PRINCETON
SYNERGETICS
INC.

145 PARKSIDE DRIVE
PRINCETON, NJ 08540
TELEPHONE [609] 924-2020

Colorado's Strategic Plan for Space [Appendices]

Prepared for

Space Foundation
[Colorado's Space Strategy Initiative]
2860 South Circle Drive
Colorado Springs, CO 80906

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The Study Team

Space Foundation

Elliot G. Pulham
Senior Vice President, Customer & Public Affairs

Princeton Synergetics, Inc.

Joel S. Greenberg
President

Futron Corporation

Carissa Christensen
Director, Space & Telecom Industry Analysis

Evelyn Brewster
Director, Advanced Communications Solutions

Robert K. Morris
Program Manager

Pam Luskin
Analyst

Stephanie Roy
Analyst

Consultants

Dr. Marshall Kaplan
Chairman, Launchspace Consulting Group

Dr. Henry Hertzfeld
Sr. Research Scientist, George Washington Univ.

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Appendix A: Space Technology: An Overview

1.0 Introduction

The strategic plan for space of the State of Colorado must consider the technology needs in support of future space endeavors. It must also address Colorado's capabilities to participate in the identified technology areas. Technologies for space represent a most ambitious and complex opportunity for advancement and growth of state resources, because space technologies impact all aspects of life, economics and the environment.

Space technology includes all those activities which involve the application of science to space flight, space infrastructure and applications of the space environment. The following paragraphs present a brief description of the many technologies and related programs which are designed to pursue their application. Additionally, the rationale and justification for each activity in the context of future needs are identified. Emphasis has been placed on two aspects: [1] longer term strategic technology efforts that may have broad impact across the full spectrum of space activities; and [2] those technologies which may increase the transfer of the space technology investment to non-space applications. In both cases the value of the investment is greatly enhanced.

In the context of space, "technology" is defined as the practical application of basic knowledge, derived from basic science, to create the capability to do something entirely new or in an entirely new way. "Engineering" is the process of using technology to solve specific technical problems. Technology is distinguished from "scientific research," which is the discovery of new knowledge.

A particular technology begins with an idea, and as more time and energy are invested, it begins to advance in the direction of maturity. This process consists of various steps of testing and analysis which progressively reduce the risks of implementing that technology in the form of an application, i.e., the process of increasing readiness for use in a mission. In fact, NASA has developed a scale which defines and quantifies Technology Readiness Level [TRL], the levels which reflect the extent to which a technology has been proven in a realistic situation. NASA policy dictates that it will fund technology efforts up to TRL 6, or in those cases where the space environment is required to fully demonstrate the technology readiness, up to TRL 7. The technology overview presented in the following paragraphs is limited to those aspects which are likely to assist in the strategic planning process for the State of Colorado.

Technology needed for the space program and its applications can be divided into two types. The first is that technology enabling space science and other missions to be carried out. Such technology pursuit is the mission of NASA and other government agencies interested in space. The second is that technology enabling and enhancing the use of space for practical applications and is pursued by both government and industry. A good percentage of both types do find their way into non-space applications through technology transfer.

A great deal of technology development is driven by scientific, military, operational or business objectives and has resulted in schedule slips and cost overruns in government and private sector programs. NASA has recently attempted to change this situation by taking a different approach to defining space missions. Instead of selecting missions on the basis of desirability of scientific objectives and opportunities, it now pursues needed technologies for certain types of missions in advance. This approach is referred to as "missions enabled by technologies." In the private sector this has been the "de facto" approach for highly conservative companies. For example, companies which offer "fixed" and "direct broadcast" communications services via satellite are extremely reluctant to add technology which has not been flight proven. Although this philosophy has delayed the addition of such devices as electric thrusters to GEO satellites, such companies have been highly successful from a financial viewpoint.

The latest approach to balancing mission needs with available technology is being implemented at NASA and in industry by creating what is called a "Collaborative Engineering Environment." The basic concept is to enable the continual and rapid exploration of new technology effects and advanced concepts on potential space missions and applications. This approach helps to guide advanced technology investments and to determine when critical technologies are ready to be incorporated into missions at an acceptable level of risk. Most effective use of the collaborative engineering environment is achieved when the best analytical tools for engineering and design have been incorporated, and the best communications networks link the various participants. This environment allows simultaneous involvement by advanced technology specialists from government, industry, and academia.

NASA is working hard to bring about long-term evolutionary improvements in technology investment strategies. It has initiated the "intelligent synthesis environment" [ISE], which is intended to be NASA's future science and engineering design, development, and operational environment. The objective is to significantly enhance the rapid creation of innovative, affordable products and missions by providing design teams with holistic representations of products and design processes throughout the life cycle

Technology advances needed to support future government and private sector missions are daunting in terms of complexity and cost. Thus, whenever possible, industry and government agencies should share technology challenges and costs. One important function of governments, including state governments, is to help identify areas in which technologies or capabilities may already exist or where common interests could lead to collaborative efforts.

Technology investment strategy in the private sector is typically rather simple and conservative. There is no investment unless there is a direct link to profits, market share retention, or expansion. Usually, such investment means less profit. Thus, help from governments is a technology enhancing factor, and many companies pursue such help from federal and state governments. For example, NASA has three investment approaches to addressing its technology needs. The first is associated with areas where NASA can take advantage of services provided by the private sector. The National Space Policy, requires NASA to take advantage of commercially available systems and services, e.g., commercial launch and communications services. A second approach applies when commercial demand for products or services may not exist or not be sufficiently mature to support private sector investment. In such cases, NASA or other government agencies may identify opportunities for partnerships and joint investments. The X-33 program, a joint partnership between NASA and Lockheed Martin, is one example. The third approach applies when technology demands are unique to NASA mission needs. In this type of situation NASA must make the technology investment either by supporting industry and academia through contracts and grants, or by supporting efforts within NASA and with other government agencies.

2.0 Sources of Technology Requirements

The motivation for technology advancement in the space program comes from the need or desire to: [1] enable science missions; [2] create a military advantage; [3] carry out other government operational requirements; and [4] creation and advancement of business objectives. The first three motivating factors represent technologies which are supported by government, both at the federal and state levels. The fourth factor is created by the desire of the private sector to better compete and increase profits. All factors represent real and compelling reasons to pursue technology advances.

In Fulfillment of Space Science Missions:

In the past few years, faint folds have been seen in the fabric of the Universe, the most ancient ancestors of all the galaxies, stars, and planets that surround us. Telescopes have been used on the ground and in space to discover disks of gas and dust surrounding young stars--nurseries of potential worlds--and to discern evidence for giant planets orbiting nearby stars. Living creatures have been found in extreme environments previously not thought capable of sustaining life--the dark depths of Earth's oceans and the dry valleys of the Antarctic. Meteorites from Mars have been studied, one of which shows evidence of the presence of ancient water and the chemical building blocks of life, and--possibly--tiny, fossilized microbes. Spacecraft have returned images of what may be ice floes above a liquid water ocean on Jupiter's moon Europa, and raised the question if life may begin on moons as well as planets. A comet has been seen colliding with Jupiter and a supernova has been observed from its initial explosion to an expanding gas cloud. It has been determined that Earth's climate, biosphere, and the workings of the entire technological civilization are profoundly influenced by the behavior of the Earth's varying Sun, a star that can be studied close-up. Giant black holes have been detected that may be as massive as a billion suns at the center of the galaxy and in other galaxies, turning centuries of theory into fact. Bursts of gamma rays have been observed from distant reaches of space and time, momentarily more powerful than a million galaxies. Understanding of the Universe has been altered forever.

NASA that has the sole responsibility for accomplishing space-related science missions, and its stated space science objectives are:

- To advance and communicate scientific knowledge and understanding of the Earth, the solar system, and the universe and use the environment of space for research.
- To explore, use, and enable the development of space for human enterprise.
- To research, develop, verify, and transfer advanced space and related technologies.

Based on these high level objectives NASA has been charged with answering six fundamental questions of space science and research:

- How did the universe, galaxies stars, and planets form and evolve? How can our exploration of the universe and our solar system revolutionize our understanding of physics, chemistry, and biology?

- Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on planet Earth? Are there Earth-like planets beyond our solar system?
- How can we utilize the knowledge of the Sun, Earth, and other planetary bodies to develop predictive environmental, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?
- What is the fundamental role of gravity and cosmic radiation in vital biological, physical, and chemical systems in space, on other planetary bodies, and on Earth and how do we apply this fundamental knowledge to the establishment of permanent human presence in space to improve life on Earth?
- How can we enable revolutionary technological advances to provide space travel for anyone, anytime, anywhere more safely, more affordably, and with less impact on the environment and improve business opportunities and global security?
- What cutting-edge technologies, processes, and techniques and engineering capabilities must be developed to enable our research agenda in the most productive, economical, and timely manner? How can we most effectively transfer the knowledge we gain from our research and discoveries to commercial ventures?

Although much has been learned, many questions remain to be answered. The quest for the answers has taken the form of an initiative called the "Origins Initiative." It is a set of new missions and enhancements to current programs, which emerged from NASA's efforts in strategic planning as directed by President Clinton's call for a reconsideration of space science following the August 1996, announcement that a Martian meteorite contained possible evidence of ancient microscopic fossilized organisms. As a result science and technology "Roadmaps" evolved for each of four science themes:

- Structure and Evolution of the Universe
- Astronomical Search for Origins
- Solar System Exploration
- Sun-Earth Connection

The President requested funding for the Origins Initiative, and the resulting programs include:

- An enhancement to the Mars Surveyor Program enabling return of selected samples from Mars by a mission launched in 2005.
- A series of missions to the outer planets including missions to Europa and Pluto and the Solar Probe, which first flies by Jupiter (first New Start in 2000).
- The Space Interferometry Mission (New Start in 2001).
- The Next Generation Space Telescope (New Start in 2003).
- The Terrestrial Planet Finder (New Start in 2007).
- Enhanced technology investments to enable the above missions.
- An enhanced Astrobiology research and analysis program.

These programs are aimed at satisfying 19 objectives of the space science program:

- Observe the earliest structure in the Universe.
- Observe the emergence of stars and galaxies in the very early Universe.
- Observe the evolution of galaxies and the intergalactic medium.
- Measure the amount and distribution of dark and luminous matter in the ancient and modern Universe.
- Test the Theory of General Relativity.
- Identify the origin of gamma-ray bursts and high-energy cosmic rays.
- Study compact objects and investigate how disks and jets are formed around them.
- Study the formation and evolution of the chemical elements and how stars evolve and interact with the interstellar medium.
- Measure space plasma processes both remotely and *in situ.*
- Observe and characterize the formation of stars, protoplanetary disks, and planetary systems, and detect Neptune-size planets around other stars.
- Measure solar variability and learn to predict its effect on Earth more accurately.
- Study the interactions of planets with the solar wind.
- Characterize the history, current environment, and resources of Mars, especially the accessibility of water.
- Determine the pre-biological history and biological potential of Mars and other bodies in the solar system.

- Determine whether a liquid water ocean exists today on Europa, and seek evidence of organic or biological processes.
- Investigate the composition, evolution, and resources of the Moon, small bodies, and Pluto-like objects across the solar system.
- Complete the inventory and characterize a sample of near-Earth objects down to 1-km diameter.
- Reconstruct the conditions on the early Earth that were required for the origin of life and determine the processes that govern its evolution.
- Investigate the processes that underlie the diversity of solar system objects.

A central technology element of the overall space science program is developing new capabilities and innovative techniques that will enable the challenges set forth above to be met. The identified missions must be accomplished within fixed budgets that are dramatically lower than those of past generations of missions. In many cases they require fundamentally new observational and measurement techniques. To meet these needs, NASA must be committed to an aggressive and carefully planned program of technology research, development and utilization in which mission concepts and supporting technologies are developed in synergism. As a result, four pillars of the technology program have been defined:

- An aggressive, long-range core technology program to enable the next generation of high performance and cost-effective space science missions.
- A solid, mainstream set of focused technology programs to enable near-term emerging missions.
- A flight validation program, complemented by advanced development to bring laboratory pre-prototypes to flight readiness.
- A far-reaching mission studies and advanced concepts program to explore the full range of near- and long-term mission options and how to achieve them.

NASA has begun to form partnerships with industry and universities. This will ensure that the revolutionary developments that result from this program will be infused into the American economy via a pathway of new products, new commercial applications, and enhanced competitiveness for the benefit of the entire nation. At the same time the space science program is committed to the principles of open competition and merit review as a key to excellence. Thus, fundamental technology research is being selected through open, peer-reviewed competition.

All this has resulted in a set of five technology goals, which are being pursued by NASA:

- Lower mission life-cycle costs and provide critical new capabilities through aggressive technology development.
- Develop innovative technologies to address far-term scientific goals, spawn new measurement concepts and mission opportunities, and create new ways of doing space science.
- Develop and nurture an effective science-technology partnership to help optimize mission concepts and infuse new technologies into science missions, with the goal of dramatically lowering mission cost and risk.
- Stimulate cooperation among industry, academia, and government to ensure that the nation can reap the maximum scientific and economic benefit from its space science mission and technology programs.
- Identify and fund the development of important "cross-cutting" technologies that support NASA's space science program and other NASA missions.

In Fulfillment of Military Missions

The government uses space for national defense, just as it uses the army and air force. Specific military applications of space include weather data collection, navigation on and near the ground, secure communications, nuclear and missile detection, reconnaissance and surveillance, and battlefield command and control.

The Department of Defense carries out research in several venues, i.e., government laboratories, universities and industry. For example, DARPA's mission is to develop imaginative, innovative and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and, to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems. Phillips Laboratory incorporates the Space Vehicles, Geophysics and Propulsion Directorates.

In Fulfillment of Other Government Missions

In addition to NASA and the military, the government uses space for a variety of operations in the national interest. Specific examples include the public weather service and search and rescue detection satellites. Soon, air traffic will be controlled from satellites.

In Fulfillment of Private Sector Objectives

The pursuit of technology in the private sector is simply a means to an end. Specifically, most business motivation is based on revenues, costs, competition, and market position. All of these lead to the objective of profit maximization. In some ways the commercial space business is like many other competitive businesses. But, in other ways it is unique. The combined global commercial satellite industry, the U.S. Government and foreign [excluding China and Russia] governments accounted for close to $100 billion in space spending and revenues in 1999. Colorado's share amounted to $3.3 billion which generated 38,000 jobs [direct]; $87,000 per direct job. Thus, a high level of productivity must be maintained while competing efficiently. It is technology and constant pursuit of more technology that allows this to continue.

Today, the business-to-business part of commercial space involves a variety of products and services, many of which are profitable, and all of which use a great deal of technology. But, a great deal more technology is needed to reach future objectives. For example, the cost of access to space is prohibitively high for most would-be users. An order of magnitude reduction is needed desperately, in order to open new space-based markets. Another order of magnitude reduction is needed before the general public is likely to take advantage of space travel.

The consumer market already makes use of space-based assets to provide a number of useful services. The most successful segment of the market for space-based services is in the communications arena. For example, there are over 200 active satellites in orbit over the equator acting as relay stations for the transfer of telephone calls, television programming, data and other information from many points on the Earth to many other points. As the cost of space access is reduced, the number of successful space-based businesses is likely to increase dramatically. There will be more communications satellites, new consumer applications, tourism, and more.

A Summary of Space Applications and Missions

Today, space is used for a variety of missions, operations, and services. However, the potential for expansion is very high. Listed below are many current and potential uses of the space infrastructure. Most are not yet available, but these and many more missions and applications will become real in the coming decades, thanks to new technology. The following is a summary of current and potential space-based applications and missions:

- **Communications:** Fixed satellite services, direct broadcast services, mobile satellite services, and data collection and forwarding.
- **Government Missions and Operations:** Navigation [GPS], space science research, life sciences experiments, treaty verification, technology development and demonstrations, law enforcement, space debris management, search and rescue, weather data collection and forecasting, human and automated planetary exploration, asteroid detection and mitigation, and international cooperation.

- **Transportation:** Space rescue, fast package delivery, space servicing and transfer, hazardous waste disposal, space tourism, and ultra hypersonic transportation.
- **New Orbital Missions and Operations:** Space medical facilities, orbiting hospitals, space settlements and agriculture, and orbiting business parks.
- **Remote Sensing:** Land use surveying, crop infestation and disease, private weather observation and modification, geographical information services, upper atmosphere exploration, and real-time surveillance.
- **Space Manufacturing:** Space mass production of consumer products, microgravity processing, university research, biological products and laboratories, and space robotics
- **Novel Applications:** Space burial, theme parks, athletic events, and movie studios.
- **Extraterrestrial Resources:** Lunar-based He_3 and asteroid mining.
- **Advertising:** Orbiting billboards and space product demonstrations.
- **Space Utilities:** Solar power satellites and artificial moons.

Technology Investment Budget

NASA's total annual technology investment budget is roughly $2 billion, the major part of which goes to space projects. The military annual space technology investment budget is roughly $3 billion. These funds are shared among the AF, Navy, and Army. Other government operations related to space include intelligence gathering, weather data collection and data handling. The annual technology budget for these is not available but is estimated at roughly $10 billion.

3.0 Enterprise Technology Needs

This strategic plan provides Colorado with a vision of the future of space missions and enterprises, and it indicates what technologies are likely to be developed.. This can then be used to identify areas within which Colorado can participate with current capabilities and areas which need development. This section addresses each of the needed technologies, and discusses how these needs were derived.

Technology for Space Science Missions

NASA generated a set of six fundamental questions addressing its objectives in the area of space science, and these were presented above. As a result, specific science goals were formulated to guide efforts for two time frames, i.e., 2000 to 2004 and 2005 to 2020. It is clear that technology is pivotal for reducing significantly spacecraft development cost and time, and significantly increasing the number of missions launched each year. And, new technology is critical to enabling new levels of performance and capability required by the proposed set of space science missions. The previously identified technology goals require advances in the following 10 key capabilities:

- Advanced Structures Deployment and Control
- Communications
- Design Tools and Spacecraft Operability
- Lightweight Optics
- Metrology
- Power
- Sample Acquisition and Return
- Science Instruments
- Spacecraft Systems and Intelligence
- Transportation and Mobility

The identification of these capabilities resulted from road mapping studies conducted by NASA in 1996 and early 1997, with the help of teams of space scientists and technologists working with universities, industry, and other government agencies. A set of reference missions appear at the core of each roadmap, and each mission requires technology advancements to succeed. The Table A.1 relates these missions to enabling capabilities.

