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X-37 SPACE VEHICLE: STARTING A NEW AGE IN SPACE CONTROL?

by

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Contents

Page

DISCLAIMER ii

PREFACE v

ABSTRACT viii

INTRODUCTION 1
- Thesis 1
- Roadmap 2
- Scope 2

BACKGROUND 4
- Description of the X-37 4
  - Capabilities and dimensions of the X-37 4
  - Concept of Operations for the X-37 6
  - Programmatics 7
  - Goals of the X-37 project 8

IS SPACE "THE NEXT PEARL HARBOR"? 10
- Exploring the military potential of the X-37 12
- Benefits of the X-37 18
  - Flexible configuration for on-orbit operations 18
  - Low cost access to space 18
- What has to be in place to make the X-37 successful? 19
  - Technology considerations 20
  - Exploring commercial and military space partnership 21
  - Treaties and policies guiding the military use of space 24

CONCLUSIONS 28

APPENDIX A 30

APPENDIX B 31

BIBLIOGRAPHY 36

Preface

The United States economy and certainly the military rely more and more on space assets to conduct business and obtain military objectives. There are numerous areas in the space architecture that a potential enemy can attack or exploit to cause serious damage to the U.S. economy or to achieve an asymmetric advantage in future conflicts. This paper evaluates the potential of the X-37 space maneuvering vehicle demonstrator as a stepping stone to developing a viable space control platform that the military could use to control the space environment and protect U.S. space assets that are vital to the economy and military. The paper argues that the time is right to change U.S. space policy and to develop capabilities to ensure and maintain the U.S. advantage in space. The X-37 project is an opportunity to move in that direction.

I would like to thank my wife Maureen who provided encouragement and support in completing this project despite the demanding work of caring for our first born daughter Annaliesse Marie who arrived in the middle of this research project on 17 January 2001. I also want to thank Major William Bishop for his awesome assistance and guidance in completing this research paper.

In the paper I refer to the StarBooster launch system as a potential way to get the X-37 into orbit. The StarBooster company is in the engineering design phase of developing a reusable launcher. My father is the president and CEO of Starcraft Booster's Incorporated. I include mention of this commercial venture in my paper not to indorse

that particular brand, but rather to point out a lower cost launch capability that is viable in the short term.

I am not a warmonger who believes we need a weapons capability in space to dominate space and exact fear into the enemy. But I am not naïve to think that the U.S. dependence on space will remain unchallenged indefinitely. The X-37 could be the first step to the U.S. maintaining access to its vital interests in space.

Abstract

The United States, including its military, is heavily dependent upon space assets to thrive in the global economy and to influence future conflicts or crises. The increasing reliance on space for economic prosperity and military efficiency provides an avenue for those who are hostile to U.S. interests to cause severe damage. A satellite failure, whether caused by malfunction or overt attack, can have far reaching impacts. For example, in 1998 a Galaxy IV satellite malfunctioned and shut down 80 percent of U.S. pagers along with video feeds for cable and broadcast transmissions causing weeks of disruption before operators could fully restore the service. This example not only highlights America's dependence on space, but also hints at the kind of damage a targeted attack on space assets could have if carried out by a space savvy adversary.

The U.S. can no longer rely on the "space as a sanctuary" policy, initiated by the Eisenhower Administration, to continue to exploit space for economic and military advantages. The X-37 space maneuvering vehicle demonstrator is an opportunity for the U.S. to begin to develop methods to more strategically defend and control the space environment. The X-37 is the first of NASA's x-vehicles intended to demonstrate leading edge technologies in orbit. This prototype space maneuvering vehicle co-sponsored by NASA, the Air Force and the Boeing Company is being designed to achieve the goals of reducing the cost to access space from $10,000 to $1000 per pound while improving reliability. The current project is funded to build an autonomous space

maneuvering vehicle with on-orbit testing scheduled in 2002. The X-37 is an unmanned space plane that can carry a payload, and can conduct missions while orbiting, loitering, or rendezvousing with objects in space and then autonomously return to earth by landing on a conventional runway. If the Air Force develops the X-37 to its full potential the system could strategically support each of the Air Force's four space mission areas of force enhancement, space support, space control, and force application. Transition of the space maneuvering demonstrator into a space control platform will require a change in national policy. Capitalizing on the lessons from NASA's x-vehicles and partnering with the commercial sector can potentially save costs and shorten the development of a viable space platform that could be used for space control.

Strategic development and funded evolution of the X-37 space vehicle is an immediate, tangible step the United States can take to actively pursue a more aggressive program to respond to threats in the space arena.

Chapter 1

Introduction

Thesis

The high level of commercial activity currently occurring in space and the critical support space provides to the military makes the space environment pivotal to the continuing prosperity of the United States. As an example, it would be hard to imagine fighting the Gulf War or the Air War Over Serbia without the support of space systems providing imagery, weather updates, precise navigation information, and the bulk of communications. However, the benefits garnered from space come with inherent risks. Although to date there has not been an overt hostile act in space, we have experienced sporadic malfunctions that had far-reaching effects and hint at the magnitude of the United States' vulnerability. Due to the government and private sector's growing investments and reliance on space systems, space has become a national center of gravity. United States space assets are appealing targets for enemy exploitation.

The X-37 is a prototype space maneuvering vehicle demonstrator being developed as a joint venture between NASA, the Air Force, and Boeing with the goal of dramatically reducing the cost of access to space through the development and flight demonstration of advanced space transportation technology. If successful, this highly reliable space platform will be used for autonomous on-orbit operations. Follow-on versions of the X-

37 demonstrator could be the catalysts to providing a space platform capable of projecting power in space to deter space aggression or to prevent an attack against space assets. If handled properly and with sponsorship from the National Command Authority the X-37 could be utilized as the Air Force's space platform to control the space environment or to project power from space.

Roadmap

To explore the potential of the X-37 as a space control platform we first need to provide specific background on the X-37 project, its dimensions and performance goals, the concept of operations, and the schedule to test the X-37 on-orbit. Second, we will look into whether space is vulnerable to a surprise attack due to the increased reliance the U.S. commercial and government sectors have on using space to produce revenue or perform day-to-day operations. Third, we will explore the potential benefits of the X-37 from the military perspective due to its flexible configuration for on-orbit missions and its low cost access to space. Fourth, we will explore the military potential of the X-37 to satisfy all four space mission areas of Space Support, Force Enhancement, Space Control, and Force Application. Finally, we will highlight issues that need to be addressed to make the X-37 successful. We will look at the commercial and military technology partnership, current treaties and national policy that may inhibit military operations in space, and technical challenges.

