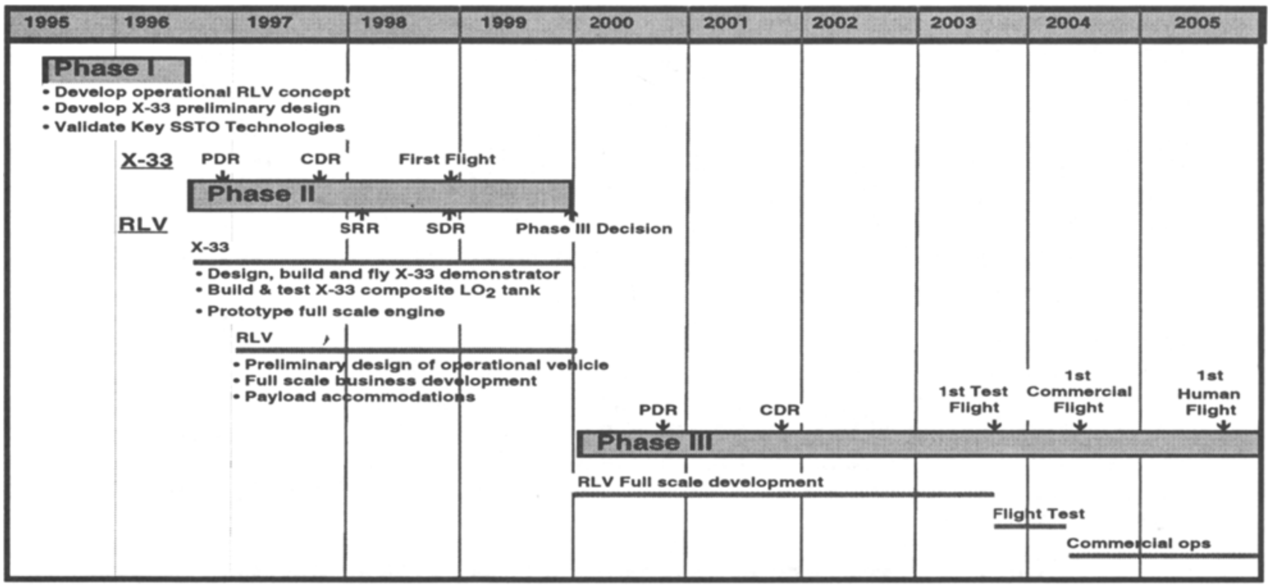
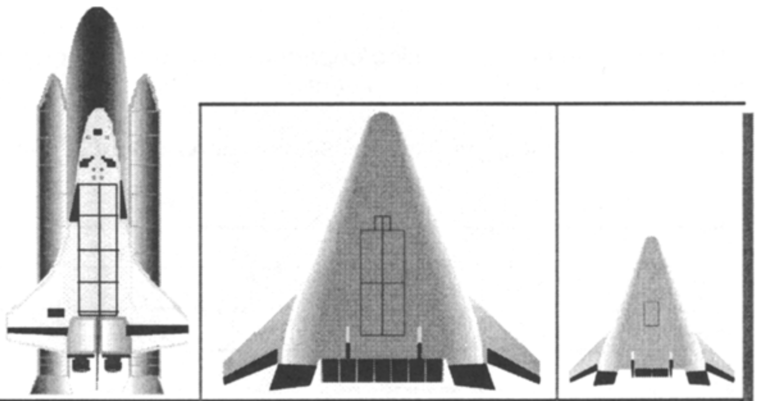


FIGURE 2. RLV Program Schedule.

VentureStar is being designed as a low cost, simple, highly reusable, autonomous space transportation system. As a low cost, efficient transportation system, *VentureStar* will provide transport to and from LEO but will not be a destination/platform for science. People will be carried on board when there is a need to transport them somewhere, i.e., the ISS. A crew will not be required to operate the vehicle. *VentureStar* will provide rapid airline like turnaround operations and maintenance.