The intimate relationship between mission studies and technology program manifests itself in the evolution of technology-push efforts formulated in response to broadly conceived technical challenges derived from science goals. If early work on a technology confirms the fundamental validity of the approach, its initial findings and parameters may be incorporated into early mission definition studies to determine its usefulness in a preliminary science mission setting. This, in turn,

Table A.1 Key Technology Capabilities Which Enable or Enhance Future Space Science Missions

Future Missions	Solar Terr Probes	Solar Probe	Europa Orbiter P/K Express	Mars Surveyor	NG Space Telescope	Space Interferom Mission	Terr Planet Finder	Far IR Sub-MM Telescope	γ-Ray Tele-Scope	Constel X-Ray
	Enterprise Key Capabilities									
Structures					A	A	A	H		
Communic.	H	H	H	H	H	H	H	H	H	H
Design Tools	H	H	H	H	A	A	A	H	H	H
Light Optics					A	A	A	A		
Metrology					A	A	A			
Power	H	A	H	H	H	H	H	H	H	H
In Situ Sampling				A						
Instruments			H	H	A	A	A	A	A	A
S/C Sys & Intel	H	H	H	A	A	A	A	A	H	H
Mobility		H	H	A						

Legend: H = Enhance; A = Enable

Table A.2 Details of the Ten Key Capabilities for Space Science Missions

- Advanced Structures Deployment and Control
  - Large Lightweight Nonprecision Structures
  - Lightweight Optically Precise Structures
  - Advanced Lightweight Materials
- Communications
  - Microcommunications RF Systems
  - Optical Communication systems
  - High Rate RF Systems and Components
- Design Tools
  - User Interfaces
  - Collaborative Design Infrastructure
  - Integrated Design and Simulation Tools
  - Verification and Validation
- Lightweight Optics
  - Large Lightweight Mirrors
  - Deployable Telescopes
  - Optical Control Systems
  - Instrument Optics Components
- Science Instruments
  - Submillimeter and Microwave Instruments
  - UV, Visible, and Infrared Instruments
  - Spectrometer and Radiometer Systems
  - High Energy Instruments
  - Active Optical Systems
  - Radar Systems
  - In Situ Systems
  - Cryocoolers and Cryogenic Systems
- Metrology
  - Vibration Control Systems
  - Precision Active Optics
  - Precision Actuators
- Sample Acquisition and Return
  - Sample Selection and Acquisition Systems
  - Sample Preparation and Storage Systems
  - Sample Recovery and Quarantine
- Power
  - Energy Storage Systems
  - Power Conversion
  - Photovoltaic Power Systems
  - Nuclear Power Systems
- Spacecraft Systems and Intelligence
  - Advanced Spacecraft Architectures
  - Instrument and Spacecraft Computing Systems
  - GN&C Sensors and Actuators
  - Autonomous Science Algorithms and Architectures
  - Autonomous Operations Components and Algorithms
- Transportation and Mobility
  - On–Board Spacecraft Propulsion
  - Surface Mobility and Navigation Systems
  - Atmospheric Mobility and Navigation Systems
  - Subsurface Mobility Systems
  - Aeronomy, Aerocapture, Aeroassist Systems
  - Planetary and Small Body Ascent Propulsion Systems

could provide more complex and constraining conditions that laboratory and testbed validations of the technology being studied must satisfy. As a result of this process, emphasis shifts from one of technology pushing a mission scenario to one of science mission pulling the technology toward application via ground or space-based system demonstrations designed to provide confidence that the planned application of the technology can meet project requirements.

Continuing analyses and mission studies have refined the detailed content of each of the 10 key capabilities, as indicated in Table A.2.

Technology for Earth Science Missions

Earth science missions are dedicated to understanding the total Earth system and the effects of natural and human-induced changes on the global environment. The objective is to answer the fundamental question:

> *How can we utilize the knowledge of the Sun, Earth, and other planetary bodies to develop predictive environmental, climatic, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?*

The related technology questions are:

> *What cutting-edge technologies, processes, techniques and engineering capabilities must we produce to enable our research agenda in the most productive, economical, and timely manner?*
> *How can we most effectively transfer the knowledge we gain from our research and discoveries to commercial ventures in the air, in space, and on Earth?*

The goals of NASA's earth science program are:

- Expand scientific knowledge of the Earth system using NASA's unique vantage points of space, aircraft, and in situ platforms, creating an international capability to forecast and assess the health of the Earth system
- Disseminate information about the Earth system
- Enable the productive use of Earth science and technology in the public and private sectors

Three major areas of focus for technology are:

- Advanced instrument and measurement technologies for new and/or lower cost scientific investigations that will expand scientific knowledge of the Earth system using space, aircraft, and in situ platforms. These include:

  Instrument and sensor architectures that provide significant reductions in the end-to-end implementation costs by decreasing mass, launch volume, power, and operation complexity for the whole spectrum of Earth-observing instruments
  Instrument and sensor architectures that enable new, high-priority science in support of the ESE research themes
  Active sensors for space-based lidar and radar applications with improved lifetime, efficiency, and performance, as well as with reduced mass, launch volume, and cost
  Detector arrays and passive sensing systems covering the wavelength bands of interest to Earth science that reduce

instrument accommodation requirements and simplify calibration, integration, and operations

Miniature, self-contained instrument packages for in situ and remote-sensing measurements from aircraft, balloons, ocean buoys, etc.

- Cutting-edge technologies, processes, techniques and engineering capabilities that reduce development and operations costs and that support rapid implementation to support productive, economical, and timely missions. These include:

  Techniques and algorithms that enable achievement of science objectives by formation flying of small spacecraft, including calibration and data fusion considerations

  Mechanical and electronic innovations that simplify design, fabrication, and operation and provide significant reductions in spacecraft system and subsystem resource requirements

  Increased levels of spacecraft and/or ground system autonomy that streamline operations and that simplify and reduce the cost of command, control, and monitoring of the flight segment

  Onboard data fusion and interinstrument data comparison for autonomous, multi-instrument campaigns and onboard, adaptive data acquisition strategies combining multiple resources including multiple spacecraft, airborne, and ground capabilities

- Advanced end-to-end mission information system technologies for collecting and disseminating information about the Earth system and enabling the productive use of ESE science and technology in the public and private sectors. These include:

  Improvements in collecting, compressing, transmitting, processing, distributing, and archiving data from all Earth remote-sensing and in situ sensing assets

  Effective approaches for linking multiple data sets and for extracting and visualizing information on the global Earth system

The technology needs of the earth science program are closely aligned with strategic technology areas identified by NASA:

- Advanced miniaturization will enable smaller, more capable missions in space, as well as on radiosondes, unpiloted air vehicles, ocean buoys, etc.

- Intelligent systems will enable the cooperative and adaptive use or multiple remote-sensing and in situ sensing assets to respond to a dynamic Earth with minimum human interference.
- Compact sensors and instruments are the hearts of any Earth science measurement system, and advances in these technologies will enable smaller missions and opportunities to leverage commercial and other cooperative mission opportunities.
- Although self-sustaining human support does not directly apply to Earth science technology needs, some synergy exists between the sensing, monitoring, and modeling needs of this area and ESE.
- Similarly, the deep space systems area will develop systems tolerant to conditions that could support Earth science in the exploration of volcanoes, the deep oceans, and other extreme environments.
- The intelligent synthesis environment, in addition to streamlining the development of missions, will directly support the collaborative scientific endeavor needed to address the Enterprise's 25-year focus of expanding scientific knowledge by forecasting and *assessing the state of the Earth system with regional accuracy on decadal time scales.*
-

Technology for Human Exploration and Development of Space

Human exploration and development of space activities are based on the objective of answering the fundamental question:

> *What is the fundamental role of gravity and cosmic radiation in vital biological, physical, and chemical systems in space, on other planetary bodies, and on Earth, and how do we apply this fundamental knowledge to the establishment of permanent human presence in space to improve life on Earth?*

The related technology questions are:

> *What cutting-edge technologies, processes, techniques and engineering capabilities must we produce to enable our research agenda in the most productive, economical, and timely manner?*
> *How can we most effectively transfer the knowledge we gain from our research and discoveries to commercial ventures in the air, in space, and on Earth?*

The broad goals of this endeavor are:

- Explore the role of gravity in physical, chemical, and biological processes
- Prepare to conduct human missions of exploration
- Continue to open and develop the space frontier

- Aggressively seek investment from the private sector

To achieve these goals NASA has identified the needed technologies on a goal-by-goal basis. For goal 1, the program needs advanced data handling, control, and communications technologies. Technology requirements include high-bandwidth ground-to-space communications, the fusion of dissimilar data types, and advanced video processing, as well as improved ground-based data networks. In addition, increasingly advanced software and data management systems will allow remote operations [ground-based control], as well as more autonomous on-orbit operations. Some applications will need advanced telerobotics technologies.

Advanced vibration isolation technologies [both passive and active] could significantly improve the scientific returns from future microgravity research projects-in particular, in the use of the ISS for such studies. In addition, technology development for high-temperature microgravity heat pipe technology [directed toward advanced furnace liners] is essential future solidification research. As noted below, implantable miniaturized biotelemetry sensors are required to enable the unrestrained monitoring of physiological parameters in rodents and small primates over periods of weeks. Similarly, miniaturized biotelemetry sensors and systems are needed for scientific monitoring of human crew subjects.

For goal 2, scenarios, concepts, and technological approaches must be developed that achieve at least an order-of-magnitude reduction in the costs of both non-transportation systems for human exploration beyond Earth orbit, and space program operations. In addition, safe, self-sufficient, and self-sustaining advanced technologies and systems must be developed that can enable humans to live and work in space and on other planets, for extended periods of time.

For goal 3, the Space Shuttle system must be improved through advancements in the areas of avionics, thermal protection systems [TPS], power generation, and various propulsion systems. Several operations-oriented technologies are also important to the Shuttle, e.g., EVA systems, cryogenic fluid storage and transfer, and communications systems.

A program of upgrades and systems enhancements for the International Space Station [ISS] will be needed following its completion of assembly. In the nearer term, some enhancements to support crew safety will be needed, such as: low-mass, long-lived energy storage systems; advanced power management and distribution; advanced thermal management capabilities; advanced reboost/propulsion capabilities; improved structural materials for Earth-orbiting structures; avionics; guidance, navigation, and control; software; and integrated system health monitoring. Enhancements in telerobotics operations and other telepresence technologies will be needed to enhance onboard research and free-flying platform operations and servicing and to reduce the costs related to crew training. In addition, advances in diverse operational and environmental sensors will be needed, taking advantage of developments in micro- and nano-technology.

In the longer term, a number of technology advances are needed to support options for future ISS evolution while driving down costs. Evolutionary systems options include improved habitation and interconnection nodes, advanced space power and thermal control systems, new logistics systems, enhanced accommodations for pressurized research, external research and free-flying platforms, and continuing improvements in operations.

To enable these options, needed technology advances are: new structural materials and concepts; improved artificial intelligence; more dexterous tele-robots; new sensors; better solar energy conversion systems; more efficient thermal control systems; and better power management, distribution, energy storage, and chemical processors.

For goal 4, various communications technologies must be improved such as microminiaturized communications and navigation systems, autonomy in-flight and ground operations, advanced data handling, and the achievement of interoperability among government and commercial systems. Specifically, high-bandwidth, multiple-beam links provided by communications satellites with onboard processing through a global information infrastructure will play an important part in enabling commercial global telemedicine because of the unique ability to connect remote, mobile, and rural areas with urban medical care centers.

Promotion of private-sector investment in the human exploration and development of space can be accomplished by facilitating the use of space for commercial products and services. For example, NASA has privatized Space Shuttle operations and is studying the feasibility of commercializing Shuttle and ISS operations. NASA would like to commercialize its space communications operations.

Technology challenges include assuring that the Space Shuttle and ISS operate at continuously improving levels of safety and efficiency while supporting commercialization opportunities-for example, including advanced solar array power generation, power management, and integrated energy storage and attitude control flywheels.

Technology for Space Transportation

Space transportation improvements are based on the objective of answering the fundamental question:

> *How can we enable revolutionary technological advances to provide space travel for anyone, anytime, anywhere more safely, more affordable, and with*

less impact on the environment and improve business opportunities and global security?

In the United States, the cost of space access is roughly $10,000 per pound of payload delivered to low-Earth orbit. Over the last 25 years, we have developed only one major new launch system and one rocket engine-the Space Shuttle and the Space Shuttle Main Engine. In the same timeframe, other nations have developed more than 25 rocket engines and many more launch vehicles. U.S. launchers, once pre-eminent, now supply less than 40 percent of the worldwide commercial market in terms of dollars. In the world's rapidly expanding launch business, the United States must continue to lower launch costs to maintain its market share. Within NASA, the Space Shuttle expends nearly 25 percent of its annual operating budget and is the primary area that must be addressed to expand space transportation technologies in today's tight budget environment.

Enabling the full commercial potential of space and the expansion of space research and exploration will require truly affordable and reliable access to space. Two enabling technology objectives have been identified in order to respond to this challenge. The first objective is to reduce launch cost to low-Earth orbit by a factor of 100, by 2022. And, the second is to reduce the in-space transportation cost by a factor of 10, by 2012.

NASA's Reusable Launch Vehicle [RLV] program is structured to respond to the industry's need to reduce or eliminate the technology risk of building a new system. The centerpiece of the program is a series of flight demonstrators [X-vehicles] that serve to force technologies from the laboratory into real-world operating environments. This approach will provide the level of technology maturity through demonstrated system concepts required to retire the unacceptable development risk. NASA has incorporated this commercial focus from early technology planning through program implementation and evaluation. Innovative partnerships have been formed that strengthen the alliance between industry and government, thus eliminating unfocused technology and assuring convergence between commercial capabilities and national needs.

The primary technology challenges for the RLV program are:

- Highly reusable technologies which are mass-fraction scaleable to a single-stage-to-orbit rocket launch system, including the primary structure, cryogenic tankage, insulation and thermal protection system
- Robust subsystems which will enable vehicles with at least a 100-mission life, 20 flights between depot maintenance, and an order of magnitude reduction in processing labor hours compared to the Shuttle
- Durable, light weight thermal protection systems that will be easy to inspect, maintain, and repair

Table A.3 Factors for a Highly Reusable Space Transportation System

• Payload Range	20,000-40,000 pounds
• Propellant Mass Fraction	Less than 80%
• Propellant Mass Fraction	Greater than 5% [allowing for increased robustness]
• Vehicle Life	1,000-2,000 Flights per airframe
• Engine Life	Greater than 200 flights per engine with 50-60 flights between major overhaul
• Propulsion System	ISP effective greater than 550
• Operability	Less than one week turn-around between flights
• Reliability	0.9999 for engine /0.9995 for vehicle
• Personnel	Less than 200 people in recurring operations
• Production Costs	$5,000-$10,000 per pound of vehicle
• Development Costs	$5B-$10B [industry/government shared]

- Main propulsion system with thrust-to-weight at least 80 with robust subsystems that will enable at least a 50 percent reduction in engine inspection time between flights as compared to the Shuttle
- System reliability of at least 0.995 for mission success and 0.999 for vehicle/payload recovery
- DDT&E costs and production costs less than one-third that of the Shuttle.

In addition, there is a 25-year objective of building on earlier aeronautics research and technology programs to create highly reusable vehicle systems and propulsion systems beyond the current RLV focus. This would allow dramatic reduction in vehicle life-cycle costs. Recently, NASA concluded that the criteria for the highly reusable space transportation system should include the factors listed in the Table A.3.

The initial focus for advanced reusable technologies has been on air-breathing rocket-based combined cycles because of an air-breathing rocket's potential to substantially increase engine performance over the pure rocket system. Future technology investments will focus on advanced materials to reduce weight and improve engine life, advanced nozzles to improve performance, and turbomachinery technologies to improve reliability and engine life. The aim will be to mature technologies through ground testing and analyses to the point where they can be considered for flight evaluation.

The second objective of reducing the in-space transportation cost by 10, is also important. Most space missions will require placement of payloads into orbits significantly higher than low-Earth orbit. Over the next 10 years, more than 30 percent of the planned expendable launches will be to geosynchronous orbit. Because approximately 60 to 70 percent of the weight of a typical geosynchronous satellite and its upper stage is the propulsion system [including propellant], significant leverage can be obtained through performance improvements in the in-space propulsion area. Performance improvements can be used to either increase payload capability or to step down to a smaller, less costly launch vehicle. For RLV, reduced requirements for upper stages will provide significant leverage for increasing delivered spacecraft weights to operational orbits. Significant opportunities exist to improve in-space propulsion performance capability either as part of a separate upper stage or as part of the spacecraft onboard integral propulsion system, which is used for transfer to the initial operational orbit, for orbit Delta-V maintenance, and for final end-of-mission disposal. Significant investments have been made by Government and industry in evolving solid, liquid-storable, cryogenic, and electrochemical systems. The primary focus is on advanced technologies to reduce system weight and improve performance. Government-industry efforts are jointly coordinated through an Integrated High Payoff Rocket Propulsion Technology Initiative.

Propulsion systems based on energy sources external to the spacecraft hold promise for significant reductions in propulsion system weight. Near-term technologies based on solar electrostatic technology [1 to 4 kilowatts] are currently being considered for spacecraft Delta-V maintenance and disposal. Power levels on the order of 20 kilowatts will be required in combination with chemical propulsion for orbit raising and orbit insertion. The limiting factor to the extent of electric propulsion utilization is the amount of time the spacecraft operators will be willing to wait for final insertion and initiation of operations. Nominal trip times from 60 to 120 days seem to be feasible to commercial operators and could result in improvements in delivered spacecraft weight by more than 20 percent. The development and demonstration of electrostatic [Hall-effect] propulsion for this application is a top priority by both NASA and Department of Defense space transfer technology programs. Another promising technology is solar-thermal propulsion if specific impulses on the order of 1,000 seconds can be obtained in an operational system; however, significant technology advancements will be required. Electrodynamic tether propulsion also shows promise for propellantless Earth orbit transfer. The technology for tethers is relatively mature, and a flight demonstration is planned to validate a small deployer system to deorbit an upper stage within days instead of the months now required. In the long term, reusable orbit transfer vehicles, either space based or returned to ground for turnaround, are key to achieving an order-of-magnitude reduction in orbit transfer costs.

Propulsion is a technology discipline critical to NASA's long-term future. Breakthrough technological approaches may be necessary for Earth-to-orbit vehicles to achieve several orders-of-magnitude reduction in launch costs. Space exploration will continue to become more ambitious. Performing an interstellar mission is an enormous challenge for space propulsion. Sending a spacecraft to our nearest neighboring star within one's career time span is a very difficult task, requiring the spacecraft to accelerate to a significant fraction of the speed of light. A large number of science objectives may be accomplished at interstellar precursor distances; exploration of the Oort Cloud and the Kuiper Belt, sampling of the interstellar medium, and refined stellar parallax observations are some examples of ambitious intermediate goals. Routine human space travel within our solar system would also benefit from high-power density propulsion technologies. The primary technology challenge is dramatic improvement in propulsion performance, including advanced cycles, new onboard energy sources, offboard energy sources, and breakthrough physics. A list of the technology challenges for improved propulsion performance includes:

Reusability:

- Long life, high power electric propulsion systems (Hall-Effect Thrusters) combined with high power solar power systems enabling direct power conversion
- Precision aeroassist/aerobraking for the return trip to Earth or Earth orbit
- Light weight, reusable thermal protection systems for earth return

In-space operations:

- Reusable cryogenic engines
- Long-term cryogenic propellant storage
- Management, and autonomous rendezvous will be necessary for any space basing option

Space science and exploration:

- Reduced propulsion system dry mass for both electric and chemical systems by up to 50 percent

- Improved Ion propulsion life, reliability, and Xenon throughput by greater than 100 percent
- Light weight, more efficient solar arrays
- Solar sails for non-Keplerian orbits and high total delta-V missions
- Electric propulsion system capability up to 100 kW level and high power plasma thrusters with direct utilization of electric power from light weight, high voltage solar cells
- Aeroassist technologies for both aerocapture and direct entry applications- light-weight TPS, active guidance & control, more precise predictive techniques and optimized design tools
- Propulsion systems for utilization of in-situ resource products
- Long-term storage and in-space utilization of cryogenic propellants

Propulsion:

- Very light weight solar sails to counteract solar gravity; achieve sail characteristic acceleration better than 6 mm/s^2
- Use of ultra-high power lasers to accelerate light sails
- Very high power plasma thrusters
- Matter-Antimatter annihilation propulsion
- Nuclear fusion propulsion

4.0 Strategic Technology Areas

Six areas of technology, which represent key factors in achieving the goals of its future space program objectives, have been identified. These are:

- Advanced Miniaturization
- Intelligent Systems
- Compact Sensors & Instruments
- Self-Sustaining Human Support
- Deep Space Systems
- Intelligent Synthesis Environment

The importance and impact of each is described briefly in the following paragraphs.