Scope

The paper will not discuss detailed program issues such as securing funds or validating the Concept of Operation and Mission Need Statement. Additionally, the

paper will not look at detailed technical issues such as technologies requiring maturation to make a remotely controlled space vehicle work in a reliable and safe manner.

Chapter 2

Background

Without government support on a large scale, it is not likely that less expensive, resilient, reliable, and flexible space lift will become a reality. Without assured access to space, Global Presence is exceedingly difficult.

—Spacecast 2020

Description of the X-37

Capabilities and dimensions of the X-37

The X-37 program is a joint venture between the National Aeronautics and Space Administration (NASA), the United States Air Force and The Boeing Company of Seal Beach, CA to develop an autonomously controlled space operations vehicle. The program represents a coordinated effort between civil space through NASA, the Department of Defense, and commercial space sectors to develop "leap ahead" technologies in the area of on-orbit operational platforms. The X-37 will be the first of NASA's fleet of reusable launch vehicles designed to operate in both the orbital and reentry phases of flight.[1] This space operations demonstrator will be capable of being ferried into orbit by the Space Shuttle or an expendable launch vehicle. It is designed to operate at speeds up to 25 times the speed of sound and test technologies in the harsh environments of space and atmospheric reentry.[2] The reusable launch vehicle is 27.5 feet long equating to about half of the length of the Shuttle payload bay and weighs about six

tons. It has a wingspan of about 15 feet, and it's payload bay is seven feet long and about four feet in diameter enabling it to carry about 500 pounds of payload.[3] The X-37 will be propelled on-orbit by the AR-2/3 high reliability engine using a hydrogen peroxide and JP-8 kerosene mix to produce about 3300 pounds of thrust.[4] The engine is a proven system with its legacy dating to the 1950's. The exhaust is less toxic providing a more environmentally friendly and compact system compared to today's rocket propellants.[5] The X-37 will demonstrate up to 41 advanced airframe, propulsion and operations technologies that can support various launch vehicle and spacecraft designs.[6]

Figure 1. X-37 in Shuttle bay

In December 1998, NASA selected Boeing for negotiations leading to the July 1999 award of a four-year cooperative agreement to develop the X-37.[7] The total value of the agreement, including government and Boeing contributions, is approximately $173 million with an approximate 50/50 sharing arrangement. The Air Force investment of $16 million is included in the government contribution and is intended to improve future military spacecraft.[8] The Air Force investment will enable various experiments on two of the X-37 space flights scheduled for 2002 and 2003.[9] The X-37 is one of NASA's Future-X Pathfinder vehicles, a NASA series of advanced technology fight demonstrators. The X program was designed to define the future of space transportation by accelerating technology into a new era of space access and on-orbit operations to promote space development and exploration. Likewise, the Air Force is seeking advanced technology to improve military capability in space.

Concept of Operations for the X-37

The X-37's mission is to demonstrate the ability of an autonomously controlled space vehicle to achieve orbit from the Space Shuttle or on an expendable launch vehicle, orbit the Earth for up to 21 days, and land autonomously on a conventional runway.[10] The design allows the Air Force to pursue future derivatives to develop the Space Maneuver Vehicle (SMV). The SMV is envisioned to increase the payload to 1,200 pounds of sensors/payload, up to 12 months on-orbit, 72-hour or less turnaround between missions, rapid recall from orbit, and up to 10,000 feet per second on-orbit velocity change for maneuvering.[11] A major focus of the X-37 will seek improvement of spacecraft thermal protection systems, which in today's systems are too fragile and expensive to maintain. Advances in spacecraft design, monitoring, and maintenance will

contribute to “leap ahead” technologies needed for safe and reliable space platforms of the future. The X-37 will demonstrate up to 41 new or improved technologies while in orbit. These improved technologies are designed to increase reliability, improve safety, and reduce production costs. See attachment A for a listing of the technologies that the X-37 will demonstrate.

Figure 2. X-37 Re-entry

Programmatics

The on-orbit demonstrator program will proceed in three phases. Phase A consists of two parts. The first part of Phase A, which was completed in May 1999, tested the flight characteristics and autonomous control of an 80 percent scale model of the vehicle, dubbed the X-40A, by dropping it from a helicopter.[12] The second part of Phase A is the manufacture of the X-37. Phase B will test the flight characteristics, autonomous control, and structural integrity of the X-37 by conducting five high altitude drop tests from a B-52.[13] This phase is scheduled to begin in 2001. Phase C will conduct two on-orbit tests of the X-37 ferried to orbit aboard the Space Shuttle in 2002 and 2003. However, the Deputy Project Manager, Lieutenant Colonel Kris Johanessen (USAF), indicated that the first orbit flight test may be delayed until the spring of 2004 due primarily to additional reviews by NASA in the wake of successive Mars mission failures. Lieutenant Colonel Johanessen also indicated potential delays caused by manufacturing problems, second-generation restructure, and an extension of Phase A.[14]

Goals of the X-37 project

The goals of the X-37 project are straightforward according to Susan Turner, the X-37 project manager for NASA's Marshall Space Flight Center (MSFC), in Huntsville, Alabama. She said, "The emphasis is on advancing technology, lowering costs and increasing reliability. We must make space transportation more affordable and reliable if we want to open the way for future exploration and commerce."[15] The overall goal according to NASA is to reduce the cost of getting into space from $10,000 to $1000 per pound while increasing reliability.[16] When asked about goals, Ron Prosser, vice president of Advanced Space and Communications for Boeing Phantom Works in Seal Beach, CA stated "potential new commercial and military reusable space vehicle market applications for these technologies range from on-orbit satellite repair to a next-generation of totally reusable launch vehicles."[17] The Air Force's goal is to leverage the lessons learned in developing the X-37 and apply it to the design of a SMV. The Air Force Research Laboratory believes a SMV can function as a second-stage-to-orbit vehicle as well as a reusable satellite with a variety of available payloads capable of performing tactical reconnaissance, identification and surveillance of space objects, and space-based logistics.[18] With the Air Force's requirements to develop a SMV, the X-37 program represents a key component for the Air Force to better manage critical assets and the potential threats in space.

Notes

[1] Marshall Space Flight Center Fact Sheet, "X-37 Demonstrator To Test Future Launch Technologies in Orbit and Reentry Environments," FS-1999-07-90-MSFC, Internet, July 1999, available from http://www.msfc.nasa.gov/news/background/facts/x37.htm, p. 1.

[2] Ibid., p. 1.