The Vehicle is a liquid hydrogen/liquid oxygen fueled SSTO lifting body which is powered by seven linear aerospike engines. The mission concept includes a vertical takeoff and horizontal landing single stage to orbit space transportation system sized to service both ISS and the commercial GEO satellite market. *VentureStar* service capability provides 11,340 kg of payload performance direct to ISS (459 km @ 51.6°) or 25,401 kg to LEO (185.2 km @ 28.5°), as shown in Figure 3. (Mattingly 1997).



Feature	*Shuttle*	*VentureStar*	*X-33*
Gross Lift Off Weight	2,041,000 kg	1,192,000 kg	123,956 kg
Length	56 m	39 m	20 m
Width	24 m	39 m	21 m
Payload to LEO	23,100 kg	25,400 kg	N/A
Payload Bay Size	4.6x18.3 m	4.6x15.2 m	1.5x3 m

FIGURE 3. Comparison of STS, *VentureStar* and X-33 Flight Demonstrator.

VentureStar has a fully removable cargo carrier with a 4.6 m diameter x 15.2 m long internal dynamic envelope to allow off line payload processing and rapid turnaround. The cargo carrier is being designed to carry commercial satellites and the ISS hardware servicing elements.

STS TO *VentureStar* TRANSITION

The first *VentureStar* test flights are planned to begin in late 2003, with the first cargo flights to ISS beginning in 2004. Certification of *VentureStar* for human flight and beginning of crew rotation flights to ISS will begin in late 2005. The transition from STS will be completed by the end of 2006.

ISS SERVICING BASELINE

The current baseline for the STS to service the ISS includes the following requirements: (DAC5, 1997)

- ISS altitude range (2004 - 2012): 370.4 - 459.3 km @ i = 51.6 °
- Provide 180 microgravity days/year in 30 day increments
- 4 crew/rotations/year ~ 90 day centers (3 crew up/down)
- ~ 44,452 kg pressurized logistics
- ~ 7711 kg Unpressurized logistics
- Change out crew return vehicle (CRV) once every three years

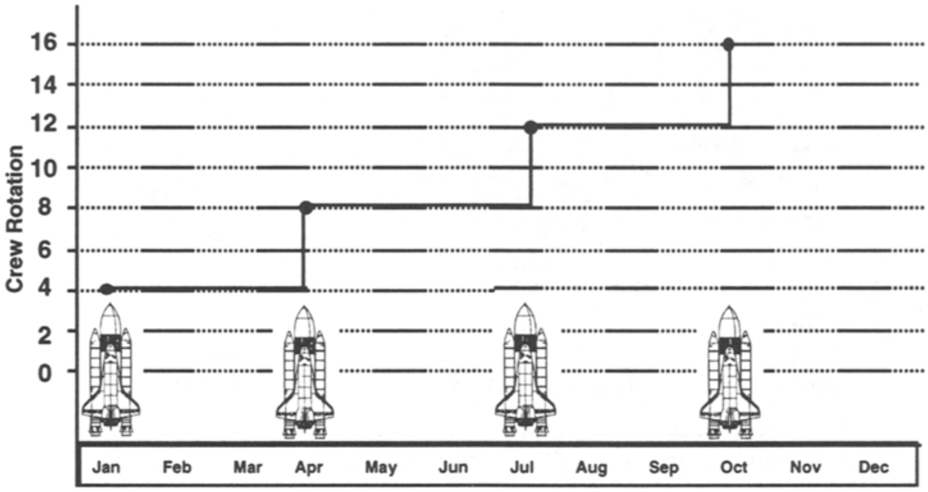
STS Servicing Concept

To achieve these requirements, the STS operates with the following servicing concept (as illustrated in Figure 4):

- 5 annual flights, STS direct to ISS
- 9 day mission
  - ~ 29 hours from launch to dock at ISS
- Crew Accommodations
  - 7 person crew (4 STS crew, 3 ISS crew)
  - 4 STS & 3 "ISS" crew members reside on STS while docked at ISS
  - STS is "self sufficient" while docked at ISS
- Logistics Operations
- - pressurized logistics is transferred to/from ISS at the International Standard Payload Rack (ISPR) level while docked to ISS
  - STS crew performs EVAs to replace ORUs while at ISS