Advanced Miniaturization:

The miniaturization of electronics and related components over the past decade has already stimulated dramatic reductions in spacecraft size. As these efforts are continued and extended, new generations of science and exploration missions will emerge. The advances in electronics and computation will allow re-configurable, autonomous, "thinking" spacecraft. Other miniaturization techniques, such as micro electro mechanical systems [MEMS], will enable the development of small sensor, communications, navigation, power, thermal, and propulsion subsystems with very low mass, volume, and power consumption that operate in the rigors of the space environment. Such components, brought together into micro-systems, can provide opportunities for entirely new space architectures, such as distributed networks of microprobes on planetary surfaces, nano-rovers that drive, hop, fly, and burrow; and constellations of micro-spacecraft that make simultaneous measurements and function as a sparse array for innovative remote-sensing applications.

On conventional spacecraft, both robotic and crewed, miniaturization technologies will dramatically reduce mass, volume, and power consumption, thus lowering launch costs and providing new capabilities for science and human support. The same benefits apply to applications in space transportation systems.

Another significant benefit of miniaturization is the ability to increase mission reliability and survivability. This can be achieved by using more reliable and radiation-resistant micro-systems and by using simple redundancy that is allowed when systems are small and have very low-power consumption.

Advanced miniaturization not only serves many different customers but cuts across many technical areas and requires a multidisciplinary approach. These disciplines include physics, chemistry, biology, and electrical, mechanical, and aerospace engineering, which are applied to areas such as sensors, instruments, avionics, mechanisms, optics, robotics, propulsion, power, communications, life sciences, life support, and space medicine.

Intelligent Systems:

Bold missions in space exploration will require advances in many areas of science and technology, and among the most critical of these enabling technologies are information technology and, more specifically, intelligent systems research. After all, it is critical that we get our computers and sensors on station so that they might tell about the distant worlds. The recent Mars Pathfinder mission is an example of a publicly engaging, interactive mission of virtual presence on the Martian surface.

NASA [and possibly the military] is planning to fill space with robotic explorers. Civilian applications include exploration in ways never before possible. Military applications include intelligence gathering and control of space. Robotic exploration of space is already well under way. The new surrogate explorers need to be smart, adaptable, curious, wary, and self-reliant in harsh and unpredictable environments.

In addition to spacecraft, there are other kinds of robotic explorers requirements for autonomy, e.g., planetary rovers. Uncertainty about hazardous terrain and the great distances from Earth will require that the rovers be able to navigate and maneuver autonomously over a wide variety of surfaces and independently perform science tasks. Such explorers will need to become progressively smarter and more independent as their roles expand to include surveying and evaluating potential science sites, recognizing science opportunities, gathering samples, and perhaps conducting some onboard analysis.

In addition to autonomy for commanding and self-diagnosis, there is an increasing need for an autonomous or semi-autonomous onboard science capability. Deep space probes and rovers send data back to Earth at a very slow rate, limiting the ability of the space science community to fully exploit the presence of our machines on distant planets. Thus, a requirement exists for research aimed at developing a new framework for performing data evaluation and observation planning autonomously onboard spacecraft. For example, the spacecraft should have some idea of what humans would be interested in, as they will not be able to send back every bit of information.

To summarize future intelligent systems requirements the three research cornerstones on which to build are:

- Automated reasoning
- Intelligent systems for data understanding
- Human-centered computing

Compact Sensors and Instruments:

Mission success of the science program directly depends on the availability of remote-sensing and in situ sensing systems that enable new and/or improved measurements of scientific parameters from a variety of surface, airborne, and spaceborne platforms and that reduce the cost to carry out such missions. Without continued improvements and innovations in this area, progress in space and Earth science will be severely restricted. Improvements in the human exploration of space, space development, and space transportation also directly depend on systems that accurately measure a wide variety of hardware performance and environmental characterization parameters.

As an era of increasingly constrained resources is approached, the next generation of sensors and instruments must be innovative in their scientific and technological capabilities while conserving limited resources, such as mass, power, volume, and end-to-end cost. Systems that use minimal resources are generically designated "compact"; however, the term does not exclude systems that inherently require large resource allocations. In these cases, compact refers to the decrease, typically by an order of magnitude or more, of the required resources in comparison to state-of-the-art systems.

Generating a new set of compact sensors and instruments based on the development and infusion of cutting-edge technology will enable significant increases in mission performance and capabilities while reducing the costs of scientific measurements. In the past, developing compact sensors and instruments has often been compromised in order to meet stringent performance requirements using available technology. In the future, compactness is going to be a necessity in order to achieve affordable missions and to drive the development of instrument architectures and technologies that enable classes of missions heretofore unattainable. Desired advances can be summarized in the following categories:

- Receivers/detector systems
- Compact instrument architectures
- Active sensor systems
- Integrated payloads

To meet needed objectives, new generation compact sensors and instruments will depend on innovative systems engineering and development of key technologies. The broad technology classes, identified above, are likely candidates for significant advances and, therefore, likely to have a major impact on the development of the next generation of compact sensors.

Self-Sustaining Human Support:

Extended onsite human exploration and development of extraterrestrial space will lead to revealing, exciting, and unpredictable scientific discoveries, a burgeoning expansion in human knowledge, and enrichment of the human experience. Before long-duration human exploration missions to the Moon, Mars, and other solar planetary bodies can be planned, however, technologies must be developed that will enable self-sustaining operations in hostile environments far from any effective support from Earth.

Three groups of long-term technologies that will lay the foundation to eventually enable affordable, safe, and productive extended human operations beyond Earth orbit have been identified as:

- Human health and performance
- Radiation Protection
- Human Factors and Crew Systems/Supplies

Human Health and Performance:

Human health and performance in space may be affected by a number of factors, including the effects of zero-gravity de-conditioning, radiation exposure, and the effects of unexpected illnesses or accidents requiring medical treatment. The effects of extended exposure to zero-gravity is a major research activity that is based on previous Russian and American space program experiences. This activity will be significantly extended with experience to be gained on the ISS. Technology must be developed to provide effective countermeasures to de-conditioning effects. Space radiation hazards to human health must be understood through multidisciplinary research into the physics, biology, and risks involved in various levels of radiation exposure. Thus, radiation protection for humans in deep space and planetary surface exploration requires investigation of materials technologies and innovative designs for spacecraft, habitats, and suits. Onboard medical technologies must be developed to enable essentially autonomous capabilities for exploration crews to diagnose and treat illnesses or traumas. Examples include expert diagnostic systems, noninvasive examination and monitoring, compact and lightweight medical equipment, and extended life pharmaceuticals and blood substitutes.

Radiation Protection:

Potential hazards and impacts of radiation on human activities in space have been recognized for four decades. With longer mission durations and exploration beyond Earth orbit, the assessment of risks to humans from space radiation and the mitigation of such risks have become imperatives. Risk decisions will play a major role in future spacecraft design, mission planning, and even crew selection. And, cost and schedule will be driven by decisions made regarding what is acceptable radiation risk. To summarize, quantitative assessment of risk depends on sufficient knowledge in five major areas:

- Environment Definition
- Shielding and Materials
- Radiation Effects on Humans
- Radiation Monitoring Strategies
- Countermeasures

Human Factors and Crew Systems:

Human factors and crew systems help to provide a safe and efficient living and working environment for the crew. These factors, coupled with expert systems, robust electronic knowledge bases, and detailed system models, permit crew-autonomous operations so that small, Earth-isolated crews can take on the roles now performed by multitudes of ground-based experts. To reduce mass, many of the human-machine interfaces will be moved into a synthetic computer environment in the spacecraft, viewed with head-mounted displays, and actuated via tracking systems and cyber gloves. Other new technologies, such as shelf-life extension, "from-scratch" cooking and processing of crops, will also be required.

Pacing technical issues include:

- Body-worn interfaces that generate a deep symbiosis between human and machine, including virtual interfaces, embedded real-time intelligence with decision support and context-driven data retrieval, and natural language interfaces
- System design information capture to allow the experience of ground-based engineers and experts to be included in a near-autonomous, Earth-isolated environment
- Non-intrusive methods for monitoring individual and group performance over time to identify, warn, and correct for human performance deficits caused by the unique stresses in exploration-class missions
- Methods for the preservation of a complete diet for 3-5 years to enable a Mars mission
- Technologies for reducing, reusing, and recycling crew systems/supplies to produce massive reductions in mission mass/cost for future exploration missions

Work is underway in the area of human-machine interfaces in the academic, military, and commercial communities. Also, commercial and military applications of augmented reality/virtual interfaces, embedded real-time intelligence and decision support, and natural language interfaces are being studied.

Deep Space Systems:

While space offers the potential of answering the fundamental scientific questions at the very core of human curiosity, the space environment is also very hostile and unforgiving. Besides operating at extremes in terms of temperature, pressure, and radiation, there is a particular set of formidable issues associated with operations at extreme distances from the Earth and, in some cases, the Sun. For example, "deep space" missions challenge the basic physics of propulsion systems needed to cover astronomical distances-power systems that must function when the Sun appears no brighter than some stars, communications systems that must convey high data rates across vast distances using virtually no power, and sufficient onboard intelligence and autonomy to phone home only to deliver new insights. These ambitious, robotic, long-lived missions, designed and executed at the limit of the technically possible, extend human reach to both the very center and beyond the edges of the solar system.

Deep Space Systems technologies fall into the following four areas:

- Power
- Propulsion
- Communications
- Robotics

And, there are additional technologies that may be required for specific classes of deep space missions.

Power:

Deep space electric power technology deals with the generation, storage, and management of electric power for deep space missions, and presents many unique challenges and requirements. Operations in extreme temperature and radiation environments are major mission drivers. Power generation options, in particular, heavily depend on proximity to or availability of solar energy. In addition, the need to rendezvous, enter atmospheres, descend, and land and operate on or below the surfaces of planets, moons, and small bodies results in requirements for high-impact resistance, resilience to dust or particulates and atmospheric gases, or special thermal management techniques.

Propulsion:

Deep space propulsion has become one of the dominant mass elements of deep space robotic spacecraft for two reasons. First, deep space missions are becoming more difficult from a propulsion point of view. Where robotic spacecraft would once fly past planetary bodies of interest, today's missions seek to rendezvous with, orbit, land on, or even return samples from these bodies. As deep space missions are more ambitious in a propulsive sense, the mass of the propulsion system increases as well, because the mass of at least part of the "dry" propulsion system is proportional to the mass of the propellant to be consumed. That proportion of the spacecraft which is devoted to propulsion components also increases as electronics systems become more mass efficient. The order-of-magnitude increase in avionics capability that has been accompanied by an orders-of-magnitude decrease in the mass of avionics systems has not only made spacecraft more capable, but these trends have also lowered the dry mass of the spacecraft. This trend is easily seen in the ratio of dry propulsion mass to the dry mass of the spacecraft, which has increased from 10 percent for Viking to 11 percent for Galileo in 1989 to 19 percent for Cassini in 1997 to a projected 38 percent for the Europa Orbiter in 2002.

Communications:

Advanced Deep Space Communications currently refers to any communication with or between any spacecraft [orbiter, flyby, observatory, and so on] beyond 2 million kilometers from Earth. Such communications uses an internationally agreed on set of radio frequency bands that are set aside for deep space communications or the currently unregulated optical frequencies. As part of the deep space mission, however, there are also more localized communications [for example, over distances of 10,000 kilometers or less] necessary for in situ instruments [lander, rover, microprobe, and so on], formation flying, EVA, or other short-range communications needs. While these short-range systems may use more traditional Earthbound frequency bands, they must also operate in the harsh deep space or planetary environment.

A number of constraints make communications with deep space missions unique: extremely weak signals, deep space specific frequencies, environmental extremes, and small highly integrated spacecraft [spaceborne or landed]. In addition, special requirements are frequently placed on the communications signals or their transmit/receive systems to enable precise spacecraft navigation, or to enable radio or optical scientific measurements of the interplanetary medium.

Robotics:

Cutting-edge deep space robotics technologies are needed for a wide range of deep space in situ exploration and sample return missions. These missions will investigate and characterize planets, comets, and asteroid surfaces, as well as penetrate sub-surfaces and atmospheres with new robotic systems. Robotics technology programs create, evaluate, and demonstrate first-of-a-kind integrated research and technology robots, in which several critical technologies are developed together to provide new system-level deep space robotics operations to planetary mission scientists and designers. Enabling robotics technologies under development include: miniaturized long-range science rovers; fast, stowable sample return rovers; nano-rover vehicles; smartly controlled micro-manipulators and drilling and coring robots; and subsurface explorer robots.

Intelligent Synthesis Environment [ISE]:

Several factors will drive the design of future aerospace systems including rapid prototyping [which aims at reducing design cycle and development times], affordability with an emphasis on reducing life-cycle costs, and improved performance due to insertion of new technologies. The benefits of Concurrent

Engineering, which became popular starting in the 1980's, are many, but techniques are still limited. Current approaches require immense human engineering effort and have limited capability for reliable life-cycle cost analysis, multidisciplinary integration and optimization, bounding of uncertainties, and collaboration of geographically dispersed diverse teams. In an attempt to eliminate such shortcomings, several government agencies and industry programs have been devoted to simulation-based design approaches, which rely on simulating entire life cycles [from concept development to detailed design, prototyping, qualification testing, operations, maintenance, and disposal], before committing to physical prototyping. Accomplishments to date has been disappointing.

As a result, ISE is replacing earlier simulation-based design approaches, and should fully address the needs not realized by concurrent engineering and simulation based design. NASA is spearheading the ISE effort, and this should provide technologies needed for collaborating diverse teams, advanced intelligent processes required for human-centered computing, rapid tools for near real-time simulation and design trade studies, and implementation strategies for a national ISE program.

Major technologies that provide the underpinnings of ISE are high-capacity communications and networking, virtual product development [including visualization and effectors for manipulating and interacting with virtual products], knowledge-based engineering, computational intelligence, human-computer interaction, high-performance distributed computing, and product information management. Three thrusts are being pursued: research and development; a testbed activity; and an educational/training thrust.

Appendix B: Summary of Colorado's Military Space Organizations

There are several military organizations in the state of Colorado which provide national security functions using space assets and the space infrastructure. Each of these organization are summarized in the following paragraphs. Figure B.1 provides an overview of these organizations.

US Space Command [Peterson AFB, CO]

This is one of the nation's nine unified [multi-service] commands. It coordinates the use of Army, Naval and Air Force space forces to support launching and operating satellites; support joint-service military forces worldwide with intelligence, communications, weather, navigation, and ballistic missile attack warning information; engage adversaries from space; and assure U.S. access to, and operation in, space while denying enemies the same freedom. The Command also plans for the operation of a system that will defend the U.S. from ballistic missile attack.

NORAD [North American Aerospace Defense Command]

A U.S. and Canadian organization charged with the missions of aerospace warning and control for North America. The NORAD mission includes monitoring man-made objects in space, and detection, validation, and warning of attack against North America.

Air Force Space Command [Peterson AFB, CO]

The Space Command provides guidance, support and funding to AFSPC wings and sites around the world. It brings space to the warfighter and assures continued military access to space. This is done through four primary mission areas of space force support, space control, force enhancement and force application.

21st Space Wing [Peterson AFB, CO]

The *21st Operations Group* provides overall management and guidance to 18 geographically separated units assigned to the wing, which provide attack warning and space control. Its responsibilities include establishment of operational requirements and managing the training, standardization and evaluation programs. The responsibilities also include conducting command-directed evaluations and staff assistance visits.

The *21st Operations Support Squadron* [OSS] provides mission support to AFSPC's worldwide network of attack warning, space surveillance and space communications units; supports weather requirements for Peterson Air Force Base, Schriever AFB and Cheyenne Mountain Air Station; directs and coordinates base operations, all flight line activities and flight records management; and provides intelligence and administrative support to wing, group and squadron commanders.

The *2nd Space Warning Squadron* [Buckley ANG Base], SWS detects ballistic missile launches using Defense Support Program [DSP] satellites, and reports that information to the NORAD and U.S. Space Command Missile Warning Center at Cheyenne Mountain Air Force Station.

The *1st Command and Control Squadron*, Cheyenne Mountain, tasks the worldwide Space Surveillance Network to get positional data for all man–made Earth–orbiting space objects.

The *2nd Command and Control Squadron*, CACS, is a geographically separated unit of the 614th Space Operations Group, Vandenberg Air Force Base, providing command, control mission planning to a worldwide network of dedicated space surveillance sensors.

The *21st Logistics Group* is responsible for hardware and software maintenance at 27 missile warning, space surveillance and satellite communications sensor sites, as well as supply, transportation, traffic management and precision measurement equipment laboratory support for Peterson and Schiever Air Force bases, and Cheyenne Mountain Air Station.