[3] Ibid., p. 1.

Notes

[4] LtCol Kris Johanessen, USAF, X-37 Deputy Program Manager, interviewed by author, 9 February 2001.

[5] Marshall Space Flight Center Fact Sheet, p.2.

[6] LtCol Kris Johanessen, USAF, interviewed by author, 9 February 2001.

[7] NASA News Release, "X-37 Agreement Signed," 99-07-14, Internet, July 1999, available from http://spacelink.nasa.gov/NASA.News/NASA.News.Releases/, p. 1.

[8] Marshall Space Flight Center Fact Sheet, p.1.

[9] Ibid., p.2.

[10] Ibid., p.2.

[11] AFRL Fact Sheet, "Space Maneuver Vehicle," Internet, May 1999, available from http://www.vs.afrl.af.mil/factsheets/smv.html, p.1.

[12] Ibid., p.1.

[13] LtCol Kris Johanessen, USAF, X-37 Deputy Program Manager, interviewed by author during visit to Marshall Space Flight Center, Huntsville, AL, 20 February 2001.

[14] Ibid.

[15] Marshall Space Flight Center Fact Sheet, p.1.

[16] Ibid., p.1.

[17] Ibid., p.1.

[18] AFRL Fact Sheet, p.1.

Chapter 3

Is space "The Next Pearl Harbor"?

> *The time has come to address, among warfighters and national policy makers, the emergence of space as a center of gravity for DoD and the nation.*
>
> —General Howell M. Estes III[1]

The loss of commercial satellites or damage to civil assets would be harmful to the United States. General Howell M. Estes III highlights the U.S. dependence on space in his article *Protecting America's Investment in Space* by asserting "nearly half of those 600-plus satellites are American. They represent an investment of more than $100 billion. U.S. News and World Report estimates we will spend more than $250 billion in space by the year 2000, and that another 1,800 satellites will be on-orbit by the end of the next decade."[2] An attack on intelligence and military satellites, especially during a crisis or conflict, could significantly disrupt or degrade the President's ability to ease a crisis between nuclear-armed adversaries or impair his ability to end a conflict before an adversary uses a weapon of mass destruction against the U.S. or its allies.[3] Congress chartered the Commission to Assess United States National Security Space Management and Organization (referred to as the Space Commission) to report on space related issues relevant to national security. The Space Commission report, delivered in January 2001, points out, "as history has shown—whether at Pearl Harbor, the killing of 241 U.S.

Marines in their barracks in Lebanon or the attack on the USS Cole in Yemen—if the U.S. offers an inviting target, it may well pay the price of attack." With the growing commercial and national security use of space, U.S. assets in space and on the ground offer just such targets. Space is increasingly vulnerable to hostile acts designed to deny or disrupt freedom of action in and through space using a myriad of products available on the international market. The source of the threat is not limited to global military powers."[4] Any organization harboring hostile intent to U.S. interests can carry out a debilitating attack on the U.S. space system by destroying key control nodes, jamming the up-link or down-link signal either on the ground or in space, or sabotaging the launch of a key satellite. The many weaknesses in the U.S. space infrastructure provide a potential enemy an asymmetric advantage if they can cripple or severely degrade U.S. access to space. This increased reliance on space as a national center of gravity has made space an appealing target for enemy exploitation in future crises or conflicts. The U.S. is an attractive candidate for a "Space Pearl Harbor."[5] There are a number of warning signs of the U.S. vulnerability in space. A Galaxy IV satellite malfunctioned in 1998 shutting down 80 percent of the pagers in the U.S. and a three hour ground station failure in early 2000 caused the U.S. to lose all information from a number of its satellites.[6] According to Vice Admiral Thomas R. Wilson, director of the Defense Intelligence Agency, "a number of countries are interested in or experimenting with a variety of technologies that could be used to develop counter-space capabilities."[7] The admiral continued "future adversaries will be able to employ a wide variety of means to disrupt, degrade or defeat portions of the U.S. space support system."[8] In his essay Brigadier General Simon P. Worden asserts that the military plays a role in the protection of commercial assets much

like the navy does in the protection of merchant shipping lines. He further asserts that the military may need to block access to commercial satellite products in times of war or crisis much like a naval blockade.[9] Since vulnerabilities are frequently acknowledged only in hindsight and hostile acts in space could be confused with natural phenomenon such as solar activity to help mask hostile acts, the Space Commission believes that the U.S. is not prepared to handle the spectrum of potential threats to its space systems.[10] This is especially true since the U.S. has not experienced an overt hostile act in space, which has lulled the U.S. into a false since of security. General Ralph E. Eberhart, Commander-In-Chief of the U.S. Space Command, maintains "the importance of space control and space superiority will continue to grow as our economy becomes more reliant on space."[11] The Space Commission questions whether a disabling attack against the country or a "Space Pearl Harbor" will be the only events that might galvanize the nation and force the U.S. Government into action. Will the U.S. be wise enough to act responsibly to take prudent steps in the near future to reduce the U.S. space vulnerability?[12] The Space Commission warns that "We are on notice, but we have not noticed."[13]

Exploring the military potential of the X-37

> *Number one, we have lacked space-control technology and capabilities. We don't have space-control capability, in my view. If we intend to maintain our information superiority, we need a strong space control program to protect our assets and to deny our adversaries the use of their own systems. Secondly, the United States lacks a flexible power-projection capability that would allow U.S. forces to use space to project their military power elsewhere on Earth.*
>
> —Senator Bob Smith[14]

The military has a responsibility to protect U.S. national interests, including interests in space, using military force if necessary. The Air Force has an opportunity to respond to space related threats to national security by taking a more strategic approach to investment in the X-37 and propelling the project to a more promising space control platform. A prudent way to evaluate the value of any military space system program is through the lens of the four space mission areas: Force Enhancement, Space Support, Space Control, and Force Application as established in National Space Policy.[15] The X-37 has the potential to provide benefit to all four mission areas if it is designed as a multi-role platform.

