Appendix E

Relevant Space Technology Studies and Reports

E.1 Spacecast 2020

The Spacecast 2020 study was conducted by Air University in 1994. The study was conducted to identify capabilities for the period of 2020 and beyond and the technologies to enable them that will best support preserving the security of the United States. The study considered the full vertical dimension, including the important region of the transatmosphere that both separates and integrates air and space. The study identified the most important reason to be in space as having the global presence required to maintain global view. Global presence and global view are the enablers for Global Reach, Global Power. The implementation of global presence and the concept of global view depend on:

- An integrated, on-demand information system
- Increased and improved sensing capabilities
- Relatively inexpensive spacelift

Two Spacecast system concepts showed the greatest potential for enhancing space operations:

- Transatmospheric vehicle (TAV)
- Space-based high-energy laser (HEL) system

The study assessed technologies by considering the number of systems each technology supported, the degree to which each system depended on it, and the importance of the system. Three technologies stood out because they were important to a large number of high-value systems:

- High-performance computing
- Micro-mechanical devices
- Navigation, guidance, and vehicle control

Three other technologies were also important, but to a smaller range of systems. These technology areas showed promise to open the way to space systems that would dramatically improve the effectiveness of space operations. These technologies are:

- Materials technology
- Pulsed power systems
- Robotics, controllers, and end-effector

E.2 Space Systems Technology Working Group

The purpose of the Space Systems Technology Working Group (SSTWG) was to identify those technologies that were space-unique, military-critical, and dual-use to provide the basis for policy and priority decisions regarding technology support, cooperative agreements, and export controls. The SSTWG identified and described the military-critical space technologies (using service mission deficiencies as a major input), explained their military significance, identified the key quantitative parameters involved, estimated their dual-use potential, assessed their foreign availability, defined more completely the threshold specifications in order to free from control those technologies that were not militarily critical, and discussed the economic security implications of the critical military and dual-use technologies. The SSTWG concluded:

- All services need an integrated space mission area road map to provide a firm basis for space technology planning and prioritization.
- Modifications to the development process techniques of systems engineering and integration as applied to space systems (defining, developing, manufacturing, integrating, testing, launching and on-orbit operations) have significant potential for greater efficiencies, cost saving, assured access to space, and continued US space leadership.
- Forty technologies of the 116 military-critical space technologies identified and categorized as critical space-unique should be recognized as such in the appropriate DoD documentation. Thirty-six technology areas were considered high payoff areas and candidates for additional investment.
- Payload modules, buses, and interfaces must be standardized to improve technology insertion and provide improved interoperability and savings within the military and commercial space community.
- Selling the products of space technology or on-orbit capabilities rather than selling the specific technology had the significant potential of protecting the US job and production base and associated development and production technologies.

The SSTWG recognized space as a unique environment that provides unparalleled military operational advantages. To withstand space environmental conditions, components must operate in conditions of extreme thermal cycling and radiation exposure and with lifetimes that are measured in years instead of days or weeks. Technologies were divided among 12 subgroups: space systems integration, launch vehicles, structures, propulsion, power and thermal management, communications, electronics and computers, astronautics, sensors and surveillance, optics, vulnerability and survivability, and qualification and testing.

E.3 Seven Strategies for Space

This study identified actions to improve mission accomplishment (global presence in the post cold war world) and to improve resource allocation. The study was conducted because of the need for a comprehensive reexamination of the US space program in light of the changing world environment and reduced resources. The seven strategies included:

- Establish a comprehensive architecture
- Provide an interactive forum for space operations and modernization
- Integrate the requirements processes

- Spearhead joint training
- Adopt horizontal engineering
- Exploit combined test
- Develop new partnerships with industry

E.4 Space Launch Ad Hoc Study

This study was a Scientific Advisory Board study with the following objectives:

- Assess the state of current launch systems, including infrastructure, and define the deficiencies in the current systems
- Review concepts and technologies for improvement of the present and future launch systems, expendable and reusable
- Select approaches which address the shortfalls of current systems, show the merit of those approaches, and identify technologies related to those approaches
- Recommend technology options for reducing development, production, operation, and support costs while supporting reliability and operational flexibility
- Develop a transition strategy from the current launch vehicle inventory to one taking fullest advantage of the most promising concepts and technologies

Deficiencies included costs, responsiveness, scheduling, and reliability. The study found that most of the space launch community did not believe that responsiveness was a major problem. Spacecraft constellations were viewed as robust and offering some flexibility in replacing nonfunctional systems. Some satellites were seen to be so complicated and expensive that a launch delay would be acceptable if changes of successful on-orbit operation would be enhanced. Existing launch systems were found to be significantly limited by design in their ability to provide responsive launch capability. Responsiveness was identified not as a technology limitation, but as a design issue.

The study found that commercial distributed satellite systems will likely bring about a paradigm shift in launch vehicle design, manufacturing and operations, driven by several factors:

- There may be a rapidly growing market for medium to medium- heavy launch vehicles for payload delivery to low altitude orbit
- There will be a market for smaller launch vehicles for constellation maintenance
- There will be a premium on launch on schedule, simple standardized operations, and quantity production
- There is the potential for a larger (factor of two increase) market for medium launch vehicles and facilities that will incentivize improvements
- The trend toward distributed systems may extend to the military

The study called for an examination of the technology drivers in propulsion, vehicle design and operations for:

- Existing launch vehicles
- A new, expendable medium-lift vehicle
- Partially reusable, medium-lift vehicles
- All solid rocket booster
- Single State to Orbit (SSTO) and/or totally reusable systems

Reusable Launch Vehicles (not necessarily single-stage-to-orbit) were identified as the ultimate answer to affordable launch capability.