US Space Command (AFSP) (Peterson AFB, CO)

NORAD (Peterson AFB, CO)

21st Space Wing (Peterson AFB, CO)
Cheyenne Mountain Training and Simulation System
21st Operations Group
21st Operations Support Squadron
2nd Space Warning Squadron (Buckley ANG Base)
1st Command and Control Squadron (Cheyenne Mountain)
2nd Command and Control Squadron (Schriever AFB)
21st Logistics Group
21st Logistics Support Squadron
21st Contracting Squadron
21st Support Group
21st Mission Support Squadron
21st Civil Engineer Squadron
21st Security Forces Squadron
21st Services Squadron
21st Communications Squadron
721st Support Group (Cheyenne Mountain Air Station)
721st Communications Squadron
721st Civil Engineer Squadron
721st Security Forces Squadron
821st Space Group (Buckley Air National Guard Base)
11th Space Warning Squadron (Schriever AFB)
137th Space Warning Squadron (Greeley, CO)
3rd Space Communications Squadron
821st Operations Support Squadron
821st Support Squadron
821st Security Forces Squadron
821st Medical Squadron
21st Comptroller Squadron

50th Space Wing (Schriever AFB)
50th Operations Group
1st Space Operations Squadron
2nd Space Operations Squadron
3rd Space Operations Squadron
4th Space Operations Squadron
22nd Space Operations Squadron
Colorado Tracking Station (Schriever AFB)
50th Operations Support Squadron
55th Space Weather Squadron (Boulder, CO)

Figure B.1 Colorado Military Space Organizations

50th Communications Group 50th Communications Squadron 850th Communications Squadron **50th Support Group** 50th Missions Support Squadron 50th Civil Engineer Squadron 50th Security Forces Squadron 50th Contracting Squadron **18th Intelligence Squadron (Schriever AFB)** **76th Space Operations Squadron (Schriever AFB)** **Operating Location, Space and Missile Systems Center, Detachment 11** **310th Space Group -- Air Force Reserve Command in Space** 6th Space Operations Squadron 7th Space Operations Squadron 310th Security Forces Squadron **Space Battlelab (Schriever AFB)** **Space Warfare Center (Schriever AFB)**
Joint National Test Facility (JNTF) (Schriever AFB)
Space Warfare Center (US Space Command) 55th Space Weather Squadron 76th Space Operations Squadron 18th Intelligence Squadron 310th Space Group Air Force Reserve Command in Space
Army Space Command (Colorado Springs, CO) Space and Missile Defense Battle Lab (Colorado Springs, CO)
NAVSOC (Naval Satellite Operations Center) Detachment DELTA (Schriever AFB)

Figure B.1 Colorado Military Space Organizations [Continued]

The *21st Support Group* SPTG makes sure the base runs smoothly and effectively by paying the bills, making sure the base stays secure, overseeing telephone services, keeping facilities in good condition, keeping records and taking care of the well–being of the people stationed in the Peterson AFB Complex.

The *721st Support Group* operates, maintains, secures, sustains, mobilizes, tests, and controls the worldwide warning and surveillance system for North America, normally referred to as the Integrated Tactical Warning and Attack Assessment

[ITW/AA] weapon system. It consists of airborne, land-based and space-based systems which sense and report on all activities in air and space.

The *821st Space Group* consists of several ballistic missile warning squadrons; an early warning network of ground-based and space-based sensor systems that provide worldwide continuous surveillance and early warning of intercontinental ballistic missiles; the Attack and Launch Early Reporting to Theater [ALERT] system; and worldwide missile warning, space launch and detection in the event of an attack against the United States.

2nd Space Warning Squadron [Buckley Air National Guard Base, Aurora, CO]

The 2nd SWS detects ballistic missile launches using Defense Support Program satellites, and reports that information to the North American Aerospace Defense Command and U.S. Space Command Missile Warning Center at Cheyenne Mountain Air Force Station, Colorado.

Schriever AFB, CO

The newest base in the USAF, backs up to Onizuka Air Force Base, where all DoD satellites were being controlled. In 1983, the 2nd Space Wing was formed to take over mission responsibility from Onizuka AFB. The take over occurred in the fall of 1987. But, in 1992, Air Force restructuring resulted in the 2nd Space Wing being deactivated and the 50th Space Wing [50 SW] was activated. Satellite operations are conducted from the Jack Swigert Space Operations Facility. From the operations facility, the 50 SW controls several satellite programs, including DSP, DMSP, GPS, DSCS, NATO III, the Navy's FLTSATCOM and Ultrahigh Frequency Follow-on (UHF F/O) systems, and the Milstar satellite communication system.

50th Space Wing [Schriever AFB, CO]

The 50th Space Wing commands, controls, and provides launch support to over 100 operational satellites, which support the National Command Authorities, federal and civilian agencies, and all U.S. and allied military forces. It provides operational leadership, trains space operations crews and provides standardization and evaluation to over 1,300 space system operators. Six space operations centers perform 24-hour tracking, telemetry and command functions during launch, early-orbit and on-orbit spacecraft operations, and anomaly resolution. It operates and maintains eight worldwide remote tracking stations and associated communications systems comprising the Air Force Satellite Control Network. The Wing also develops, publishes and executes network tasking for all AFSCN users.

50th Operations Group [Schriever AFB, CO]

The *1st Space Operations Squadron* at Schriever Air Force Base is responsible for launch and early orbit operations, as well as anomaly resolution for the Defense Support Program and Navstar Global Positioning System. It conducts day-to-day operations for DSP and is the lead squadron for capitalizing on the operational potential of several developmental satellites.

The *2nd Space Operations Squadron* provides precise, three-dimensional position, velocity and timing information to military and civilian users around the globe via GPS. It operates and maintains the Master Control Station at Schriever Air Force Base and a worldwide network of GPS-dedicated ground antennas and monitoring stations to provide around-the-clock command and control of the 24-satellite constellation.

The *3rd Space Operations Squadron* at Schriever Air Force Base conducts day-to-day command and control for the Defense Satellite Communications System. It conducts both launch and on-orbit operations for the Navy's Ultrahigh Frequency Follow-on satellite program.

The *4th Space Operations Squadron* at Schriever Air Force Base is responsible for day-to-day command and control, communications payload management and ground segment maintenance for the joint service Milstar satellite program.

The *22nd Space Operations Squadron* at Schriever Air Force Base develops, publishes and executes the network operations tasking order, as well as operates and maintains the worldwide remote tracking stations and associated communications systems comprising the Air Force Satellite Control Network. *Colorado Tracking Station* provides on-orbit tracking, telemetry, commanding and mission data retrieval services to support the NASA Space Transportation System, NATO and DoD satellite operations including the DMSP and DSCS.

The *50th Operations Support Squadron* at Schriever Air Force Base is responsible for implementing operations and training policy for seven squadrons. It integrates new satellite and ground control programs into current operations, conducts Force Development Evaluation throughout the 50th Space Wing, and provides intelligence data to 50th Space Wing units and it manages the $150 million Space Operations and Maintenance Contract.

50th Communications Group [Schriever AFB, CO]

The 50th Comm. Group plans, programs, operates, and maintains command and control, and common-user communications and computer systems in support of USSPACECOM, Space Warfare Center, 21st SW and 50th SW missions. The Group functions as the single focal point for all 50th SW communications and computer systems. The Group is responsible for both command sponsored C-CS [common-user and base C-CS systems], and communications-computer systems that are configuration-managed by Air Force Materiel Command [mission systems supporting satellite command and control, and operations].

The *50th Communications Squadron* provides, operates and maintains Schriever AFB's communications in support of the Air Force Satellite Communications Network for 50th Space Wing units located worldwide. It operates and maintains two Defense Satellite Communications System earth terminals and one Milstar earth terminal which provides Integrated Tactical Warning/Attack Assessment data to NORAD and United States Space Command. It provides diverse base telecommunications services including administrative telephones, local area and wide area computer networks, small computers and secure voice and data systems. The Squadron maintains the Security Control System that provides access, control and intrusion detection, and annunciation for Schriever Air Force Base and it plays a critical role in maintaining cryptographic equipment, wideband multiplexers and modems, weather support equipment, and base cabling for all units on Schriever Air Force Base.

The *850th Communications Squadron* plans, programs, and maintains command and control, and common user communications and computer systems supporting satellite, missile warning, and space surveillance operations for 43 units and 22 locations worldwide. The Squadron is responsible for logistics management and the integrity of satellite communications systems for the Air Force Satellite Control Network controlling over 90 DoD satellites. It provides C4 plans, configuration control, security management, training, and maintenance analysis in support of AFSPC, USSPACECOM, and the National Command Authority. It manages all budgetary issues for the 50th Communications Group, to include planning and execution and is responsible for all spectrum management issues and concerns for the entire wing and associated units.

50th Support Group

The 50th Support Group provides security, engineering services, contracting services and general base support to the 50th Space Wing, its worldwide sites and Schriever tenant units.

The *50th Mission Support Squadron* provides general base support to the 50th Space Wing, its worldwide sites and Schriever tenant units. It support includes the base fitness centers, the military personnel flight, transportation, Information, Ticket and Tours office and the Satellite Dish dining facility. It provides administrative support functions for approximately 120 people assigned to the 50th Space Wing staff and the 50th Support Group staff.

The *50th Civil Engineer Squadron* protects the Current and Future Environmental Conditions of all 50 Space Wing Installations.

The *50th Security Forces Squadron* provides around the clock protection for a myriad of space assets.

The *50th Contracting Squadron* provides all Schriever AFB contracts and support of the Space Warfare Center and 750th Space Group specialized contracts.

Joint National Test Facility [JNTF]

The Joint National Test Facility is a subordinate command of BMDO, and its primary field activity. It provides a state-of-the-art capability for Ballistic Missile and Theater Air Defense testing, modeling and simulation, and analysis. Several critical BMDO activities are housed at the JNTF, including the control node for the Ballistic Missile Defense Network, the Human-in-Control Testbed for wargaming and exercise support, the BMC3 Element Support Center [BESC], the Joint Effectiveness Analysis Center, and several BMD test capabilities include TMDSE and EADTB. Houses several tenants, including the Space Warfare Center, the Attack and Launch Early Reporting to Theater [ALERT] center, and the Cheyenne Mountain Training System.

The *Space Battle Lab [Schriever AFB]* identifies innovative space operations and logistics concepts and assesses their potential for advancing Air Force core competencies and joint warfighting using field ingenuity, modeling and simulation, and actual employment of exploratory capabilities in operational environments.

Space Warfare Center [Schriever AFB]

The Space Warfare Center identifies innovative space operations and logistics concepts and rapidly measure their potential for advancing the Air Force core competencies and joint warfighting using field ingenuity, modeling and simulation, and actual employment of exploratory capabilities in operational environments. It identifies improvements to space systems within the context of joint warfighting architectures, optimizing resource investments and assessing space operational and logistical concepts for warfighting.

55th Space Weather Squadron [Boulder, CO]

The Squadron provides space environmental analysis, forecasts, and warnings to enhance the capability of worldwide Department of Defense forces and other Federal agencies. Operating Location-A [OL-A], Boulder, CO, provides technical liaison between the Air Force and NOAA's Space Weather Operations [SWO] to observe and report space weather and issue forecasts and warning of geoeffective solar activity for national and public use.

76th Space Operations Squadron (14th AF) (Schriever AFB)

The Squadron aids Air Force Component Commander [AFCC] in understanding space capabilities [systems, satellites, and data] and applying these capabilities [tactics, techniques, and procedures] in support of theater air operations. It tailors each deployed team with the specialties required to meet the needs of the Numbered Air Forces or Major Commands and it can draw additional expertise from other mission-critical areas.

18th Intelligence Squadron [Schriever AFB]

The Squadron provides 24-hour intelligence support to operators of the Air Force Space Command's passive space surveillance mission. It provides intelligence data in support of Air Intelligence Agency, National Air Intelligence Center and U.S. Space Command missions and information critical to the National Security Agency and other national-level organizations.

310th Space Group Air Force Reserve Command in Space

The 310th Space Group is comprised of the 6th Space Operations Squadron, 7th Space Operations Squadron, 8th Space Warning Squadron, 9th Space Operations Squadron and the 310th Security Forces Squadron. A new unit, the 14th Test Squadron will activate in October 2000. It provides reserve unit integration into an array of Air Force Space Command mission areas.

The *6th Space Operations Squadron* operates the Defense Meteorological Satellite Program [DMSP] satellites in support of the Department of Commerce and the National Oceanic and Atmospheric Administration.

The *7th Space Operations Squadron* augments space operation squadrons of the 50th Space Wing.

The *8th Space Operations Squadron* provides full-time and part-time Reserve augmentation to the Space Based Infrared System [SBIRS] operations.

The *9th Space Operations Squadron* provides full-time and part-time Reserve augmentation to the COMAFSPACE Aerospace Operations Center [AOC].

The *310th Security Forces Squadron* gives the AFSPACE commander extra capability to protect the terrestrial elements of the Air Force Satellite Control Network and Spacelift resources world-wide.

Army Space Command [Peterson AFB]

USARSPACE commands and integrates state-of-the-art space and national missile defense capabilities, operations, and expertise to deliver decisive combat power at precisely the right time and precisely the right place on the battlefield. It controls the Defense Satellite Communications System Operations Centers and AN/MSQ-114s through the 1st Satellite Control Battalion [1st SATCON Bn], controls joint tactical use of Ground Mobile Forces Satellite Control [GMFSC] on the Defense Satellite Communications System [DSCS] through Regional Space Support Centers [RSSCs], controls Army Ballistic Missile Defense [BMD]/Anti-Satellite [ASAT], Theater Missile Defense [TMD], and operational facilities/forces as assigned. It provides space capabilities to Army components of Warfighter CINC's by deploying Army Space Support Teams [ARSST] and organic equipment upon request of Army units and/or as approved by DCSOPS HQDA. USARSPACE provides flight crews for manned space programs, engineering expertise for human interface and an Army focus for space operations and requirements, all of which enhance the Army's ability to execute operational doctrine using manned space capabilities.

USARSPACE is the Army Component Command of US Space Command [USSPACECOM] and provides the Commander-in-Chief US Space Command [USCINCSPACE] a chain of command to the Defense Satellite Communications System Operations Centers, Regional Space Support Centers, the Theater Missile Defense Joint Tactical Ground Station [JTAGS] program, and the Army Space Support Teams [ARSST].

The *Space and Missile Defense Battle Lab [Colorado Springs, CO]* links the technology and the warfighter through experiments simulating modern "battlefield" conditions, often using sophisticated computer simulations, interfaces and networks.

NAVSOC [Naval Satellite Operations Center]

Detachment DELTA [Schriever AFB] is responsible for remote tracking, telemetry and commanding [TT&C] facilities in support of satellite missions. Serves as an alternate Satellite Operations Center [SOC] to the Point Mugu headquarters and to coordinate scheduling with the Air Force.

Appendix C: Description of Representative Colorado Commercial Space Suppliers and Service Providers

There are more than 100 companies in the state of Colorado which provide materials, equipment, software and services for the space infrastructure and to end users of space applications. A partial list of companies is provided in the following paragraphs together with a summary of each company's products, services, and customer base.

Advanced Research Corporation: *http://www.starwatch-gps.com/www_starwatch-gps_com.html*

Provides services and products in the Global Positioning System [GPS] technology and software engineering for numerous clients. Service includes the design and development of software for GPS-based asset location systems, and consulting on GPS applications. Advanced Research's premier product is the StarWatch™ Asset Location System, an off-the-shelf system using cellular and ORBCOMM satellite communication technologies. StarWatch is designed for fleet and high value asset tracking. StarWatch runs on a personal computer under Windows™, and provides map display and geocoded location information for assets and vehicles anywhere. It operates with cellular telephone technology and ORBCOMM satellite subscriber communicators. StarWatch's low price and ease of use will be of interest to fleet managers and shippers interested in obtaining the technology without making a major investment.

ANALEX Corporation: *www.analex.com*

Provides design, development, analysis, and testing of products and systems for the aerospace, medical, hi-tech manufacturing, telecommunications, and information technology industries. Analex is a woman-owned small business [SIC 8731] and has expertise in many areas of engineering including: verification and validation, software development, systems design and analysis, design control, product development, risk/hazard analysis, optical systems and design, telemedicine systems, thermodynamics, control dynamics, payload analysis, system integration, software simulation and modeling, space experiments, satellites, stress analysis, and trajectory analysis. The 200+ members of the Analex staff have extensive experience in science, engineering, information systems, and management. Ninety-four percent of the staff have bachelor degrees and forty-six percent of the professional staff hold advanced degrees. Its Denver group is ISO 9001 Registered.

AntennaPro Inc.:

Provides down-linking [C-band and Ku-band]; VSAT installation, maintenance and networking; business television; and audio and video integration.

Antennas America Inc.: *www.antennas.com*

Manufactures C- and Ku-band phase array antennas for data and voice, and designs, manufactures and markets disguised GPS antennas.

AT&T Broadband and Internet Services: *www.attbis.com*

Provides transportable Ku-band uplinks, fixed uplinks and a terrestrial microwave network for voice, data and occasional-use voice. The company set up cable business unit AT&T Broadband after acquiring TCI and is now the #2 US cable TV operator, with more than 11 million customers [2 million are digital subscribers]; it will leapfrog over the leader, Time Warner, after AT&T buys MediaOne. Off the small screen, AT&T Broadband is upgrading its cable networks to allow for cable-based telephony, and the unit already has 60,000 local and long-distance phone customers. AT&T Broadband also provides high-speed cable Internet access to more than 200,000 subscribers [AT&T@Home]; the service is offered in conjunction with Excite@Home, which is controlled by AT&T.

Automated Systems Engineering Inc.: *www.goase.com*

Manufactures a full line of deicing control equipment, including sensors, controllers, and remote control/monitor panels. We also manufacture the DP-32B general alarm/status panel. ASE has also completed an extensive list of custom turnkey projects for both military and commercial customers in many different fields of application, including antenna positioners, military test fixtures, and status multiplexers to name a few.

Autometric, Inc.: *www.autometric.com*

Develops software for processing and displaying state-of-the-art 3D visualizations. Advanced graphic simulations can preview the orbits of space-bound vehicles before the launch, or animate the expressions of virtual humans. Achievements include visual technology for surveying the Apollo Lunar Landing sites, to exploiting early satellite imagery from space, to 3D modeling and visualization of radioactive particle transport in the atmosphere.

AVT Inc.: *http://www.thomasregister.com/olc/avt/*

Products include custom battery assemblies, smart chargers, and combinations of the two. Any opportunity that depends on portable power can benefit from this expertise. Custom battery design and manufacturing.

Ball Aerospace & Technologies Corporation [BATC]: *www.ball.com*

Provides imaging, communications, and information systems, products, software, and services to government and commercial aerospace customers. Designs and manufactures spacecraft and space systems, space and scientific sensors, cyrogenic subsystems and antenna systems and video products for commercial and government customers.

Baylin Publications: *www.baylin.com*

Provides publications for the satellite TV, SMATV and wireless cable industries.

Bortz Media and Sports Group: *www.bortz.com*

Provides analysis, planning and research services to broadcasting, cable TV and professional sports. Offers financial analysis, market research and technological assessment to commercial broadcasters, cable television operators and programmers, wireless cable operators, new media and Internet companies, and industry organizations, among others.

Channel 2000:

Installs and services DSS/DBS, C-band and home theater entertainment systems.

Colorado Video Inc.: *www.colorado-video.com*

Pioneered the development of unique video instrumentation and communications equipment. Products include instruments for measuring dimensions, intensity, and position. Crosshair, pattern, and character generators superimpose reference marks or alpha numeric data onto real-time video displays. Manufactures video communications equipment that can multiplex four video signals into one or piggy-back frozen images onto a standard video signal using its vertical interval.

Crosslink, Inc.: *http://www.crosslinkinc.com*

Focuses on System Integration and Information Technology products for cost efficient, high-speed data gathering, processing and transmission. Manufactures a line of camera telemetry systems such as Eagle Vision Mercury Launch Vehicle video system, which are used on launch vehicles such as Delta, Titan, Atlas and the Space Shuttle external tanks.