Under the first mission area of Force Enhancement, the X-37 can contribute by filling Intelligence, Surveillance, and Reconnaissance (ISR), timing and navigation, communication, and weather needs of the terrestrial military forces engaged in peacetime or wartime operations. The cornerstone of the X-37 meeting requirements of the Force Enhancement mission area is the planned flexibility of the platform. Initially, the X-37 is designed to carry a payload of up to 500 pounds into orbit and perform remotely controlled maneuvers and operations in space for up to 21 days. Follow-on versions of the X-37 can be scaled up in size to carry even heavier payloads if launched on an expendable or re-usable rocket. Assuming that the payload bay and interfaces with the X-37 space vehicle are designed with an open architecture and adaptable power supply, the platform can employ various types of payloads to meet the needs of the theater commander. Ideally, the theater commander can have a menu of space enhancement capabilities on hand to request additional support in times of crises. If for instance the theater commander is not getting enough reconnaissance support from existing national

systems he can request an X-37 launch to employ a reconnaissance payload that he can task to meet his needs during a crises. This scenario is not practical today due to the high launch costs and long-lead time of launching a reconnaissance satellite on an expendable launch rocket. This scenario is feasible with the goals of lower cost and improved reliability the X-37 can attain using a re-usable launch system.

Under the second mission area of Space Support the X-37 can be used to carry out a variety of tasks that support space through deploying satellites, recovering damaged or malfunctioned satellites, or re-fueling or repairing satellites already in orbit. The size of the satellite launched is obviously constrained to the size limitations of the payload bay. With the advent of microchip technology and dramatic miniaturization, the size of future satellites is only going to shrink in size and increase in capability.[16] Also, once the X-37 concept is proven, the size of follow-on versions could be scaled up to meet the requirements to launch standard size satellites. Additionally, to reduce costs for launching the X-37 the Air Force can employ a flexible and reusable launch system like the StarBooster, one of several re-useable first stage concepts being studied by the Air Force (see appendix B). The X-37 is being designed to rendezvous with satellites in space using remote control from operating bases in the United States. Once in proximity of the target satellite the X-37 can use a Shuttle-like robotic arm to retrieve damaged satellites and bring them back to earth for repair and refurbishment. If a satellite is designed to have easily replaceable fuel tanks or critical components (e.g. the solar array) the X-37 can be employed to refuel the satellite or replace a failed solar array using the robotic arm. In each case the mission planners will need to perform a cost/benefit

analysis to determine if it is worth it to retrieve a failed satellite or launch a new and improved one.

Under the third mission area, Space Control, the Air Force can use the X-37 in a number of ways to control the space environment. An X-37 equipped with the appropriate payload can satisfy the two subsets of Space Control of Offensive Counter Space (OCS) and Defensive Counter Space (DCS).[17] OCS is the ability to use space systems to deny, degrade or disrupt the enemy's ability to use space systems against U.S. or coalition forces both in space and on the ground. [18] The X-37 can rendezvous with enemy satellites and use its payload to jam the electronic cross-link or downlink thereby temporarily disrupting the enemy's capability to control the satellite or to retrieve the satellite's stored information. The payload or the X-37 itself can shield or block the view of the enemy satellite's optical lens rendering an enemy reconnaissance temporarily useless. Or the X-37 can employ a more overt method by using a kinetic kill or explosive device to destroy an enemy satellite. One question that could be asked is why not just degrade or destroy the downlink or command and control station on the ground? Brigadier General Simon P. Worden in his article "Space Control for the 21st Century" best answers this question:

> The two sets of viable targets, therefore, are the satellites themselves and/or the end user on the ground. It is, of course, possible to focus on denying the receipt of final space products to a user. However, with increasingly flexible and diverse means to transmit information to this user, many not involving any space-asset, we are being driven to get ever closer to the user we are trying to influence. This is hard, expensive, and in many cases politically and physically risky. We turn back, therefore, to the nodes in the great "common" of space, the satellites.[19]

The X-37 has the potential to satisfy the Offensive Counter-Space (OCS) role by rendezvousing with enemy satellites and employing its payload to jam or interfere with

the operation of the satellite. Or perhaps the X-37 can ferry a number of micro-satellites designed to carry out the OCS mission and place them in proximity of several enemy satellites for future OCS operations during times of crises. In this example, the X-37 provides the means for the US to effectively blockade the enemy's ability to use space by employing the micro-satellites to carryout their disruption and cutoff the space lines of communication.

The second aspect of Space Control is Defensive Counter-Space (DCS). DCS is defined as the ability to conduct surveillance of the space environment, detect an attacking satellite, and to defeat it before it destroys or disrupts the operations of a friendly satellite.[20] The X-37 could be employed to rendezvous with a friendly satellite and use a DCS payload to protect the satellite from attack. The DCS payload would need to be able to perform surveillance of the area around the satellite, detect and track an aggressing enemy satellite, and use a kinetic or laser weapon to defeat the attacking satellite.

Under the fourth mission area of Force Application, the Air Force could use the X-37 to employ a force application payload to attack terrestrial targets. The X-37 is well suited to ferry a force application payload into space on a rapid call up schedule. Armed with precision weapons such as GPS or laser guided hypersonic rods, the X-37 can be directed to launch these weapons to attack targets deep within enemy territory with no risk to human life. One can envision several X-37 squadrons coupled with a re-usable launch booster based in the US and poised to carry out Force Application missions on a rapid call up schedule. Over the course of the mission both the X-37 and the reusable booster return to base to be refueled and reloaded to carry out additional missions. Clearly, this

Force Application capability can provide theater commanders with critical options to accomplish their mission, taking decisive action especially during the halt phase of the conflict.

The X-37 has the potential to meet all four of the space mission areas as a multi-role space platform. Theoretically, the Air Force could have several X-37 squadrons stationed on the east and west coasts of the U.S., poised and ready to meet the requirements of the theater commander. Some of the space vehicles could be dedicated to the Space Support and Force Enhancement missions ready to retrieve failed satellites or able to launch new satellites to fill gaps in coverage for a particular theater. Others could be dedicated to supporting the Space Control mission and readied to launch an OCS or DCS payload to ensure space superiority is secured for the US during a crisis. Finally, some assets could be ready to carry out precision bombing attacks anywhere on the globe in a matter of hours. The X-37 Deputy Project Manager, Lieutenant Colonel Johanessen believes the X-37 could be a viable space control platform, but he cautioned that a system designed to meet all four mission areas may not be best suited to cover each of the mission areas sufficiently due to the varying performance requirements needed for each area.[21] All four space mission areas could be served by the X-37 to make it an attractive and compelling military investment. Because we currently have alternatives for space force enhancement using existing satellite systems and space support can be achieved through redundancy and replenishment, these two mission areas may not be sufficient to make the X-37 concept compelling for the military. The addition of space weapons and control capabilities, however, makes the X-37 technology suite very attractive to the military.

Benefits of the X-37

Just as the navy needs suitable platforms to control the seas to protect national interests, the Air Force needs to have similar platforms to control space and the national assets therein. The X-37 offers some key features to support this responsibility.