The panel study recommendations for new launch vehicles included:

- Emphasizing technology development programs needed to resolve questions about the cost, risk, schedule, and feasibility of reusable and partially reusable systems
- Developing any new launch system with standardized payload interfaces, utilizing encapsulated payloads, and minimizing on pad operations
- Including technology demonstrations prior to committing to the development of any new space launch vehicle
- Exploiting the advantages of modular systems in the development of a new launch vehicle

The panel recommended the following high priority investments: clean solids, upper stages, high-energy fuels, storable propellants, and low-cost engines and components.

E.5 Recent DoD Space Launch Studies

The years 1992, 1993, and 1994 were marked by several studies on the issue of space launch. In 1992, Pete Aldridge, former Secretary of the Air Force, led a study effort on behalf of Vice President Quayle and the National Space Council. This study became known as the Aldridge report. In early 1993, NASA responded to Congressional tasking with its own Access to Space Study, which included both NASA and DoD requirements. Almost simultaneously DoD announced its own plans to conduct a "Bottom-Up Review" of space launch requirements. Most recently, Congress (in the FY94 Defense Authorization Act) directed DoD to accomplish yet another space launch study. This study, known as the Moorman Study, was able to achieve consensus within NASA, DoD, the Intelligence community, and the US commercial sector on the needed direction for space launch. The Moorman study was the basis for President Clinton's August 1994 Space Transportation Policy. Each of the foregoing studies is briefly reviewed, highlighting the technology recommendations each made.

E.5.1 Aldridge Report

The Aldridge study focused on the leadership issue for space launch, recognizing that past failures to build a national consensus were the result of too many actors in this arena. The report suggested that a "Space Czar" position should be created, a recommendation that was never seriously considered. As a near term solution to the nation's needs, the report suggested that the Air Force "spacelifter" program be adopted to solve the nation's medium lift needs (up to 20,000 lb to LEO). The Aldridge report recognized that technology is a vital part of the path to the future. A major finding of the Aldridge report was "the technology efforts associated with NASP, SSRT, and HSCT are essential for application to future generations of fully reusable space launch vehicles."[5] The report referenced the ten-year DoD space launch technology plan and indicated that the needed national level of investment in launch technology was on the order of $700M.

E.5.2 NASA Access to Space Study

This study was completed in the summer of 1993. It examined three options for solving the nation's space launch needs. Option 1 maintained the Shuttle and the expendable launch vehicle (ELV) fleet until the year 2030. Option 2 examined developing a new expendable launch system using state-of-the-art technology with a transition date of 2005. Option 3 contained a new, advanced-technology, next-generation reusable launch system and associated technology demonstration program with an operational transition date of 2008. NASA recommended adoption of Option 3. The Executive Summary for Option 3 identified five enabling technologies for the three reusable vehicle options identified in the report. These technologies are:

- Reusable cryogenic tanks
- Vehicle health management and monitoring
- Autonomous flight control
- Operations enhancements
- Long-life/low maintenance thermal protection systems

E.5.3 OSD Bottom-Up Review

The OSD Bottom-Up Review also examined the nation's space launch needs and came to a very different conclusion than NASA. Similar to NASA's study, the OSD Bottom-Up Review examined three options: Alternative 1 considered using today's launch systems; essentially a life extension of the current expendable DoD fleet, Alternative 2 studied the development of a new launch system (included SSTO), and Alternative 3 examined the so-called "leapfrog" reusable launch system options. Leapfrog technology included fly-back first stage, two-stage-to-orbit, and airbreathing rocket single-stage-to- orbit. For primarily affordability reasons, OSD adopted Alternative 1. Alternative 3 identified a list of technologies required:[6]

- Thermal protection systems
- Expander engine with high I_{sp}
- Graphite epoxy truss and tank
- Lightweight metallic tiles

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5. The Future of the U.S. Space Launch Capability, Vice President's SpacePolicy Advisory Board, November 1992
6. DoD Space Launch Systems Review, prepared by SMC, 15 April 1993 and Space Launch Systems Bottom-Up Review, briefing prepared by the Director, Strategic & Space Systems, 4 May 1993

- Landing software
- Hypersonic air breathing propulsion

E.5.4 Moorman Study

A strength of the Moorman study was the effort to include both governmental and commercial space sectors in requirements and investment process. Importantly, the study group came to a consensus on a construct for characterizing the nation's top level launch system requirements. They adopted the CORE model to specify vehicle characteristics: Capable, Operable, Reliable, Economical.

Rather than try to solve the leadership problem by taking equities away from the various sectors, the Moorman study strove to play to sector strengths. To that end, the study recommended that NASA be placed in charge developing the nation's reusable technology. Given the expense of operating the Shuttle fleet, it was judged that reusability and the promise of lower operating costs were vital to NASA in light of its International Space Station venture. Similarly the study recommended that DoD be placed in charge of evolving the nation's expendable launch fleet. This arrangement was later ratified in President Clinton's 1994 Space Transportation Policy Directive. The Moorman study examined four options:

- Baseline President's FY95 budget - continued existing fleet (STS, Delta, Atlas, and Titan)
- Evolved Expendable Launch Vehicle (EELV) option
- "Clean Sheet" ELV option
- Reusable option

The study did not make explicit recommendations, but suggested a two pronged approach to solving the nation's problem: DoD should lead the EELV option and NASA should lead the reusable option. Importantly, the report noted that DoD's space launch technology effort was underfunded and recommended an annual investment on the order of $90M to $120M.