Cullimore and Ring Technologies, Inc. [C&R Technologies]: *www.crtech.com*

Provides products and services in the areas of heat transfer and fluid system design and analysis. Offers full analysis consulting and training services.

Denver Uplink:

Provides uplinking [two agile and two fixed C-band units], dowlinking, beta, SP and ¾ inch videotape playback and interconnects for ABC and CBS affiliates.

Earthwatch Inc.: *http://www.digitalglobe.com*

Leading-edge information content provider developing and selling a wide variety of remote sensing based imagery and geospatial information products. Building both a constellation of high-resolution satellites and a comprehensive multi-source online digital imagery store, which provides customers online access to a wide array of imagery and derivative information products.

Echostar Communications Corporation: *www.dishnetwork.com*

A public company with over 6,000 employees, delivering direct broadcast satellite [DBS] television products and services to customers worldwide. Manufacturer and distributor of C-band satellite TV products and programming.

ExeComp Inc.: *http://www.execomp.com*

Specializes in in-house large format monochrome/ color imaging and archiving [turning hard copy into an electronic format] for items such as engineering drawings, maps, architectural drawings, aerial/satellite photos, mining strip charts, etc.

Global Crossing: *www.confertech.com*

A pioneer in the telecommunications industry, developing the first digital full-duplex audio conferencing bridge in 1978. Expanded to include audio conferencing services and a variety of client-initiated services such as broadcast fax, automated conference calling, digital playback, Q and A session coordination and custom services for the investor relations community.

Hewlett-Packard Company: *www.hp.com*

Provides test equipment for satellites.

Hewlett-Packard Test and Measurement Organization: *www.hp.com/go/gov/*

Provides test systems and instruments for satellite components and systems.

Information Handling Services Engineering Products:
http://www.ihsengineering.com/index.html

Publishes the most comprehensive suite of desktop information tools available to help engineers and technical professionals make better, faster and more cost-effective decisions.

Intertec Publishing: *www.satellitecom.com*

Publishes *Satellite Communications*, a monthly satellite industry magazine.

ITT Industries: *http://www.ittsystems.com*

Provides advanced science and technology services and customized, high-tech products to government, industrial, and commercial customers.

Johns Manville: *http://www.jm.com*

A leading manufacturer and marketer of premium quality insulation products for aerospace applications.

Jones Earth Segment: *www.jones.com*

Provides cable network uplinking and playback.

Kyocera Solar, Inc.: *www.kyocerasolar.com*

The world's largest vertically-integrated producer and supplier of solar energy products. Provides electric systems designed to supply power for satellite earth stations, cellular communications sites, rural telephony systems and microwave networks.

Lockheed Martin Mission Systems:
http://www.missionsystems.external.lmco.com

An industry leading integrator of complex information technology systems for federal and commercial users. Provides systems engineering and software integration for high technology programs. Develops mission critical distributed systems to support satellite command and control ground systems.

Mega Hertz: *www.megahz.com*

Distributes satellite systems and cable television products.

Merrick & Company: *http://www.merrick.com*

Full service architecture and engineering firm.

Microsemi Corporation: *www.microsemi.com*

Global supplier of Power Management, Power Conditioning, Transient Suppression and RF/Microwave semiconductor devices.

Mobile Tool International: *www.mobiletool.com*

Manufactures pressurization equipment for microwave antennas and waveguides. An employee-owned manufacturer of telecommunications, CATV, electrical utility, and contractor construction equipment.

Mountain Optech Inc.: *www.mtn-optech.com*

Provides higher-performance optical storage solutions. Products include removable Non-volatile Solid State, Magnetic Hard Drives, CD-ROM Drives, 3.5" and 5.25" Rewritable Optical Drives and 4mm DAT and 8mm Tape.

Navsys Corporation: *www.navsys.com*

Focuses on the development of innovative products using the Global Positioning System [GPS].

Novanet Communications Ltd.: *www.novanetcomm.com*

Accesses satellites Anik E1, Anik E2, Galaxy III R, SBS5 and SBS 6. Offers custom system design, implementation, operations and network control of satellite networks for organizations seeking cost-effective wide area distribution of information. Provides software products for content production and display, audio network management and single-console multivendor system control. Operates as a prime service provider to the broadcast, media, retail and paging industries.

NSN Network Services: *www.nsn.net*

A global leader in the out-of-home advertising industry. Provides VSAT audio and data networks and turnkey systems, including equipment, installation, space segments and maintenance. Provides access to the Internet through satellite systems and services worldwide. Provides paging systems over satellites.

Orion Dynamics and Control: *http://www.sni.net/oriondc/*

Sells analysis services and custom subsystems. Develops and analyzes full spectrum of aircraft and spacecraft guidance, navigation, and control systems, simulations, and embedded flight software.

Owen Research Inc.:

Develops advanced optical measurement systems tailored to specific applications in aerospace, industry, environmental monitoring and biotechnology. Provides optical design, prototyping and testing services. Develops optical systems with emphasis on interferometric and holographic prototypes.

Peregrine Control Technologies, Inc.: *http://www.pagetap.com*

Designs and manufactures easy to use "plug & play" paging products that can remotely control virtually any electrical device from any location.

Raytheon Systems Company: *www.raytheon.com*

Manufactures ground stations; tracking, telemetry and command stations; antenna systems, command and control equipment and systems, custom RF equipment and systems; custom digital equipment and systems; custom analog equipment and systems; information and data systems; software systems; mission management systems; and expert systems. Distributes commercial off-the-shelf [COTS] hardware used to maximum extent in custom applications. Provides software and hardware systems engineering, mission engineering, system integration, turnkey facilities implementation, operations and maintenance, product support and custom design.

Research Systems Inc.: *http://www.rsinc.com*

Develops visualization and data analysis tools.

Ridgeway Cable Vision:

Installs satellite equipment and sells cable TV.

Satellite Broadcasting Inc.:

Provides brokerage services and transmission services, including satellite time, uplinking, downlinking, turnarounds, microwave and fiber optics, on US satellites and international satellites.

Satellite Communications: *http://www.satellitecom.com*

Produces monthly magazine covering the satellite communications industry.

Satellite Pro, Inc.:

Sells and services commercial and residential satellite systems.

Satieo!:

Manufactures modular CATV headends. Sells and installs commercial and home satellite televisions and silent radios.

Seakr Engineering Inc.: *www.seakr.com*

World's leading supplier of spacecraft solid state memory systems. Produces memory systems for avionics applications and digital signal processing boards for on-board spacecraft data reduction and processing.

Space Analytic Associates Inc.: *http://www.sni.net/saa/*

An aerospace consulting company.

U.S. Space Foundation: *http://www.spacefoundation.org*

Fosters a greater understanding and awareness of space.

Space Imaging: *http://www.spaceimaging.com*

A world leader in digital Earth information. Launched IKONOS, the world's first one-meter resolution, commercial imaging satellite, on September 24, 1999. Produces economical information products with delivery timelines that far exceed the standards in the marketplace.

Systems Technology Associates, Inc.: *www.stainc.com*

Resells telecommunications equipment [data, frequency agile and SCPC], subassemblies, signal converters, channel banks, echo cancelers, multiplexers, compression units and wireless PBX.

Stanford Telecommunications Inc.: *www.stanfordtelecom.com*

Specializes in providing ground systems and comprehensive technical services to US government agencies primarily for SATCOM applications. Services include life-cycle engineering and technical support services for worldwide computer and communication systems for satellite communications, secure global network, and global network, and local and wide are network [LAN/WAN] applications.

Telewire Supply – A Division of Antec Corporation: *www.telewiresupply.com*

Value-added logistics and distribution channel for ANTEC Corporation and a leading nationwide supplier of products needed to build and service a hybrid fiber and coaxial [HFC] broadband communications system.

Tempo Satellite Inc.:

Leases all of its transponder capacity to Primestar Partners, LP; satellites operated: Tempo 1 and Tempo 2.

Terra Firma Technologies: *www.rossie.com*

Performs market analysis and feasibility studies. Provides general, technical and international consulting and strategic planning for video, voice and data distribution systems and satellite and terrestrial interfaces.

Trans Sales International:

Distributes hydrogen gas detectors.

UTMC Microelectronics Systems: *http://www.utmc.com*

Supplies broad range of standard products_for avionics and space applications including microcontrollers, logic, programmable logic, memory and serial communication interfaces for MIL-STD-1553 and 1773.

Vexcel Corporation: *http://www.vexcel.com*

Provider of remote sensing products and services with expertise in radar signal processing, software engineering, close range and aerial photogrammetry and real-time systems. Provides end-to-end system solutions and markets a line of hardware and software products as well as data processing services.

Virginia A. Ostendorf, Inc.: *www.videoconference.com*

Provides consulting services, workshops in audio and satellite and video-conferencing workshops for most response systems.

VR Source LLC: *http://www.thevrsource.com*

Provider of virtual reality technology.

VYVX – Teleport Denver: *www.vyvx.com*

Provides C-band and Ku-band uplinking and downlinking services; video-conferences; agile turnarounds; network origination; and fiber and microwave interconnectivity to local television stations.

Wavelength Commercial Communications, Inc.: *www.wavelengthsatellite.com*

Installation and servicing of Satellite equipment. Provides data networks, private cable, VSATs and teleconferencing.

Appendix D: Addressable Markets: Space Spending & Revenue Patterns

The global space industry experienced significant growth during the 1990s as new commercial markets emerged to drive revenues upward. At the same time, both civil and military government space spending first stagnated and then declined. As the industry adapted to its new environment, traditional space firms sought mergers to consolidate operations and shore up markets. In a further bid to adjust, these same firms both competed with and acquired new ventures in the emerging services markets. This context for the space industry, where the most significant growth is driven by commercial services markets, will shape the next decade of space business as it has shaped the last. New markets will continue to surface, presenting economic opportunity to those that step forward. This appendix provides an overview of Colorado's addressable space market. Forecasts are provided for NASA, DoD, and commercial revenue sources through the next decade, providing qualifications, where relevant, as to what portion of those markets are captive and therefore not addressable by Colorado. An overview of Colorado's forecasted share of these addressable markets is provided in Appendix F.

D.1 NASA Expenditures

NASA expenditures have declined over the past decade. If realized, the FY 2001 President's Budget for NASA will be the first real increase in NASA funding in over six years.[1] Still, NASA projections through 2005 hover around the $13.4 billion mark with little real growth. The pattern of NASA funding should remain more or less the same, with Space Station assembly and operating costs decreasing slightly in the out-years while research investment increases; NASA has already

[1] Office of Management and Budget, *FY 2001 President's Budget*, February 2000.

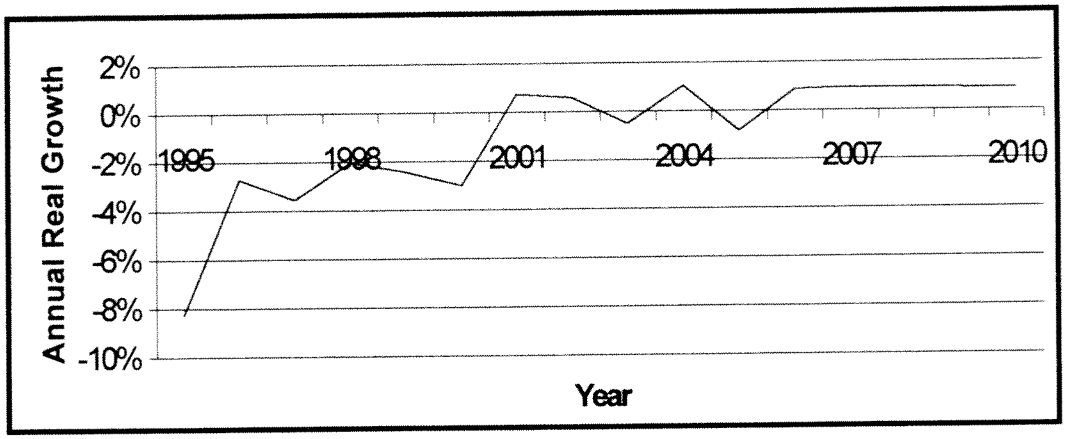

Figure D.1: Percent Change in Real NASA Budget Authority, Historical and Forecasted

stepped up its funding to educational institutions; Figures D.1 through D.4 illustrate NASA's historical and forecasted funding patterns.

The Space Shuttle will continue to be NASA's only mode of human space transportation,[2] along with Station tying up almost half of NASA's total funding.[3] The forecast of NASA budget authority for out-years keeps pace with NASA's own, nearer-term projection, and uses a real growth rate under one percent a year.

Approximately 92 percent of NASA's budget is outlayed in some form of procurement. While much of the NASA budget is captive to construction and operational contracts [such as the Shuttle and Station, along with facilities costs], NASA's investment in research activities is on the upswing. This growing R&D budget reflects the Agency's shift away from operational activities and toward more exploratory activities. While this shift means that more standard operations are contracted out, NASA also expects to derive cost-savings from the new arrangements, freeing up budget for the desired R&D. Without a major NASA facility in Colorado, this increasing R&D budget represents the most promising growing wedge of the NASA pie for Colorado [see Appendix F].

D.2 DoD Space Expenditures

U.S. military space expenditures include space-related procurement, personnel, and facilities. Of these three components, space procurement is by far the largest share. Dedicated [or near-dedicated] DoD space personnel and facilities are already largely concentrated in Colorado and are covered in detail in Appendix F, Section 2.

[2] Notwithstanding occasional past and future flights on the Russian *Soyuz* vehicle.

[3] NASA past budget authority figures drawn from Aerospace Industry Association, *Aerospace Facts and Figures 1999/2000*, p. 69.

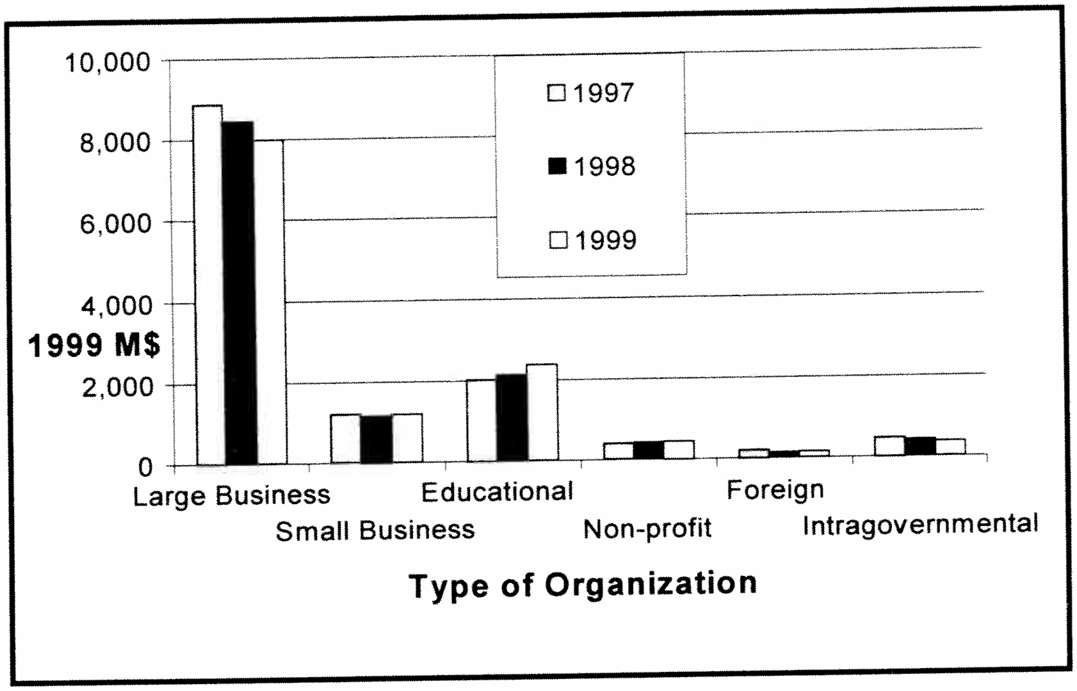

Figure D.2: Historical NASA Obligations by Type of Organization[4]

	# Contractors [organizations]			# Contracts [awards]		
	1997	*1998*	*1999*	*1997*	*1998*	*1999*
Large Business	626	593	590	2578	2210	2153
Small Business	2095	1896	1748	3829	3555	3615
Educational	477	471	457	7998	7594	7400
Non-profit	283	303	318	1209	1227	1330
Foreign	88	98	88	134	148	126
Intragovrnmental	67	74	73	1153	1347	1440
Total	3,636	3,435	3,274	16,901	16,081	16,064

Figure D.3: Historical NASA Contract Statistics, 1997, 1998, and 1999

Obtained DoD space procurement data are extrapolated from DoD reporting of procurement information for "missiles and space," [M&S] one of the 25 major military procurement programs.[5] The Aerospace Industries Association has historically rolled up DoD annual spending on missile programs from individual program budgets.[6] The forecast model uses this data to infer the proportion of the

[4] NASA Acquisition Internet Service.
[5] Department of Defense, DIOR.
[6] Aerospace Industries Association, p. 50.

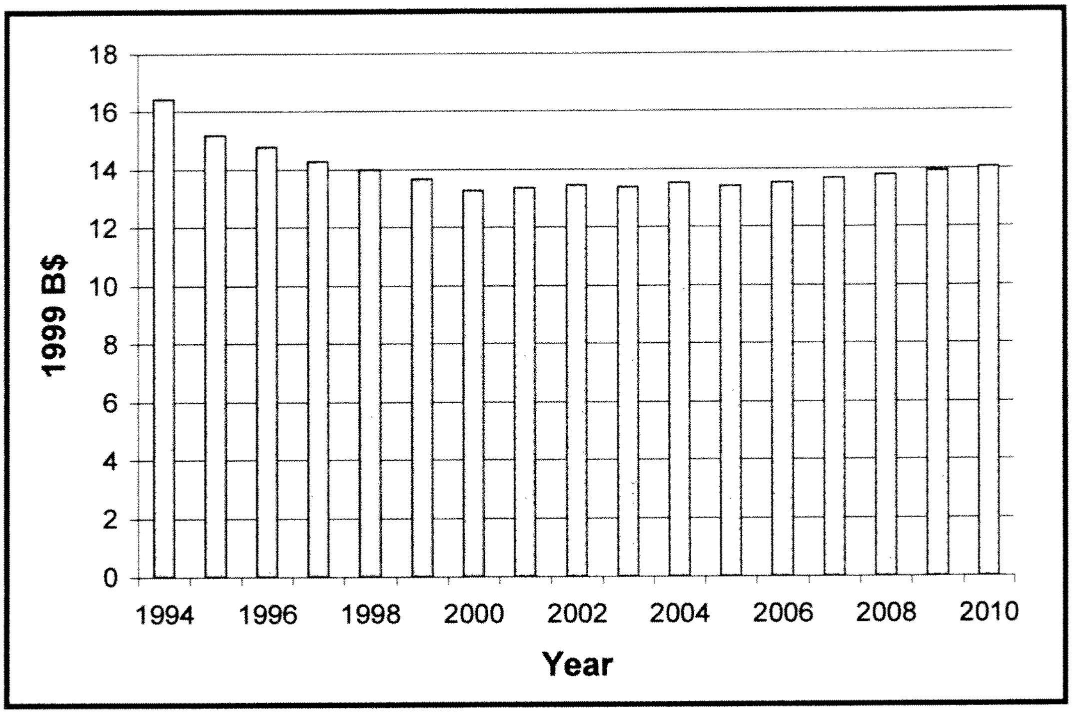

Figure D.4: Historical and Forecasted NASA Budget Authority

missiles and space procurement budget line that is actually spent on space activities. This percentage varies slightly over the forecast period to reflect DoD procurement program emphases.