Flexible configuration for on-orbit operations

The X-37 contributes to the development of a standard Space Maneuvering Vehicle (SMV) which when perfected will give users reliable and remotely controlled operations in space for an extended period of time. The X-37 will be designed to rendezvous with objects in space or carry different payloads into space. Once the X-37 has completed its mission it is designed to return to earth and land on a conventional runway. Based on the type of payload placed in the X-37 it can perform various types of missions including controlling the space environment by interfering with a target satellite's operation or deploying conventional weapons designed to attack terrestrial targets. Conceptually, the flexibility inherent in the X-37 makes it ideally suited to meet all of the space missions areas described earlier in the paper. The X-37's flexibility could be considered akin to the Air Force's F-16 multi-role fighter due to its ability to meet several fighter requirements in one platform.

Low cost access to space

The X-37 is designed to reduce launch costs, while improving safety and reliability compared to current systems such as the Space Shuttle. The X-37 program is one of many NASA programs designed to reduce launch costs from $10,000 per pound to around $1000 per pound. Currently, the X-37 must be carried to orbit by the Space Shuttle which can cost in excess of $300 million per flight or an expendable launch

rocket like the Delta IV or Atlas IIA at an approximate cost of $5000 per pound.[22] The X-37 is one element of achieving lower-cost access to space, and operations in space, by providing a lower-cost platform for space operations. To achieve its goal of reducing launch costs to $1000 per pound NASA must rely on using a fully reusable launch system like StarBooster (see appendix B) to carry the X-37 to orbit. A fully reusable and unmanned space operations vehicle married with a fully reusable launch system may be the best means to achieving this goal in the near future. The cutting edge technologies could help space transportation become more like airline travel with highly reliable and low cost space flight that is available on demand.[23] The X-37 could be employed in rapid launch configuration or extended ready mode of operations to fill timely requirements to support the theater commander in a crisis situation. The X-37 and follow-on SMV development should benefit from commercial space sector innovations to reduce development and maintenance costs. Since the SMV might be used by both sectors to perform similar operations, the SMV could share common production facilities, common components, and similar maintenance schemes such as leading edge artificial intelligence (AI) based diagnostic maintenance systems. The cost sharing is similar to that experienced with the Air Force's KC-10 and KC-135 aircraft which saves costs from parts to maintenance facilities to simulators.

What has to be in place to make the X-37 successful?

In addition to establishing normal funding and program elements, technical challenges must be addressed and a partnership with the commercial sector should be established if the X-37 program is going to be successful in meeting the needs outlined in

this paper. But further, to accommodate the weapons component of the X-37 concept we must address international treaties and national space policy.

Technology considerations

Due to the advanced technological nature inherent in the X-37 test demonstrator the technological challenges to develop a production SMV are not trivial. Aerospace engineer Hubert P. Davis offers an opinion on some key challenges.[24] Davis, currently the Vice President for Engineering with Starcraft Booster Inc., has nearly 30 years experience in the space field including his tenure as the program manager for NASA's Lunar Excursion Module. According to Mr. Davis, technical barriers to be overcome include the proper balance of inert mass with systems redundancy and features to provide the desired mission capabilities. As an example the lifting body shape selected for the X-37 may later be shown to be inappropriate to the military mission due to high landing speeds and limited control authority at approach speeds. NASA has selected a parafoil terminal recovery system for its X-38 prototype Crew Rescue Vehicle because of these concerns. Alternate, simpler and lighter weight shapes, such as the conical shape under investigation by the Air Force Research Laboratory, also to be recovered by parafoil, may prove to be preferable. Another concern is the provision of sufficient orbit maneuvering capability to permit accomplishment of its missions. In particular, should geo-stationary targets need to be addressed, a much larger velocity-change capability will be required if loiter is necessary. This contrasts with an approach at the high closing speeds characteristic of the geo-stationary transfer orbit (nearly 2km per second), which probably limits time within effective range for observation or interdiction to a very few seconds. Finally, the required capability of "rapid turnaround" for the SMV does not

now exist for space vehicles. The technologies, training, and procedures to achieve this goal will require serious development effort and perhaps several evolutionary stages of development. Mr. Davis' insight offers a glimpse of the magnitude of technology challenges to be investigated.

Exploring commercial and military space partnership

The partnership between the civil and military space sector, dating back to the early 1960's, was constructive due to their common goals to reach orbit and explore the space environment. The partnership between the civil and commercial space sectors was minimal until NASA issued a new policy in May 1996 encouraging mutually beneficial partnerships. The military has traditionally not worked closely with the commercial space sector except in managing and maintaining the spaceports used to launch commercial satellites. In order to drive down development and even maintenance costs the military needs to partner whenever it makes sense with the commercial sector in developing mutually beneficial products such as launch systems and space vehicles such as the X-37.

The commercial space sector has much to offer the military when it comes to developing space systems due to the commercial sector proliferation and experience in space. The civil and military space sector used to dominate the space domain, but this is no longer true as 1997 marked the first time the number of commercial satellites launched by the U.S. exceeded the number of government satellites.[25] Additionally, the revenues earned by the commercial space sector exceeded the amount the government spent on space in the same year.[26] In fact, projections show that the commercial space sector is expected to fuel industry growth at an annual rate of 20 percent creating as many as

70,000 new high technology jobs and over $100 billion in worldwide revenues each year.[27] The focus of the space commercialization activities center on transportation services, remote sensing and geographic information services, micro-gravity materials processing and research, life sciences, communications, and navigation.[28] We can see that the commercial space sector is proficient in space operations and the military can benefit from partnerships with the commercial space sector to reduce development costs, improve efficiency, and reduce duplication of effort.

The barriers to cooperation between the government and private sector are diminishing. NASA's Administrator, Daniel Goldin, issued a new policy in May 1996 to improve development of cooperative space ventures. Mr. Goldin stated "I must emphasize that the commercial technology mission is critical to NASA's future. It will ensure that NASA remains a relevant part of the national economy and that the American economic system efficiently uses all resources."[29] He further states, "We are collaborating with our private sector partners more each day. The results are more jobs, more technology applied to improve our daily lives, a more cost-effective NASA, and a stronger America of which we can all be proud."[30] The policy outlines ways to encourage contractor technology commercialization; industry led partnerships, commercial product development, dual-purpose development, small business development, regional alliances, commercial technology acquisition, and post development technology diffusion. The policy directs NASA managers to consider these practices when planning each expenditure of research and development funds.[31] The military space sector should consider a similar policy for future space systems enabling a speedy development and lower cost of mutually beneficial products. This will allow U.S.

companies to gain and maintain their advantage in space and benefit the military in acquiring systems faster while fostering a large commercial base to develop follow-on capabilities. The partnership between the military and commercial space sector can only promote a systematic approach to maintain the U.S. leadership role in space.