- ISS Operations
  - ISS maneuvers to STS docking/departure attitude from Torque Equilibrium Attitude (TEA) and back for each docking/departure event

- **Four (4) crew rotations/year, approx. 90 day centers (3 up / 3 down)**



- **Approx. 115K lbs total annual cargo (pressurized & unpressurized)**

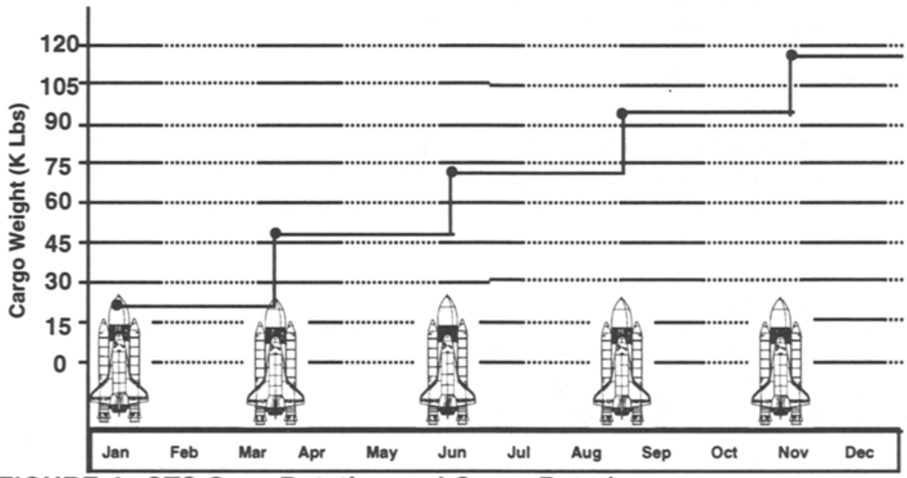


FIGURE 4. STS Crew Rotation and Cargo Rotation.

VentureStar ISS SERVICING BASELINE

The *VentureStar* ISS servicing architecture developed during Phase I was based on *VentureStar* meeting ISS servicing requirements in a method identical to STS. This method was adopted in order to minimize the impact to ISS operations.

This concept included the following features:

- 15 annual flights, *VentureStar* direct to ISS
  - 9 pressurized logistics flights
  - 4 crew rotation flights
  - 2 unpressurized logistics flights
- 5 day mission
- Crew Accommodations
  - 4 person crew (all ISS crew members)
- Logistics Operations
  - pressurized logistics is transferred to/from ISS at the ISPR level while docked to ISS
  - 1 ULC transferred to/from ISS while docked at ISS

- ISS Operations
  - ISS maneuvers to *VentureStar* docking/departure attitude from TEA and back for each docking/departure event

The ISS servicing support equipment includes the following, as illustrated in Figure 5:
- Crew carrier
- modified (2 bay) mini Pressurized Logistics Module (mPLM)
- Unpressurized Logistics Carrier (ULC)

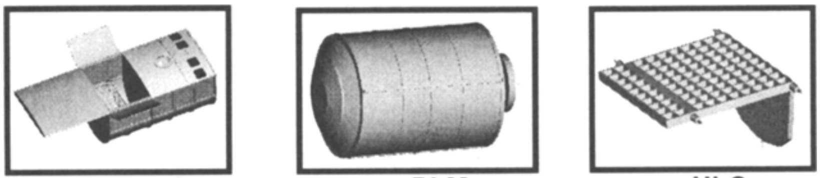


FIGURE 5. *VentureStar* ISS Servicing Hardware Elements

VentureStar ISS SERVICING STUDY

Lockheed Martin is studying ways to improve the *VentureStar* ISS servicing architecture based on continual refinement of ISS requirements and the RLV design. ISS servicing logistics and operational requirements for the STS are designed around the STS capabilities and limitations. The purpose of the study was to determine the true ISS servicing requirements (not STS capabilities) and develop an optimized *VentureStar* ISS servicing architecture. Three key architectural alternatives were defined and studied.