M&S procurement fell both in absolute terms and as a percentage of total DoD procurement from 1994 through 1998. Missile programs were hardest hit with the funding decrease, although space procurement shared the burden [see Figure D.5]. DoD space procurement fell by almost $2 billion through the mid-1990s, reaching a low of $6.4 billion in 1998. 1999's space procurement total of $6.8 billion was the first in what is projected to be a modest but steady increase [at a real CAGR of 2.5 percent] in DoD space spending throughout the forecast period [see Figure D.6].[7]

DoD space procurement is one of the most significant addressable markets for the Colorado space industry. Appendix F, Section 2 details Colorado's historic strength in this market, and offers a perspective on Colorado's prospects in capturing a growing share of this increasing pie.

[7] CAGR derived from DoD reporting of space spending plans. General Accounting Office, p. 30.

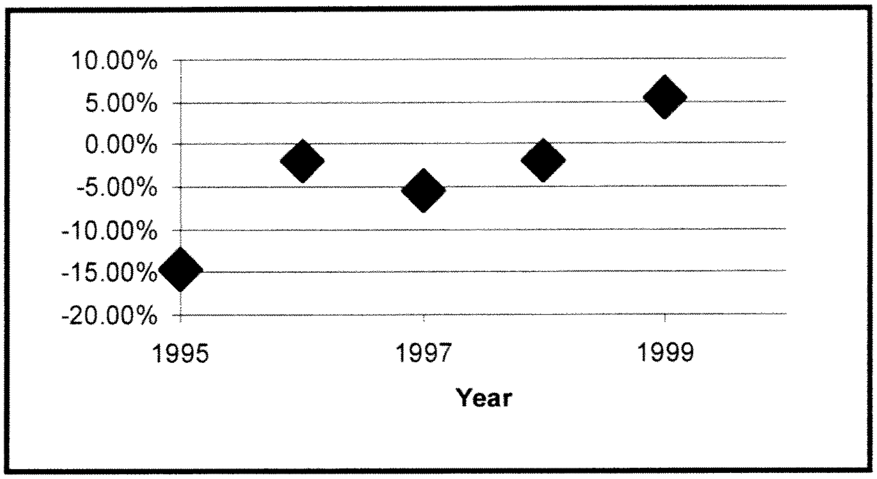

Figure D.5: Historical Percent Change in DoD Space Procurement from the Previous Year

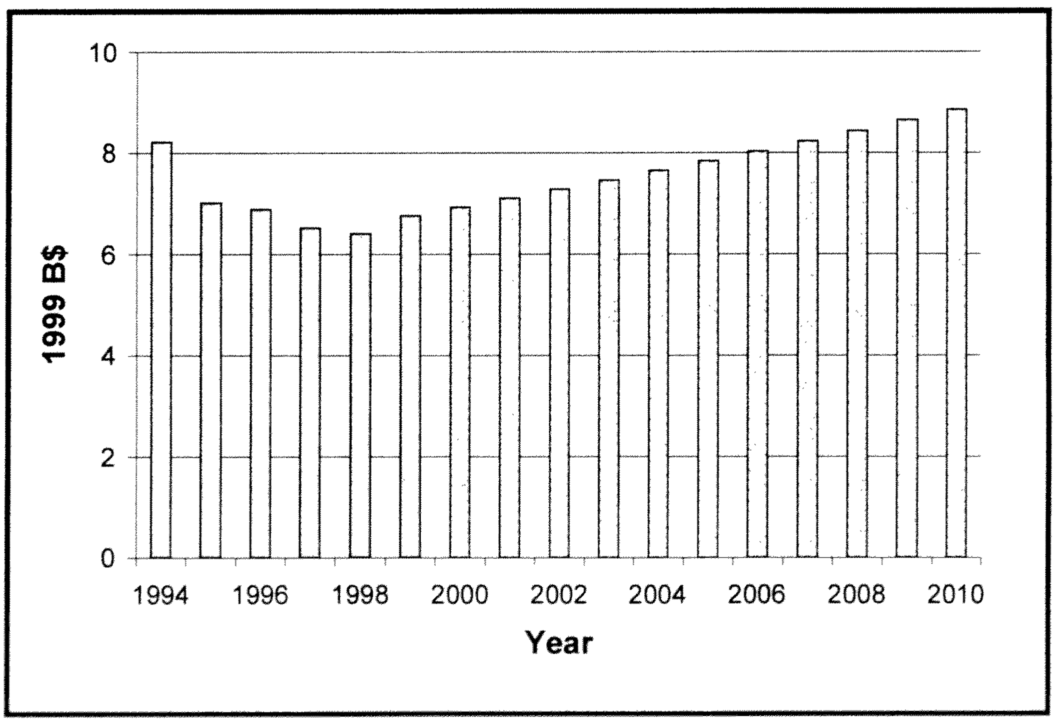

Figure D.6: Historical and Forecasted DoD Space Procurement [1999$]

D.3 Commercial Markets

The developed commercial forecast models for the world, the United States, and Colorado [see Appendix F] divide the space industry into four primary segments:

- The *satellite-manufacturing segment* includes the construction and sale of satellites to both commercial and government customers.
- The *launch industry segment* includes the manufacture of launch vehicles and the provision of launch services.
- The *satellite services segment* includes transponder leasing services [e.g., video and radio services, data/business services, and telephone relay services] and subscription/retail services [e.g., DTH television services, mobile voice and data, VSAT services, and remote sensing imagery].[8]
- The *ground equipment segment* includes data from major satellite-related hardware [e.g., gateways and satellite control stations]; mobile uplink equipment; VSATs and USATs; and consumer electronics such as DBS dishes and GPS terminals.

In the Colorado forecast, an additional category was added, an "*other*" segment that includes professional services such as management consultants, engineers, and technicians supporting space customers in government or industry. Unless otherwise noted, world and U.S. forecast figures do not include payments to subcontractors. Due to survey methodology [see Appendix F], the Colorado numbers may include payments to subcontractors.

World and U.S. industry data include revenues from government customers in those instances where an item or service was commercially procured and was relevant to the satellite industry; revenues from the creation, launch, or operation of non-satellite spacecraft [such as science probes] are not reflected, nor are revenues procured in relation to any human space flight program. In some instances, the commercial industry revenues may overlap with reported DoD and NASA space procurement as reported in this section, although the level of overlap is not taken to significantly affect overall forecast magnitude and trends.

The forecast projects that the global commercial space marketplace will almost triple in size over the next decade. A surging satellite services sector drives commercial growth, having more than doubled in the past five years [see Figure D.7]. The ground equipment-manufacturing sector has kept pace, almost doubling in size over the same time period [from $12.3 billion in 1996 to $22 billion in 1999]. Largely the burgeoning DTH market has propelled satellite services, while ground equipment manufacturing has benefited from demand surges for both DTH equipment and consumer GPS devices.[9] Despite the rapid growth in services,

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[8] Since many satellite services are provided over leased transponders, payments to transponder leasing companies are reflected in the figures for transponder leasing.

[9] Derived from: International Trade Administration, Department of Commerce, *Global Positioning System: Market Projections and Trends in the Newest Global Information Utility*, 1998, p. 26.

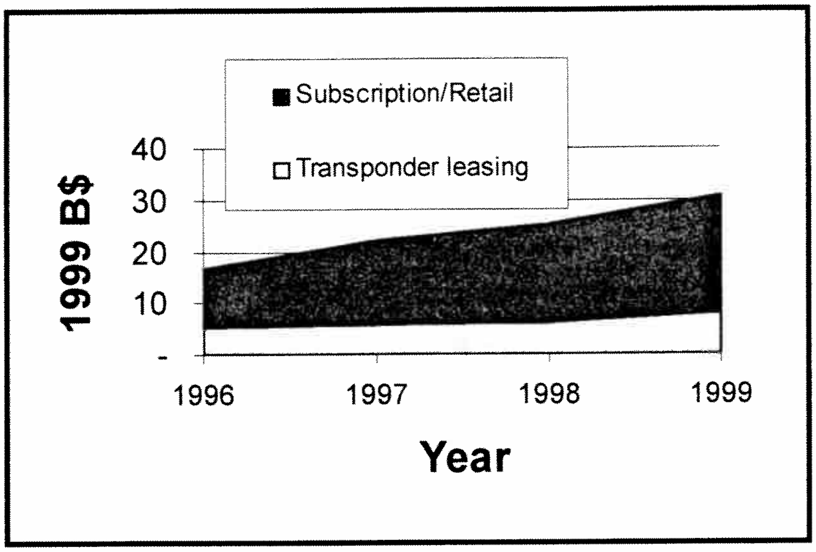

Figure D.7: Historical Global Revenues of the Satellite Services Segment[10]

launch industry growth has been sporadic, while the satellite manufacturing sector has displayed but modest growth.[11]

The forecast projects that the satellite services segment will ramp slowly down to single digit growth in the second half of the forecast period, from its current pace of 21 percent real, annual growth. Today, more than an estimated three-quarters of the services sector valuation is derived from subscription and retail services versus transponder leasing; the forecast maintains these rough proportions through 2010. Ground equipment manufacturing will likely match the pace set by the services sector, starting off at almost 20 percent real, annual growth and following the services sector, approaching the single digits in the second half of the forecast period. The ground equipment manufacturing sector growth rate will be boosted by strong growth in GPS user equipment, which comprised only one-fourth of the ground-equipment market in 1999, but is forecast to comprise more than 40 percent of the sector by 2010. The services forecast is sensitive to the adoption rate of new technologies and services; higher than expected growth in emerging markets such as Internet-protocol multicasting could keep satellite services growing in the 20 percent—or higher—range through 2010.

In contrast to the satellite services and ground equipment sectors, satellite manufacturing and launch services will likely experience sporadic growth over the

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[10] Satellite Industry Association, *Satellite Industry Indicators 2000*, published by Futron Corporation for the Satellite Industry Association.

[11] Advancing technology has steadily increased individual commercial communications satellite capabilities, keeping the required number of satellites moderately stable, despite rapid increases in overall on-orbit capacity.

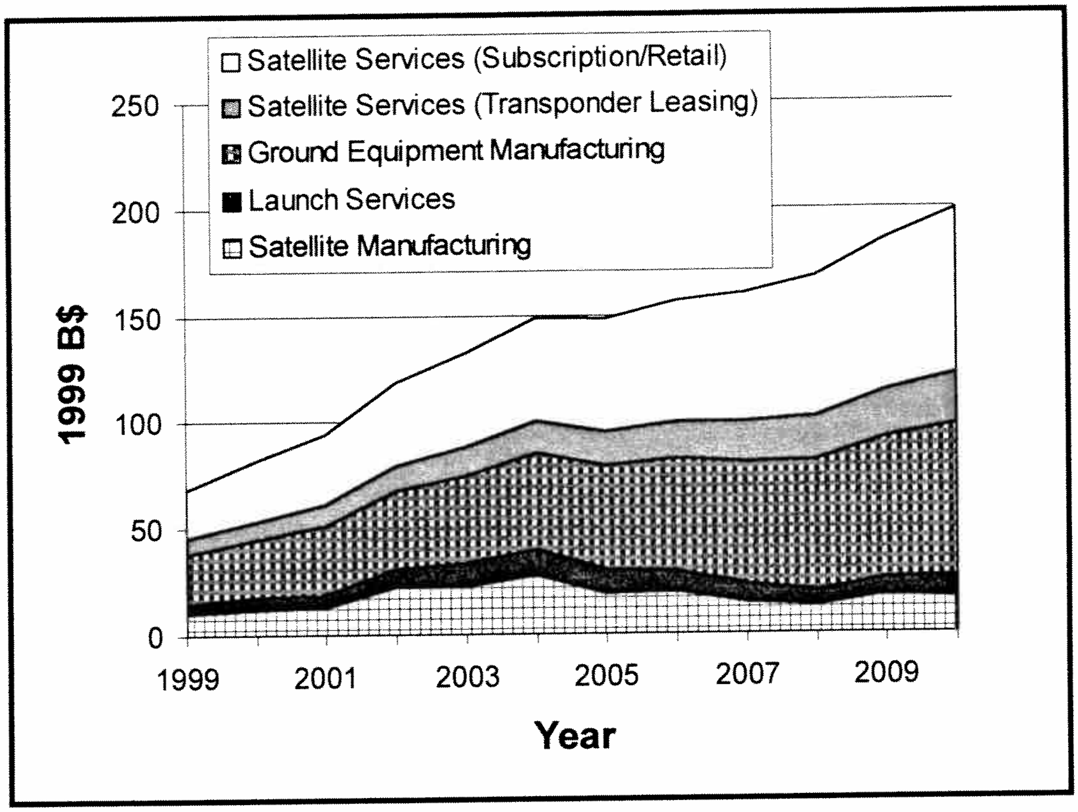

Figure D.8: Forecasted World Satellite Industry Revenues by Segment

forecast period. Increasing satellite capability enables services growth without any significant increase in on-orbit satellites. Moreover, an anticipated new market for launch services—low-Earth orbit [LEO] satellite constellations—has yet to be fully realized.

The U.S. commercial space forecast closely tracks the pattern set at the world level. The forecasted world satellite industry revenues by segment is illustrated in Figure 8 and the forecasted U.S. satellite industry revenue, by segment is illustrated in Figure 9. Figure 10 illustrates the forecasted U.S. commercial satellite industry revenues together with DoD space procurements and NASA procurements. The present forecast presumes that trade relations between the United States and the world's space economies remain stable, with no significant, long-term policy changes that would either greatly disadvantage or advantage [from the recent historical state] the competitive position of U.S. space firms in addressing the global space market.[12]

[12] The U.S. forecast does not incorporate any possible, long-term, negative impact on the U.S. space industry from recently tightened U.S. technology export regulations.

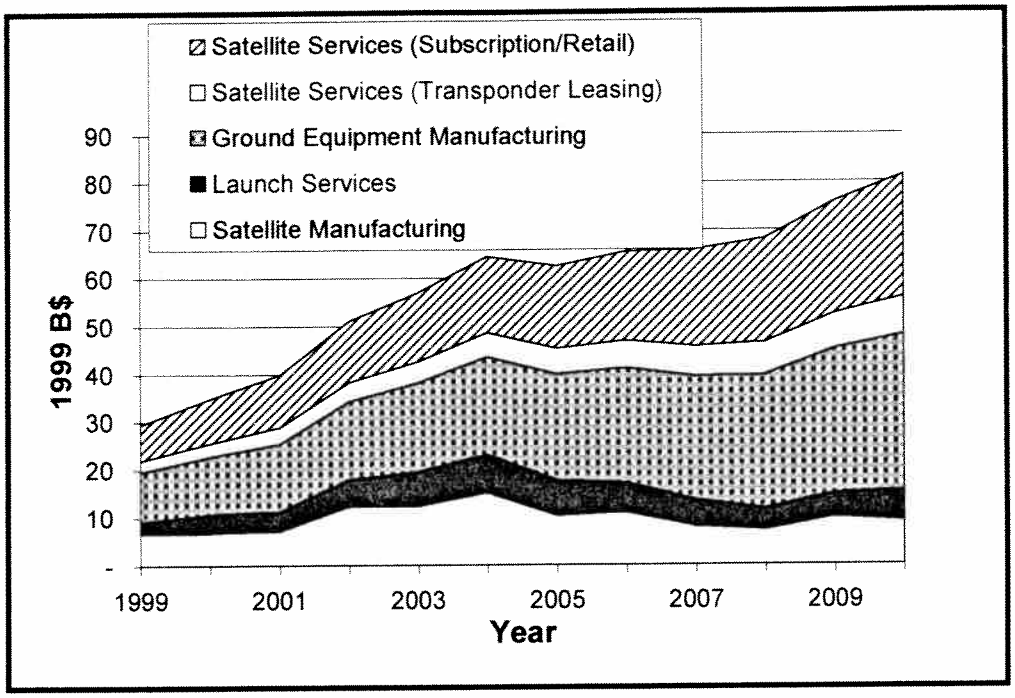

Figure D.9: Forecasted U.S. Satellite Industry Revenues, by Segment[13]

The U.S. held just over a 42 percent of the global commercial satellite industry in 1999. If U.S. firms retain existing market share, by 2010 the industry could realize more than $81 billion in 1999 dollars from the satellite business.

D.4 Space Spending and Revenues Patterns Conclusion

A 40 percent global share of the commercial satellite industry, in addition to DoD space procurement and NASA spending plans, could combine to create a U.S. space industry with revenues well over $100 billion [1999 dollars] by 2010. While a good portion of these revenues is captive to long-term procurement contracts and/or is set by historical relationships, tens of billions of dollars in annual revenue could migrate with industry intent on choosing a geographic location that optimizes available business incentives. With high-tech, high-wage, low-environmental impact employment, the space business is an attractive addition to most economies.

[13] Note: The U.S. industry numbers presented here are distinct from those in Figures 3.3 and 3.4, where the commercial revenue numbers do not include revenues received by commercial firms for satellite services and hardware commercially procured by government agencies [and as detailed in the text above].

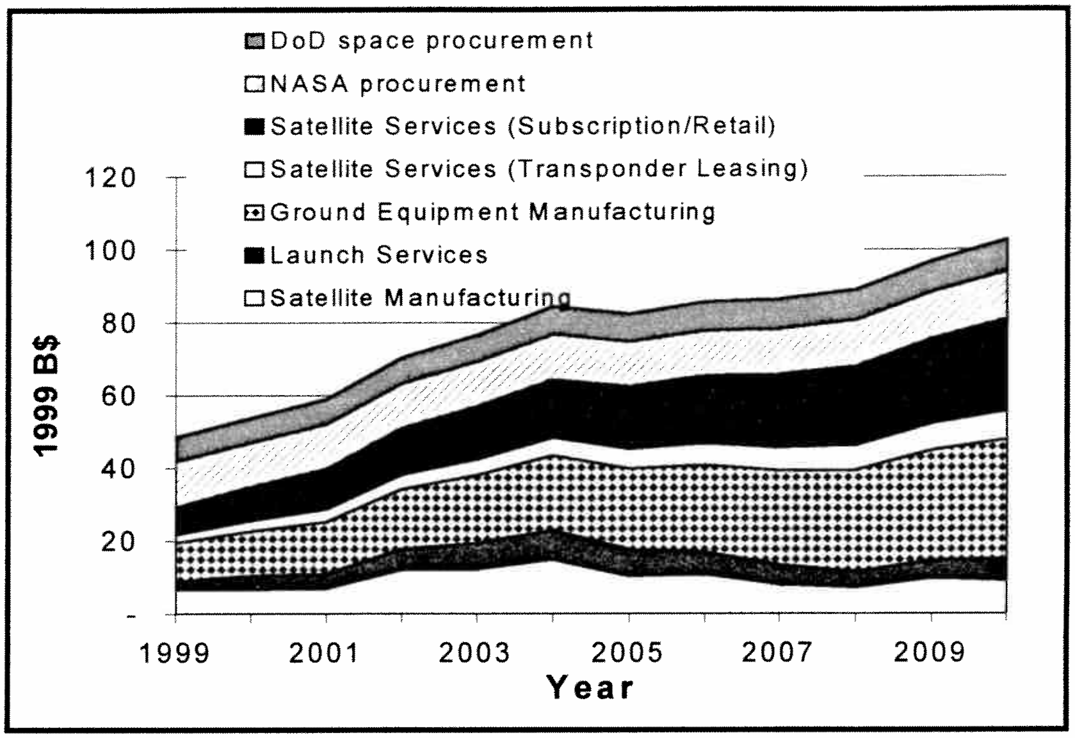

Figure D.10: Forecasted U.S. Commercial Satellite Industry Revenues, DoD Space Procurement, and NASA Procurement[14]

[14] Note: The government expenditures reported here are distinct from the government space expenditures reported in Figure 3.3. Figure 3.3 reflects only procurement to commercial firms and not awards to educational institutions and non-profits, which are included here.