When feasible, the military space sector should work together with the private sector to co-develop space systems meeting similar needs. The X-37 falls into this category because both the private sector and the military have a need to operate cheaply and reliably in space. The military should promote this common interest by developing a mutually inclusive Mission Needs Statement that both the military and private sector can adopt. In the case of the X-37, Boeing has committed approximately $85 million to the project with NASA and the Air Force making up the remainder of the projected $173 million price tag. This 50/50 arrangement between the government and private sector is a good example of potential development cost savings through partnering arrangements. In fact the Air Force is only paying $16 million to test technologies that may be beneficial to future military SMV platforms.[32] According to the Deputy Project Manager representing the Air Force, Lieutenant Colonel Kris Johanessen, the Air Force will be testing new solar array blanket technology and Vernier thruster technology designed for fine maneuvering in space.[33] This is a small price for the Air Force to explore SMV capabilities and how they might meet future military needs in space. The Air Force should invest even more R&D funds to co-develop maintenance and operational technologies that improve reliability, enhance readiness, and decrease the turn around time after the X-37 returns from a mission. Clearly the X-37 project demonstrates a

capability that can benefit both the private sector and the military, and the Air Force should use these opportunities to promote U.S. leadership in space.

Treaties and policies guiding the military use of space

To realize the full potential of the X-37, and develop its weapons capability, we need to address the relevant international treaties and national space policy. No treaties expressly prevent weapons in space, but our current national space policy emphasizes "peaceful uses" and therefore is not conducive to placing weapons in space.

The 1967 Outer Space Treaty and the 1972 Antiballistic Missile (ABM) Treaty do have relevant articles addressing weapons in space. Article IV of the Outer Space Treaty specifically prohibits placing in orbit nuclear and other weapons of mass destruction.[34] Article IV also restricts any state from conducting military maneuvers, establishing military bases or installations, or testing any type of weapon on celestial bodies.[35] Article V of the ABM Treaty prohibits development, testing, or deployment of space-based ABM systems and components.[36] Neither of these two treaties expressly forbids the use of conventional weapons in space unless they are for ABM purposes. The premise the United States adheres to when it comes to international law is that any act not specifically prohibited in the treaty articles is therefor permitted.[37] In fact the January 2001 Space Commission report states, "there is no blanket prohibition in international law on placing or using weapons in space, applying force from space to earth or conducting military operations in and through space."[38] Another accepted "rule of engagement" with regard to treaties is that the agreement between the signatories is maintained when the signatories are at peace with each other. But the treaty is nullified when the signatories are at war with each other.[39] Current treaties should not be barriers to the prototyping or

development of space-based weapons that the X-37 can demonstrate. While there are no international treaties limiting the use of space to conduct military operations with conventional weapons and such treaties if they existed would be valid only during peacetime, then why is the U.S. limiting its military options by not developing a weapons capability for the space environment? To answer this question we will need to look at the past and present National Space Policy.

Current policy must be updated or revised to allow the X-37 to be utilized to its full potential in terms of space weapons development. Although the National Space Policy is tailored to each presidential administration, the basic tenants of all space policy to date were shaped by the space policy of the Eisenhower Administration. President Eisenhower encouraged exploration and peaceful uses of space. He formalized his space policy in the 1958 National Space Act. "The government formally established a dual space program comprising separate civilian scientific and military application projects. Both were directed to "peaceful," or scientific, defensive, and non-aggressive purposes."[40] Even though the Clinton Administration identified "force application" as a key part of his space policy, his administration consistently avoided fielding such systems.[41] So the "space for peaceful purposes only" policy established by President Eisenhower still remains the centerpiece of current national space policy. The Space Commission identified this limitation as one of its key conclusions in the final report. In the Commission's unanimous conclusions, the report stated "First, the present extent of U.S. dependence on space, the rapid pace at which this dependence is increasing and the vulnerabilities it creates, all demand that U.S. national security space interests be recognized as a top national security priority." The report further concluded, "The only

way they will receive this priority is through specific guidance and direction from the very highest government levels. Only the President has the authority, first, to set forth the national space policy, and then to provide the guidance and direction to senior officials, that together are needed to ensure that the United States remains the world's leading space-faring nation."[42] Presidential support expressed through National Space Policy and careful diplomatic articulation of the U.S.'s stance on relevant treaties are essential to creating the environment where the full potential of the X-37 demonstration program can be realized by the military.

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Chapter 4

Conclusions

America's key to maintaining its status as a global superpower and continued economic prosperity are inextricably tied to the United States' persistence as the world's leading space-faring nation. The vulnerability of the United States due to its inability to control the space environment is clear. The military depends on space to prosecute modern warfare. United States citizens and commercial entities are increasingly dependent on space assets. Yet U.S. policy makers should recognize the magnitude of this vulnerability and that space provides potential enemies an attractive target producing asymmetric consequences. The X-37 demonstrator provides an opportunity for policy makers and the Air Force to prepare for and mitigate the consequences of this vulnerability. With its autonomously-controlled, cheap and reliable space platform the X-37 has the potential of becoming the Air Force's means to protect the "space lines of communication" and ensure freedom of access to space. The Air Force has an opportunity to respond to space related threats to national security by taking a more strategic approach to investment in the X-37 and propelling the project to a more promising space control platform. If properly designed, funded and utilized a follow-on version of the X-37 could provide quick, low cost means of carrying various and inter-changeable payloads. These payloads could perform in the realm of all four space

mission areas providing a custom response to the theater commander's needs. Thus the X-37, already in its prototype stage, is a viable catalyst to bolster America's control of space. A follow-on to the X-37 could rapidly deploy force application from space to protect U.S. space assets or destroy enemy space capabilities. It could also be used to rapidly attack targets on the ground without putting airmen in harms way. A more strategic view and increased investment is needed to propel the X-37 beyond its currently limited scope. Experience shows that government partnerships with the commercial sector aid in reducing costs and promotes a wider adoption of standards making the interchangeability of flexible platforms like the X-37 more valuable and versatile.

To harness a portion of the X-37's potential to control or apply force from space requires a policy change and strong endorsement from the highest levels of the national government. Maintaining a policy of space as a sanctuary only sets the stage for a surprise attack and subsequent debilitating consequences for both the military and economic prosperity. While no international treaties expressly prohibit weaponization of space our policy makers must engage our diplomatic representatives to support and promote the cogence of such a policy change. A stepped up development of the X-37 could be the first step in a more aggressive program to respond to a space threat and inevitable attack.