1. Direct Flight: *VentureStar* delivers crew and cargo direct to ISS (i.e., STS or baseline RLV concept)
2. Upper Stage: *VentureStar* delivers upper stage (space tug) and crew/cargo to Low Earth Orbit (LEO-100 nautical miles), upper stage transfers crew/cargo to ISS
3. Hybrid: *VentureStar* delivers crew direct to ISS, VentureStar delivers upper stage and cargo to LEO, upper stage transfers cargo to ISS.

Preliminary evaluations indicate the "Direct Flight" architecture is the best using mission complexity and mission cost as discriminators. The "Upper Stage" architecture is no longer under evaluation due to lack of abort for crew missions. The "Hybrid" architecture is still under consideration to deliver cargo via upper stage and crew direct with *VentureStar*.

An assessment was performed for benefit cost sensitivities on each architecture with respect to annual flight rate. An optimum annual *VentureStar* ISS servicing flight rate of 8 to 10 was identified by considering minimizing micro gravity window perturbation (fewer annual flights best) and ISS servicing flexibility (more annual flights best), as shown in Figure 6. Study results indicated that reducing the annual flight rate from 15 to 8 would require a 16% larger *VentureStar* Gross Liftoff Weight (GLOW) to provide the additional performance to ISS (does not include servicing hardware and operations optimization). In addition, an annual ISS servicing flight rate of 8 to 10 could be achieved without upsizing the *VentureStar* through ISS servicing hardware tare weight reduction and operational improvements.

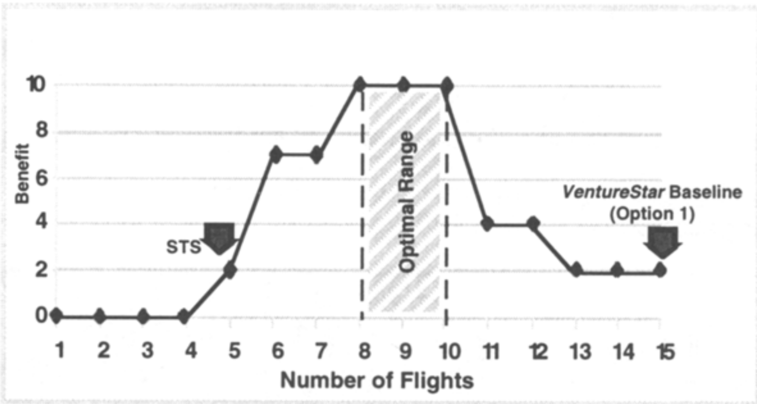


FIGURE 6. ISS Annual Service Rate.

The mPLM used by STS for pressurized logistics transfer to the ISS is a 4 bay (16 ISPR racks) aluminum module and was not optimized for weight because of the STS performance capabilities to ISS. The *VentureStar* baseline requires a 2 bay mPLM due to performance limitations. Current studies are assessing concepts for a composite 3 bay mPLM which has more logistics capability than the 2 bay at a reduced weight.

The *VentureStar* baseline crew carrier concept was developed in 1995 with the groundrule to minimize development cost and utilize existing hardware to the maximum extent possible. The concepts developed in 1995 were all based on using a modified mPLM for the crew carrier. This baseline crew carrier is inefficient in that it delivers crew only, no cargo, and is mated inside the removable *VentureStar* cargo carrier resulting in an inefficient structural design. Current studies are focused on integrating the crew carrier with an ISS unique cargo carrier using composite construction to minimize tare weight and maximize crew/cargo capability.

A key driver to crew carrier design is mission duration which impacts crew accommodations and system size. The baseline *VentureStar* servicing mission is 5 days, with approximately one day from launch to dock at ISS, 3 days at ISS and 1 day return to earth. This timeline is being reviewed to identify operational improvements that may significantly reduce the mission duration. For example, ...(6 hours up, 2 hours down, 12 (TBD) hours to swap mPLM or ULC).