Appendix E: Economic Multipliers

Multipliers in General

Economic multipliers estimate the total expenditures resulting from a change in the economy such as the addition [or removal] of one job or $1 from the economy. Often they are used to evaluate changes in government policies, ranging from the effects of a raising or lowering of taxes to the construction of a new large facility. Typically, income and employment multipliers at a national level are in the range of 2:1 to 3:1, meaning that for every job created by an investment, an additional two or three jobs can be expected to be created.

In other words, revenue growth in Colorado's space industry will create a growth in the industry's employment, i.e., direct employment. The increase in direct employment will cause an increase in the demand for supporting services such as health, recreational, and domestic services. These are referred to as indirect employment. Thus, for every direct job created, there are likely to be an additional 2 to 3 jobs created.

Multipliers can be national, regional, or sub-regional. They can be industry or sector based, or they can be economy-wide. They are usually calculated for the short-run [as long as it customarily takes for the change to iterate through the economy, but generally a year or so].

Since multipliers are based on the infusion of new funds into a region, once the additional investment ends, the multiplicative effects also end. Thus, a government program that pumps new money into a region will continue to create support jobs as long as the program continues. If it stops and is not replaced, the multiplier effects end. And, if it is replaced by something else, the distribution of the additional jobs and income will change, even if the total multiplier remains the same.

In the long-run, multipliers of the sort described above have less meaning. However, the concept of long-run investments such as R&D or capital infrastructure having sustained multiplier effects on an economy is valid. These, however, are much more difficult to measure because they are based on productivity improvements within industry that enable companies to compete more effectively and produce greater profits that then translate into additional jobs and income. Making the transition in economic data from investments to productivity and then jobs is difficult because of the indirect and probabilistic nature of the diffusion of benefits from investments. However, it should be noted that the space industry is very R&D intensive as compared to most other industries and it is thus likely to have a significantly higher long-term multiplier than the less R&D intensive industries.

Regional Multipliers

Multipliers can be calculated for any size or given region. For data reasons, in the U.S. county data is the smallest practical area to consider. However, the smaller the region, the more problematic the data. First, the data, particularly at an industry or detailed level, may have more errors than for large regions due to the lack of consistent reporting and small number of observations. Second, some industries [notably those most important to the region] that employ large numbers of workers in one or two firms may not have data disclosed due to confidentiality.

At a regional level, multipliers may be much larger than at higher levels of aggregation if the industries most affected by the changed economy are very important in the local economy. This is a dual-edged sword: the more development in those industries, the faster the economy can grow, but if a slowdown occurs, the faster the region is hurt.

Theory of Regional Multipliers

Unlike the Keynsian multipliers used for national estimates, regional multipliers are based on the ratio of industries with sales outside the area to industries with sales inside the area. Growth in industries that "export" to other regions is considered good for the region since it encourages new money into the area. Industries that primarily service local residents and businesses essentially regenerate money within the area.

The space sector generally sells its products outside the producing area. Thus, if there is growth in space industries in Colorado [or its regions], then multipliers can be expected to be very positive. In the long-run, growth depends on the productivity of those firms and industries and may not be as robust as the short-run multipliers, depending on the types of investments made.

U.S. Data Sources

The Bureau of Economic Analysis, U.S. Dept. of Commerce, produces most regional data for the United States. It is county-level and can be aggregated any way desired. The BEA also produces estimates of Gross State Product, regional multipliers, and projections. The most recent projections were made in 1995 and, thus, are based on relatively old data. Reliability should be questioned, particularly for a study being performed now with projections out to 2010.

The determination of economic multipliers for the space industry suffer from the fact that there is no good definition of the space sector. The space sector is combined with other SIC industries. For example, the space industry is combined with some aeronautics in SIC 376 [and defense as well] and satellites are combined with radio equipment.

Productivity effects of R&D are not accounted for in the multipliers produced by the government, and price changes are not accounted for [i.e. quality of output is assumed constant]. These factors must be kept in mind when analyzing projections of an industry into the future, especially when it is a large industry in a local and fairly small area.

In order to be conservative with respect to employment forecasts, long-term multipliers [i.e., productivity] were not considered and indirect labor impacts were considered based upon a short-term multiplier of 2 [i.e., the lower end of the range].

Appendix F: Colorado's Space Situation

F.1 Identifying the Colorado Commercial Space Industry

Defining Colorado's Space Industry

Colorado's space industry is well represented in terms of revenues from commercial customers as well as government customers. In addition to procurement dollars, Colorado receives government grants from NASA and DoD as well as payroll and other program expenditures.

Four commercial segments of the space business are considered in this strategic plan.

- The *satellite manufacturing segment* includes the construction and sale of satellites to both commercial and government customers.
- The *launch industry segment* includes the manufacture of launch vehicles [including payments to sub-contractors] and the provision of launch services.
- The *satellite services segment* includes transponder leasing services [e.g., video and radio services, data/business services, and telephone relay services] and subscription/retail services [e.g., DTH television services, mobile voice and data, VSAT services, and remote sensing imagery].
- The *ground equipment segment* includes data from major satellite-related hardware [e.g., gateways and satellite control stations]; mobile uplink equipment; VSATs and USATs; and consumer electronics such as DBS dishes and GPS terminals.
- The *other segment* includes professional services such as management consultants, engineers, and technicians supporting space customers in government or industry.

Colorado companies in these segments range from a multi-billion-dollar business like Lockheed Martin Astronautics to retailers of DBS or GPS equipment. Following is a sample of companies surveyed for this plan:

ANALEX Corporation, a women-owned small business, provides design, development, analysis, and testing of products and systems for the aerospace, medical, hi-tech manufacturing, telecommunications, and information technology industries.
Autometric, Inc. develops software for processing and displaying state-of-the-art 3D visualizations, such as graphic simulations to preview orbits of space-bound vehicles before the launch.
Ball Aerospace & Technologies Corporation designs and manufactures satellites and space systems, space and scientific sensors and provides imaging, communications, and information systems, products, software, and services to government and commercial aerospace customers.
Earthwatch Inc. is building both a constellation of high-resolution satellites and a comprehensive multi-source online digital imagery store and is a leading-edge information content provider developing and selling a wide variety of remote sensing based imagery and geospatial information products.
Echostar Communications Corporation delivers direct broadcast satellite (DBS) television products and services to customers worldwide.
Lockheed Martin manufactures satellites and launch vehicles and is a leading integrator of complex information technology systems for federal and commercial users.
Raytheon Systems Company manufactures ground stations; tracking, telemetry and command stations; and antenna systems.
Space Imaging, a leader in digital Earth information, launched IKONOS, the world's first one-meter resolution, commercial imaging satellite, on September 24, 1999.

Government expenditures include not only revenues to space companies or grants to organizations, but also--in Defense facilities dedicated to space--payroll, revenues to non-space companies [for delivering products or services not focused on a space mission], and other programmatic costs. In Colorado there are several military organizations that provide national security functions using space assets and the space infrastructure. Of most significance is the U.S. Space Command at Peterson AFB, which coordinates the use of Army, Naval and Air Force space forces to support launching and operating satellites for worldwide intelligence, communications, weather, navigation, and ballistic missile attack warning information. NORAD [North American Aerospace Defense Command], operating under the U.S. Space Command, is a U.S. and Canadian organization charged with warning and control for North America and includes monitoring man-made objects in space and warning of attack against North America. The 2nd Space Warning Squadron, at Buckley Air National Guard Base in Aurora, detects ballistic missile launches using Defense Support Program satellites, and reports that information to U.S. Space Command. The 50th Space Wing [Schriever AFB, CO] commands, controls, and provides launch support to over 100 operational satellites.

A major BMDO installation is the Joint National Test Facility [JNTF], which provides state-of-the-art capabilities for Ballistic Missile and Theater Air Defense testing, modeling and simulation, and analysis. The 55th Space Weather Squadron, in Boulder, provides space environmental analysis, forecasts, and warnings to enhance the capability of worldwide Department of Defense forces and other Federal agencies. Finally, NAVSOC [Naval Satellite Operations Center] is responsible for remote tracking, telemetry and command facilities in support of satellite missions.

Survey Research Methodology

To identify the Colorado commercial space industry, a database was created of Colorado firms that were potentially part of the space industry. The database was compiled from several industry resources including the Futron Electronic Library of Space Activities, 1999 Satellite Industry Directory, member list for the Colorado Space Business Roundtable, member list for the National Defense Industry Association Rocky Mountain Chapter, NASA list of primary contractors, the Colorado High Tech Directory, and the Internet. After eliminating duplicates, there remained a list of 332 potential Colorado space manufacturing and services firms.

Two different surveys were designed and used to gather data from the Colorado firms. The first was a telephone survey that was intended to elicit general information about the participating organization[15], including its mailing address, web site, location of headquarters, contact name, and the number of facilities the organization has in Colorado that work in the space industry. This survey also was used to identify the number of employees, the space industry segment of an organization's work, the percentage of space-related business, and an estimate of total annual revenues generated by an organization.

The second survey was e-mailed to eight firms considered to be major players in the Colorado space industry. These firms were selected based on the number of employees and the value of their annual revenues, their participation in the Colorado Space Strategy Initiative, and recommendations from the Space Foundation. The "major" Colorado space firms are Ball Aerospace, Boeing, Computer Sciences Corp., Echostar, Hughes Space and Communications, Lockheed Martin, Raytheon, and TRW. This survey included all the questions that were in the phone survey as well as additional detailed questions. The additional questions were intended to gather information about these firms' key subcontractors, key customers, the percentage of product value obtained from suppliers outside the state, and the percentage of products or services delivered to customers outside the state. This survey was also used to determine the amount of space revenues generated by Colorado facilities, the percentage of space revenues generated from government and non-government contracts, and the differentiation

[15] A participating organization is a survey respondent.

of government contracts by NASA, DOD, and other government agencies. All firms that received a written survey by email also received at least one follow-up phone call to confirm receipt of the survey, answer questions, and remind firms of the deadline for returning completed surveys.

Following completion of conducting both surveys, results of telephone and written surveys were combined to estimate total Colorado space employment, space revenues, and space industry segmentation of the commercial/non-government sector of the Colorado space industry. Additional analysis was performed on results of the written surveys regarding dollar flows for major firms.

Survey Results

Three hundred thirty-two potential Colorado space firms were identified and called, including the eight "major" firms that also received written surveys by e-mail. Of the 332 potential space firms, 75 were determined to no longer be in business and 257 were contacted. Of the 257 firms that were contacted, 57 specifically stated that they are not in the space industry, 66 firms did not return messages [one was a major firm], 20 firms declined to respond to the survey, and 114 surveys were completed. Of the 114 surveys that were completed, 107 were phone surveys and seven were written surveys. Of the seven written surveys, Boeing did not complete all survey questions and therefore was excluded from certain industry analyses as noted. Echostar did not respond to the survey, but estimates of employment and revenue data were made based on its 1999 annual report.

Findings

All Survey Results Combined

Survey results, as summarized in Figure F.1, suggest there are about 24,000 space-related employees in the state of Colorado, excluding government employees. The satellite services segment has the most employees followed by satellite systems manufacturing, ground equipment manufacturing, launch industry, and other, respectively. It is not possible to calculate the exact number of employees in each industry segment because many firms reported work in more than one industry segment [i..e., the possibility of double counting].

Commercial firms' space revenue estimates for the state of Colorado are based on the survey responses of the 114 participant organizations.[16] Total space revenues to commercial firms include revenues received from both government and non-government customers. All respondents were asked to estimate their total Colorado annual revenues within specified ranges, as shown in Figure F.2. Of the

[16] Total space revenues to commercial Colorado firms may be understated due to the non-participation of the firms that did not return messages or declined to participate in the survey.

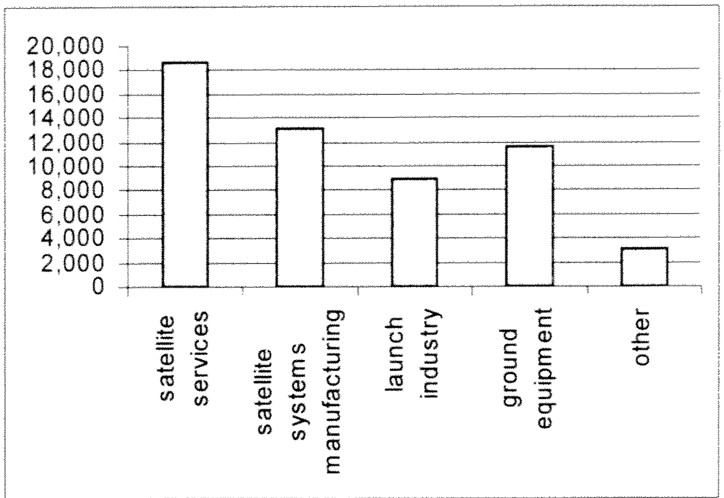

Figure F.1: Colorado Space Jobs by Industry Segment [Excluding Government]

"Which of the following categories most closely describes the revenues of your organization?"

Total CO Revenue Category	# of Respondents to This Question	# of Non-Respondents to This Question	Estimated Space Revenues of Respondents [$millions]	Estimated Space Revenues of Non-Respondents [$millions]
<$1M	27	16	9	5
$1-10M	27	16	79	47
$11-25M	7	4	87	49
$26-50M	4	2	13	7
$50M+	11	1	3655	800
TOTALS	76	39	3843	908

Total Revenue: $4751 million

Figure F.2: Total Colorado Space Revenues to Commercial Firms[17]

[17] Notes:
Total space revenues to commercial firms are based on the survey responses of 114 Colorado space firms, and they include revenues received from both Government and non-government customers.

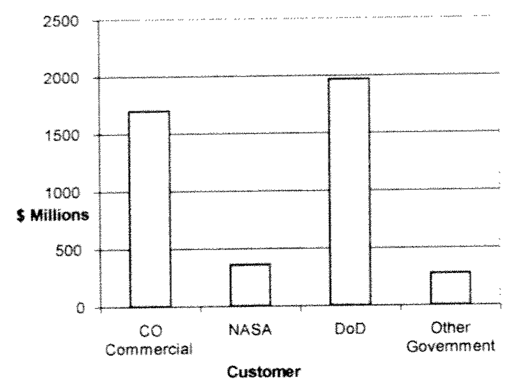

Figure F.3: Colorado Major Space Firms' Space Revenues by Customer [1999]

114 respondents, 76 provided revenue data ["respondents"] and 39 declined to provide revenue data ["non-respondents"]. The estimated revenues of respondents were $3.9 billion. Based on the ratio of non-respondents to respondents, revenue of non-respondents was estimated at $908 million. The total estimated annual space revenue to Colorado commercial firms in 1999 was nearly $4.8 billion.

Survey Results for Major Colorado Space Firms

Survey results indicate, as illustrated in Figure F.3, that 61 percent of the major firms' space revenues are generated from government customers and 39 percent are generated from non-government customers. The survey data show that 75 percent [$1,966 million] of government revenues are generated from DoD contracts, 14 percent [$365 million] are from NASA contracts, and 11 percent [$282 million] are from other government agency contracts.

The space revenue of major Colorado space firms was also analyzed by industry segment, as illustrated in Figure F.4. The launch industry segment of the space industry generates the largest share [37 percent] of the government revenues of the major commercial space firms. The majority [61 percent] of major space firms' revenues generated from *non*-government customers are from the satellite services segment of the space industry. The launch industry segment is the second largest [29 percent] non-government segment in Colorado.

Estimated revenues of respondents were determined by multiplying the percentage of space-related business reported by firms by the mid-points of the total Colorado revenue ranges. For firms with revenues over $50 million, exact dollar amounts were used when possible.
Estimated revenues of non-respondents were determined by multiplying the ratio of non-respondents to respondents by the estimated revenues of the respondents.
Echostar is the one non-respondent over $50M. Revenue estimates based on 1999 annual report.

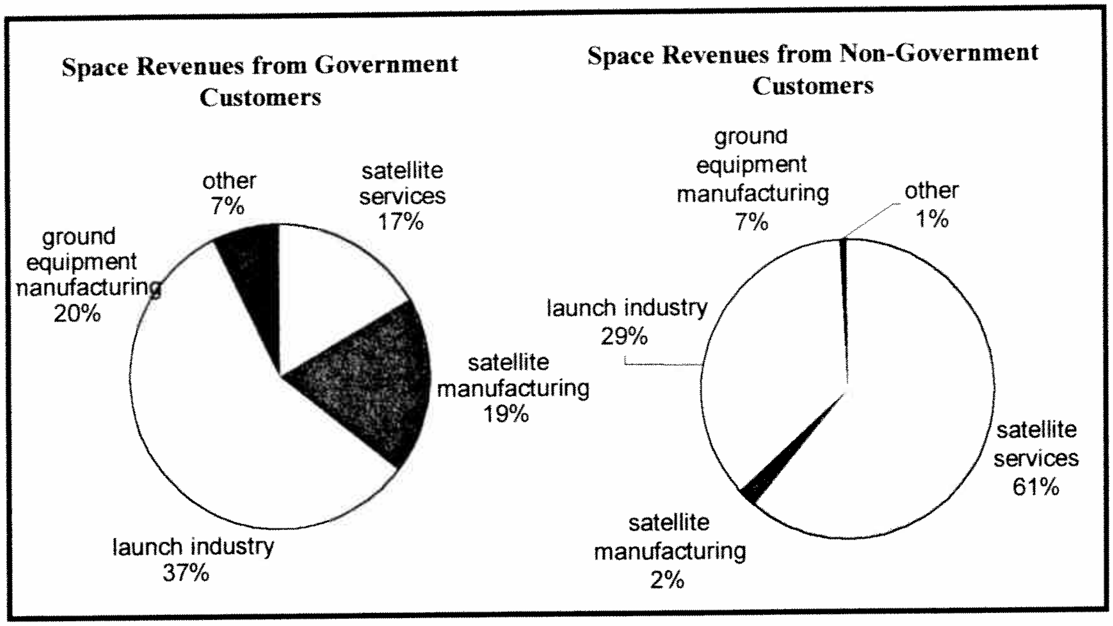

Figure F.4: Colorado Space Revenues of Major Firms by Industry Segments

As indicated in Figure F.5, Colorado major space firms received $2.6 billion in space-related revenues from government in 1999 compared to $13.3 billion received by the rest of the United States.[18] From commercial/non-government customers, the Colorado major space firms received $1.7 billion in 1999 while the rest of the United States received $22.3 billion in space-related revenues from commercial customers.[19]

Figure F.6 indicates that of the four space industry segments [satellite services, satellite systems manufacturing, launch industry, and ground equipment manufacturing], Colorado has the largest share [27 percent] of the launch industry segment of the space industry compared to the rest of the United States. In addition, survey results show that Colorado receives 11 percent of the total U.S. satellite services revenues.[20]

Figure F.7 summarizes commercial space revenues and government space expenditures that flowed in and out of Colorado in 1999. The total 1999 space revenue is estimated to be in the range of $3.3 - 5.1 billion. This range depends on

[18] Data for the United States was compiled from Futron Corp.'s SIA database, DoD Directorate for Information Operations and Reports 1999, and NASA Acquisition Internet Service. Data for Colorado that was gathered from CSSI member surveys was subtracted from the United States totals.