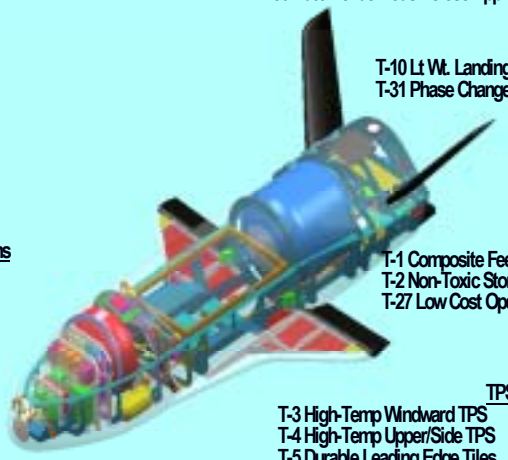
Appendix A

32 Technology Demos are Embedded in Design - Plus 8 Experiments

Avionics/Software
- T-12 Open Architecture - Tech Insertion
- T-14 Dual-Rate AS 1773; 1-20Mbps
- T-15 Low-Cost Sub-Surface/Flush Antenna
- T-16 COTS HW/SW - Low Devel/Maint Cost
- T-19 Fault Tolerant Autonomous Ops
- AFT-1 Solar Arrays
- AFT-2 Enhanced Attitude Control
- E-1 High Temp Electronics
- E-2 High-Energy-Density Batteries
- E-3 NASA IVHM Integrated System
- E-8 Docking Hardware Demo

GN&C
- T-13 Calculated Air Data System (CADS)
- T-17 All Weather Windward Adaptive Guidance
- T-26 Rapid Mission Data Loading
- T-29 X-Wind Landing for Small RSVs
- T-30 Auto Rendezvous - Close Approach

Mechanical Systems
- T-10 Lt Wt. Landing Gear (On-Orbit Qual)
- T-31 Phase Change Brakes



Ground/Flight Operations
- T-18 Rapid-Global TPS Damage Detection
- T-24 Access Doors for Operability
- T-28 Small Crew FOCC

Propulsion
- T-1 Composite Feed Lines
- T-2 Non-Toxic Storable Propellant Tanks
- T-27 Low Cost Operability - Storables

TPS/TCS
- T-3 High-Temp Windward TPS
- T-4 High-Temp Upper/Side TPS
- T-5 Durable Leading Edge Tiles
- T-7 High-Temp, Low Cost Joints/Seals
- T-9 Loop Heat Pipe TCS
- T-21 Rapid TPS Waterproofing
- E-4 Failsafe Screening Surface TPS Test Panels
- E-5 Durable, Low Conductivity/Density Tile
- E-6 Weatherized Metal Covered Blankets
- E-7 Highly Operable Metallic TPS

Structures
- T-6 High-Temp Gr/BMI Sandwich Structure
- T-8 Thin, Hot Aerosurfaces for SRSV
- T-11 Modular Airframe - Rapid Change-Out
- T-20 Lt. Wt. Std Payload Container
- T-23 Standard Payload Interfaces

Flight Sciences
- T-22 High Enthalpy Flight Profile

10/14/99 1

Appendix B

Starcraft Boosters, Inc.

3106 Beauchamp

Houston, TX 77009

Chairman: Dr. Buzz Aldrin,

President: Lt. Gen. Ret. Dirk Jameson

V.P. Engineering: Hubert Davis

V.P. Legal & General Counsel: Art Dula, (713) 861-1960, art@dula.com

StarBooster System™ Family

The people of Starcraft Boosters, Inc. have been working since July, 1995 to define an alternative to the two present courses set by government for improving access to space.

The path chosen by NASA about that time was to develop a fully reusable "Single-Stage-to-Orbit", or SSTO, vehicle to produce a dramatic reduction in costs and an equally dramatic improvement in reliability of achieving access to space by ending the practice of discarding the vehicle after first flight. It was our judgment at that time that, although meeting these goals is certainly appropriate, the selection of the demanding SSTO path to achieve these goals rather than permitting the use of two or more "stages" was not likely to succeed. SSTO would require advanced technologies, well beyond our abilities, to attain the ultra-low dry mass required for the vehicle. Our concerns have been confirmed by the adverse events and long schedule delays recently encountered in the attempt at development of the *X-33/ VentureStar* program under NASA contracts.

At the same time, the U.S. Air Force elected to avoid any work on "re-usable" space launch systems, as this was NASA's "turf". The USAF thus embarked upon a program to improve costs and reliability of their present stable of vehicles. These have been derived from the ICBM technology of 40 years ago - - close relatives to artillery rounds. Predictably, as the vehicles are used only once and the items that have flown are not generally recovered for examination, expendable systems have remained high cost and have attained only about 95% reliability. We believed in 1995 that it would not be possible for any "evolved" expendable systems to attain high reliability and low costs, as have aircraft.

NASA's *Space Shuttle Orbiter* has greatly benefited from recovery, examination and refinement - evolution made possible only by reuse. Evolution of this vehicle has reduced its costs by 40% and decreased its risks to crewmembers by 80%. Further evolution, already planned, will further reduce these risks to half or less of those presently faced.

We believed in 1995 and still believe today that these benefits must now be expanded to the largest element of a space launch vehicle - - its first stage, or Booster. Thus we have sought to devise the most cost-effective and rapid means of providing such a system. We selected the "flyback booster" concept, which acts as a subsonic airplane to return the booster to the launch site for examination, refinement, and reuse.

First and foremost, we believe it appropriate to best **use and adapt what already exists**, both to save time and costs and to benefit from the experience of prior flight use.

We selected two existing space launch vehicles to become a part of the *StarBooster System*™: the new *Atlas III* vehicle now at Kennedy Space Center and the flight-proven *Athena II* which is a comparatively low cost launch vehicle based upon proven solid rocket motors. Both are built and operated by the Lockheed Martin Corporation, whose Michoud division has agreed to provide support for us. We plan to utilize the first stage of the *Atlas III* to become the "prime mover" for our *StarBooster 200* and the *Athena II* and *Centaur* upper stage of *Atlas III* to be used as expendable upper stages. The conservatism permitted by selection of the multi-stage approach rather than requiring "SSTO" greatly decreases costs, risks, and schedules such that early flight of fully reusable boosters becomes practical,

StarBooster 200™ is a new, mostly aluminum aircraft, custom-designed by Starcraft Boosters, Inc. in the 1996- 2000 interval to house the *Atlas III* first stage, permitting its rocket engine nozzles to protrude from the aft section so that they may be used to power vertical liftoff from a launch pad. The rocket engine powering the *Atlas III* first stage is the Russian *RD-180*, a mature engine using safe kerosene fuel that has had many years of development and is now licensed for production and support in the United States by Pratt & Whitney.