The STS mission duration for ULC flights is approximately 7 days. The STS crew performs On Orbit Replaceable Unit (ORU) replacement via EVAs while the STS is docked to ISS to reduce microgravity perturbations from two serial perturbing events (STS docked to ISS and ISS EVA). The proposed *VentureStar* concept is to deliver a 1/2 size ULC simultaneously with the crew four times a year involving only a one day stay at ISS. This concept allows the ULC to be swapped at ISS in parallel with crew handover. The reduced mission stay allows the incoming crew to live on ISS not the *VentureStar*, minimizing crew carrier crew accommodations. The short mission stay will allow the ISS crew to perform ORU EVAs on their own schedule versus having to perform them while the *VentureStar* is docked thereby eliminating microgravity and crew operations impacts.

Additional benefits include a reduction of two flights in the annual flight rate and an increase in operational flexibility. This increased flexibility is a direct result of delivering logistics four times per year compared to the STS rate of one time per year. By delivering four times per year, on orbit latency is reduced and flight manifest flexibility is increased.

The baseline *VentureStar* servicing concept for pressurized cargo delivers a two bay mPLM nine times a year to ISS with a five day mission duration. The mPLM is transferred to the ISS berthing port where mPLM ISPR racks and loose equipment are transferred to/from ISS. Then the mPLM is transferred back to the *VentureStar*. This process ties up *VentureStar* for a total of 45 on orbit days per year delivering pressurized ISS logistics alone, impacting the ability of *VentureStar* to perform other missions. Current studies are investigating reducing the time required to transfer pressurized logistics to ISS by swapping out mPLMs utilizing the Space Station Remote Manipulating System (SSRMS) while docked at ISS rather than having the crew transfer International Standard Payload Racks (ISPR) by hand. This concept allows the mPLM to be used as a "pantry" and ISS crew can transfer logistics to/from mPLM at their convenience. The total docked time at ISS is expected to be reduced from 3 days to 1 day with this approach.

In order to reduce crew carrier accommodations and system sizing the *VentureStar* program is assessing an N= 3 (launch to transfer proximity phase in three orbits) rendezvous. This reduces the launch to dock time from approximately 24 hours to 6.5 hours, which minimizes the need for eating, sleeping and waste accommodations in the crew carrier.

CONCLUSIONS

The RLV ISS servicing study has determined that the *VentureStar* can service ISS, meeting all of NASA's ISS requirements and needs, with a total of 10 flights per year requiring little or no increase in ISS *VentureStar*performance. This is achieved by reducing payload support hardware tare weight and minimizing mission duration. Benefits to ISS are increased serviceability, reduced operational impacts and a significant annual cost savings over the STS.

The *VentureStar* servicing features include:

- 10 annual flights, *VentureStar* direct to ISS
    - 6 pressurized logistics flights
    - 4 combined crew rotation & ULC flights
    - Increased flexibility and frequency within microgravity window constraints
- 2 to 3 day mission duration
- Crew Accommodations/Rotation
    - 4 person crew, all ISS crew members (4 crew up/4 crew back)
    - Flexibility to increase crew size
- Logistics Operations
    - mPLM "pantry" concept
    - 1/2 ULC is transferred to/from ISS in parallel with crew transfer providing four annual windows versus STS
- ISS Operations
    - ISS not required to change attitude for *VentureStar* docking/departure
- Significant Cost Savings
- Greater availability, accessibility and responsiveness with the seven day turnaround, 40 flights per year capability of *VentureStar*

The RLV program will be a simple, low cost, highly reusable, autonomous SSTO vehicle designed for affordable access to space. The VentureStar ISS servicing concept is designed to take advantage of the VentureStar capabilities, while at the same time to provide increased servicing benefits to ISS above that provided by the STS. Increased servicing flexibility, minimum mission duration at ISS and the mPLM "pantry" concept deliver a 21st Century servicing approach for low cost access to the ISS.

Acknowledgments

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