We believe that this aircraft can be designed and built within the span of two to three years from availability of funding.

Lockheed-Martin – Michoud has agreed to do final design and to construct the *StarBooster* aircraft as a "merchant supplier", provided that Starcraft Boosters, Inc. can provide the necessary funds. We have also reached agreement with Pratt & Whitney to assume "turnkey" responsibility for all propulsion systems needed, Minneapolis Honeywell / Allied Signal to provide all avionics and electrical power systems, with Thiokol Division of Cordant Technologies and Hamilton Standard / Sundstrand to provide other needed industrial support. NASA's Langley Research Center has provided valuable technical support for much of this interval, and other government organizations

have provided favorable assessments of technical feasibility and limited technical support. Team formation continues.

StarBooster 200 is not a small aircraft; neither is it larger than the common Boeing 737 airliner. Shown below are an artist's concept of the comparison and a photo of the model.

In order to place payloads into Earth orbit, *StarBooster* will carry expendable "upper stages" drawn from existing systems to provide the additional velocity needed to attain orbit from the Mach 3 to Mach 6 "staging" of *StarBooster*. We have formulated a phased development plan that begins by producing a set of vehicles to penetrate the existing commercial space launch market, today roughly 50% of total traffic into space. The first revenue-producing flight configuration employs a single *StarBooster 200* and the *Athena II*. This combination produces payload equivalent to that of today's *Delta* launch vehicle for payloads in the 10,000-pound class. When more payload is required, dual *StarBoosters* may be employed with this same existing space launch vehicle, delivering payloads above 20,000 pounds to low Earth orbit, equivalent to that provided today by the *Atlas IIAR* vehicle, a $100 million class investment. By aiding the *Athena II* with the high altitude, high velocity starting point provided by *StarBooster*, it payload is increased by factors of 3½ and 6, respectively.

Shown here are photographs of the model set in the two flight configurations mentioned above: Single *StarBooster 200* plus Athena II and dual *StarBooster 200* plus *Athena II*.

Early indications are that only minor modifications will be required to adapt the *Atlas III* first stage to be flown internal to the *StarBooster* airplane and to the *Athena* vehicles to be carried to the stage point by *StarBooster* and subsequently used to provide the added velocity necessary to place large payloads into low Earth orbit.

Impressive as these capabilities may be, they are not adequate to address the "cash cow" portion (some 85% of the total dollars) of the commercial space launch market: placement of the 5 to 6 metric ton communications satellites to their destination orbits.

To accomplish this lucrative task, Starcraft Boosters originated and has filed patent application on what we call *StarCore I*, which consists of the lower two Castor 120 solid rocket motor stages of the *Athena II* topped by the high energy *Atlas III Centaur* second stage, coupled together by means of a new, conical adapter.

***StarCore I* also permits use of the modern mission mode, "super-synchronous injection" in which the launch vehicle delivers a large 3½ metric ton satellite equipped with a highly efficient but low thrust electric propulsion system to an extremely high altitude, permitting the spacecraft propulsion systems to adjust the orbit altitudes and inclination to the desired geo-stationary orbit position. Thus, the**

"Phase I" *StarBooster System* ™ effectively addresses all but the smallest size payloads of today's and the near future's commercial space market. The U.S. government, however, has occasional need for even greater payload capability, provided today by the expensive *Titan 4B*, the vehicle that lost three satellites in a row at a cost to the taxpayer in excess of $5 Billion. Eleven *Titan*s are in storage for future use, but the Air Force plans to replace it with the "heavy" versions of their new *Evolved Expendable Launch Vehicles (EELVs*) now in development by Boeing and Lockheed Martin. *StarBooster* can aid in satisfying this requirement of the Defense Department, provided that they will financially support the development of a new, partially recoverable upper stage we call *StarCore II*. *StarCore II* uses propellant tanks built on present tooling and a single rocket engine from the *Space Shuttle* program: the *Space Shuttle Main Engine*, or *SSME*.
This engine is, hands down, the finest rocket engine ever produced and has far more operating time and "sunk" development costs than any earlier engine. A problem, however, is its unit cost - - some $45 Million per engine. *StarCore II* sidesteps this shortcoming by recovering the engine, along with other high value upper stage elements, in a ballistic entry body resembling in size and shape the familiar *Command Module* of the *Apollo* program. Recovery on land and in the open sea is possible by use of parafoils, floatation/impact bags, and a sea-going recovery vessel fitted with arresting gear. Shown to the left is a photograph of the StarCore II model prepared for launch by 2 *StarBooster 200* fully reusable boosters. Further photographs of *StarCore II* models in free flight following staging, with its two hydrogen tanks removed after burnout in orbit as the entry vehicle housing the expensive *SSME* is separated to begin its independent journey back to Earth for recovery and reuse.

A candidate "Phase III" of the *StarBooster System*™ will provide an alternative to the *Space Shuttle* for transporting crew members to and from the *International Space Station (ISS)*. This system would not be initiated before the single *StarBooster 200* that launches it has attained maturity and the high reliability required for transporting humans into space by earlier cargo flights. Shown below are photographs of the *StarBird I*™ Phase III aspects of the *StarBooster System*™. *StarBird I* has the passenger capacity for perhaps 12 to 14 persons. Performance considerations, however, limit it to seven persons for the *ISS* crew rotation mission. All personnel are carried in a separable "crew escape module" which can, under worst- conditions, save the personnel although the vehicle is lost.

Finally, we have recently found a means of entering the reusable launch vehicle market at less cost and risk, with the *StarBooster 30* vehicle about the same size as the *F-15* fighter aircraft, powered by reusable engines of the 200,000 pounds thrust class. This vehicle can be launched quickly and economically from the Virginia Space Flight Center at Wallops Island. We now have a Memorandum of Understanding with this group and with their industry partner, Dynspace, Inc. Growth to the more capable *StarBooster 200* described above and even larger systems can come quickly, aided by early revenues from commercial flights with small payloads.

We believe the *StarBooster System* can be quickly fielded for reasonable costs, to the great benefit to commercial, civil, and military space.

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