[19] Ibid.

[20] CSSI member surveys and Futron Corp.'s SIA database.

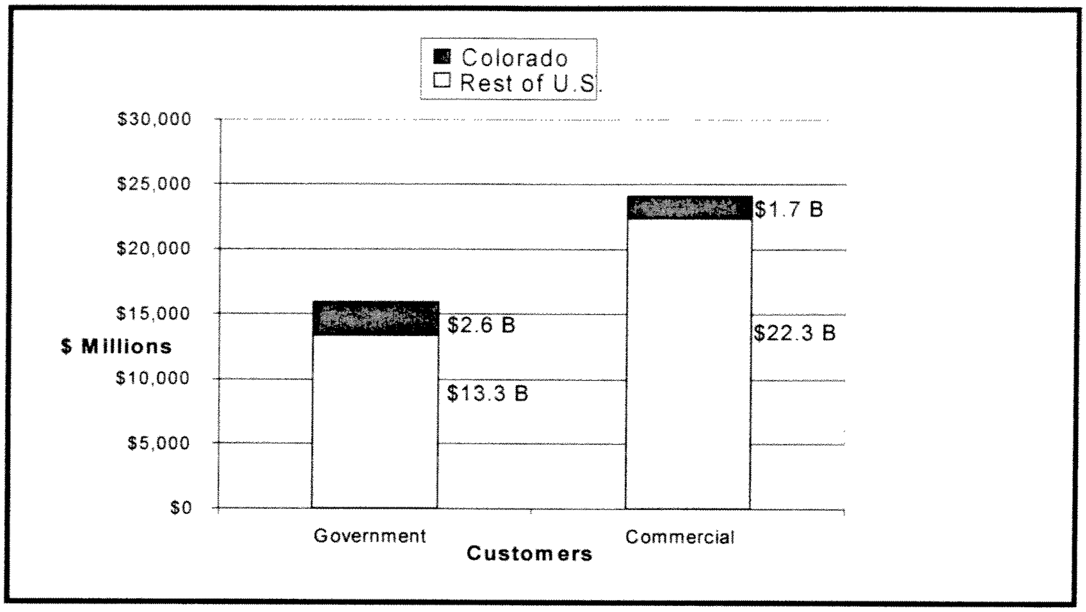

Figure F.5: Colorado Major Space Firms' vs. United States' Total Space-Related Revenues from Commercial Customers and U.S. Government Space Expenditures

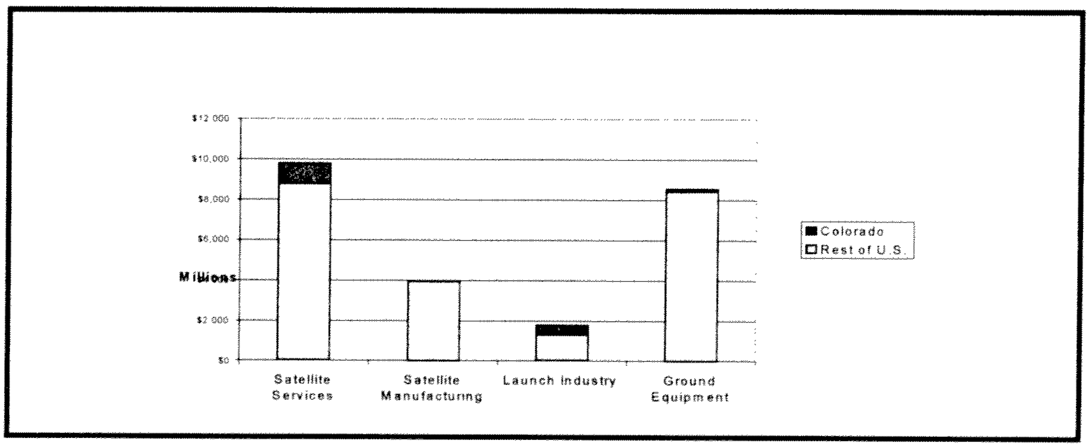

Figure F.6: Colorado Major Space Firms' vs. United States' Total Space-Related Revenues from Commercial Customers by Industry Segment

differing estimates of revenues from government customers. Government revenue estimates depend on information source: in particular, revenues estimated by survey respondents exceed those estimated by government procurement sources. *Forecasts shown in Section 3 use the lower estimates provided by government sources.* [Government and commercial revenues in these figures are also discussed in Section 3.]

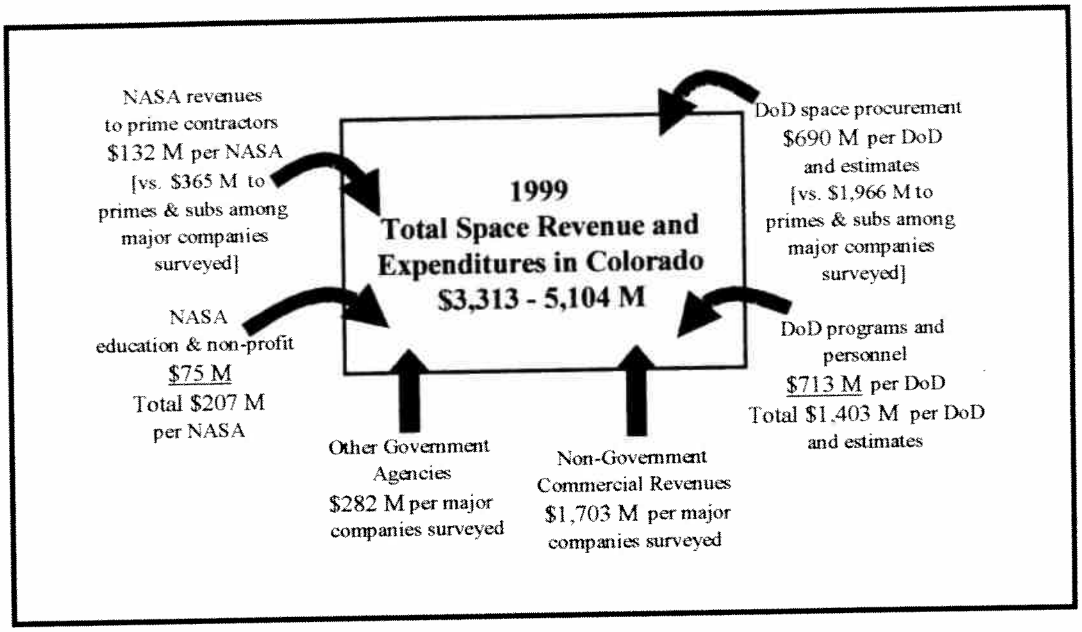

Figure F.7: Flow of Revenues and Other Government Expenditures

Greater detail is given in Figure F.8. Note that subcontractor revenue from government contracts were identified in company interviews but not government estimates. Additionally, it is possible that government estimates exclude classified expenditures that company interviews include.

F.2 Colorado's Space Forecast

It is anticipated that Colorado's space industry will experience significant growth if the industry as a whole maintains a competitive position vis-à-vis other states. Maintaining and improving the competitive position of Colorado's space industry requires that the state support industry in ways that at least compare with and preferably exceed those exercised by competing space states. The presented forecasts are premised on the continuation of historical trends, the realization of federal procurement plans, and maintained growth in commercial satellite services markets.

Methodology

Colorado's space industry forecast is broken into two major components: [1] revenues from commercial customers, and [2] federal space expenditures in the state.

The forecast draws base year [1999] space revenues from commercial customers from data supplied by Colorado's largest space firms. These data are reported as belonging to one of five industry segments: *satellite manufacturing, launch*

Estimate Sources	Low	High
Revenues from government customers	Government + analysis	Company interviews
Revenues from commercial customers	Company interviews	Company interviews

Source of Revenues	**Low Estimate**	**High Estimate**	**Comments**
NASA	$ 132 M	$ 365 M	Subcontractors are accounted for in interviews, not in government estimates
DoD	690 M	1,966 M	Subcontractors are accounted for in interviews, not in government estimates
Other agencies	--	282 M	Further research required in government budgets. Agencies may include DoE and NOAA.
Total government revenues	$ 822 M	$ 2,613 M	
Commercial	1,703 M	1,703 M	
Total revenues	$ 2,525 M	$ 4,316 M	
… Other Govt. Expenditures			
NASA	$ 75 M	$ 75 M	
DoD	713 M	713 M	
Other agencies	--	--	
Total revenue	$ 788 M	$ 788 M	
Grand total	$ 3,313 M	$ 5,104 M	

Figure F.8 Comparison of Colorado Space Expenditure Flows

services and manufacturing, satellite services, ground equipment manufacturing, and *other*. Individual growth profiles for each segment are used to forecast the market through 2010. The growth profiles for satellite manufacturing and launch services are derived directly from Futron Corporation's model of underlying demand for satellite services.[21] The forecast translates that demand into

[21] Futron's proprietary demand model for satellite services looks at demand for existing and projected satellite-addressable services in individual countries on a worldwide basis. An affordability analysis is used to determine the resources available for such services, and terrestrial competition to satellite services is taken into account. National service demand growth profiles are extrapolated from a combination of historical trends; wealth distribution; and physical,

transponder and satellite equivalents, taking into consideration ongoing advances in satellite and information compression technology. The forecast then uses a launch services mission model to estimate demand for space launches over the same time frame.[22] The historical relationship between the ground equipment manufacturing and satellite service segments is exploited to model the ground segment growth through 2010. The forecast holds the "other" segment constant through 2010. Unless otherwise noted, all dollars are real dollars, adjusted to reflect their 1999 purchasing power. Note that "revenues from commercial customers" does not include those revenues garnered *from* government clients *by* Colorado's space firms. Federally reported data for space spending in Colorado are used for the government portion of the Colorado forecast, as described below.

DoD and NASA contribute the vast majority of federal space expenditures in Colorado. Other federal space activities, such as the National Oceanic and Atmospheric Administration's Space Environment Center and operations in support of the National Environmental Satellite Data and Information Service, represent only marginal space expenditures [less than 1 percent] and are not included here.

DoD spending in Colorado is culled from federally reported procurement and facilities expenditures data. Published DoD data on Colorado facilities and personnel spending are added to DoD space procurement in the state to derive total DoD space spending in Colorado. Obtained DoD space procurement data are extrapolated from DoD reporting of procurement information for "missiles and space [M&S]," one of the 25 major military procurement programs.[23] The forecast uses historical data to establish reasonable trends for Colorado's percent share of national M&S procurement throughout the forecast period. The Aerospace Industries Association [AIA] has historically developed a summary of DoD annual spending on missile programs by rolling up spending on individual missile systems budgets.[24]

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cultural, and political environmental considerations. The forecast rolls up national demand into regional demand profiles for satellite services and translates demand into an estimate of number of satellites required for each application. Futron's 10-year forecast of demand is presented in the fundamental units of demand for transponders and satellite equivalents, but can be overlaid on known revenue numbers to project industry revenues by market segment over the same time frame [as was done here].

[22] Futron's forecast estimates demand for satellite equivalents on a year-by-year basis corresponding to the year of service demand. Futron takes this demand for satellite equivalents and translates that into demand for real satellites, taking into consideration regional demand distribution patterns, political sensitivities, and satellite back-up requirements. Satellite demand is then translated into demand for launch services on a yearly basis, incorporating data on launch vehicle payload capacities, double-manifesting capabilities, launch range throughput capacity [historical and forecasted], reliability rates, and political sensitivities.

[23] Department of Defense, DIOR. Note: The database does not include awards with total value less than $25,000.

[24] Aerospace Industries Association, p. 50.

The current forecast pairs the national M&S procurement information with the AIA missiles data to infer the proportion of M&S procurement line item that is actually spent on space activities; the forecast takes into account DoD space procurement plans. The forecast applies the national percentage [of M&S as space] to Colorado's M&S procurement [as reported by DoD] on a year-by-year basis to derive the state's forecasted share of DoD space procurement. Base and personnel expenditures for Peterson Air Force Base, Schriever Air Force Base, Buckley Air Force Base, and Cheyenne Mountain Air Station were held constant [in real dollars] over the forecast period in accordance with reported DoD facilities and staffing plans. Considering the central role of the four major Colorado facilities involved in military space activities, all base expenditures and payroll for the facilities[25] are included in the forecast. The military space spending profile does not reflect classified spending on space programs, for which public data is not provided.

Virtually all of NASA's spending in Colorado takes the form of procurement to commercial firms, research grants, cooperative agreements, and educational awards. The forecast projects Colorado's historical share of NASA procurement [all types] throughout the forecast period, factoring in the state's respective strengths and weaknesses and how these mesh with NASA program plans.

Revenues from Commercial Customers Forecast

1999 was the first year in which Colorado space business revenues from commercial customers exceeded federal space expenditures in the state [$1,703 million vs. $1,609 million, respectively]. This trend follows that of the global industry, for which commercial revenues exceeded government expenditures for the first time in 1997.[26] The forecast projects that Colorado's overall space market will grow at a *real* [constant 1999$] compound annual growth rate of 6.3 percent through 2010.[27] Colorado's space revenues from commercial customers are likely to increase at a real compound annual growth rate approaching 10 percent, with significant year-to-year variations.

Growth in revenues from commercial customers will be led by strong initial growth in satellite services, starting off at more than 20 percent real annual growth, and reducing to single digits in the second half of the forecast period. Continued strong build-up in direct-to-home services in the United States will likely propel this sector forward in Colorado, building on the state's strong incumbency in the field. At over $1 billion in 1999, the satellite services sector comprises more than half of

[25] As reported in the economic impact analyses provided to CSSI by the Air Force.
[26] Futron Corporation, proprietary database.
[27] Futron Corporation, *2000 Satellite Services Forecast*. International Trade Administration, Department of Commerce, *Global Positioning System: Market Projections and Trends in the Newest Global Information Utility*, 1998. SIA, *Satellite Industry Indicators 2000*, compiled by Futron Corporation for the Satellite Industry Association.

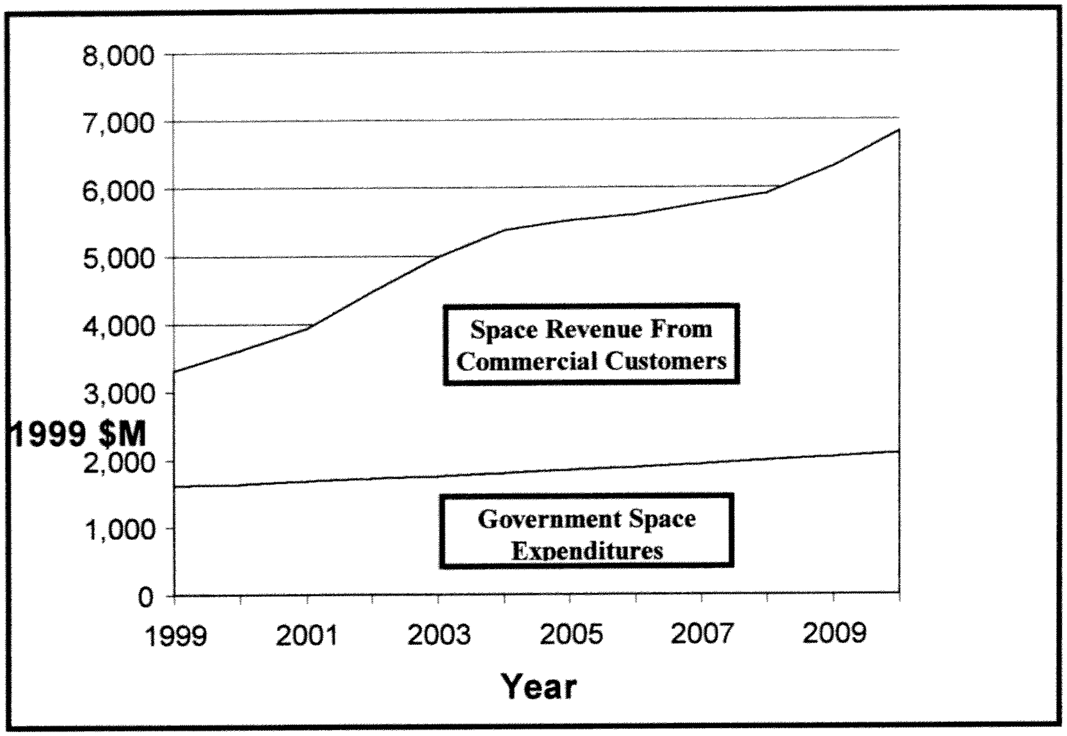

Figure F.9: Forecasted Space Revenues from Commercial Customers and Federal Space Expenditures in Colorado [1999 M$]

Colorado firms' revenues from commercial customers. Following global trends [see Appendix D], more than three-quarters of the services sector valuation will likely be derived from subscription and retail services versus transponder leasing. Similar to the global and national markets, growth in this segment for Colorado will be sensitive to the development and adoption rate of new data services and technologies, such as Internet-protocol multicasting and content caching. If market penetration proceeds rapidly for new services, growth in the services segment could remain well into the double digits throughout the forecast period.

Ground equipment manufacturing is also forecast to grow at a robust pace through 2010, starting off at more than 20 percent real, annual growth and following the services sector, declining to the single digits in the second half of the forecast period. The ground equipment manufacturing sector forecast growth rate received a boost from forecasted strong growth in GPS user equipment, which comprised only one-sixth of the ground-equipment market in 1999, but is forecast to comprise one-third of the sector by 2010. The ground segment will likely follow the services segment to an extent if services growth exceeds this forecast.

In contrast to the satellite services and ground equipment sectors, satellite manufacturing and launch services experience sporadic growth over the forecast period. Increasing satellite capability enables services growth without any

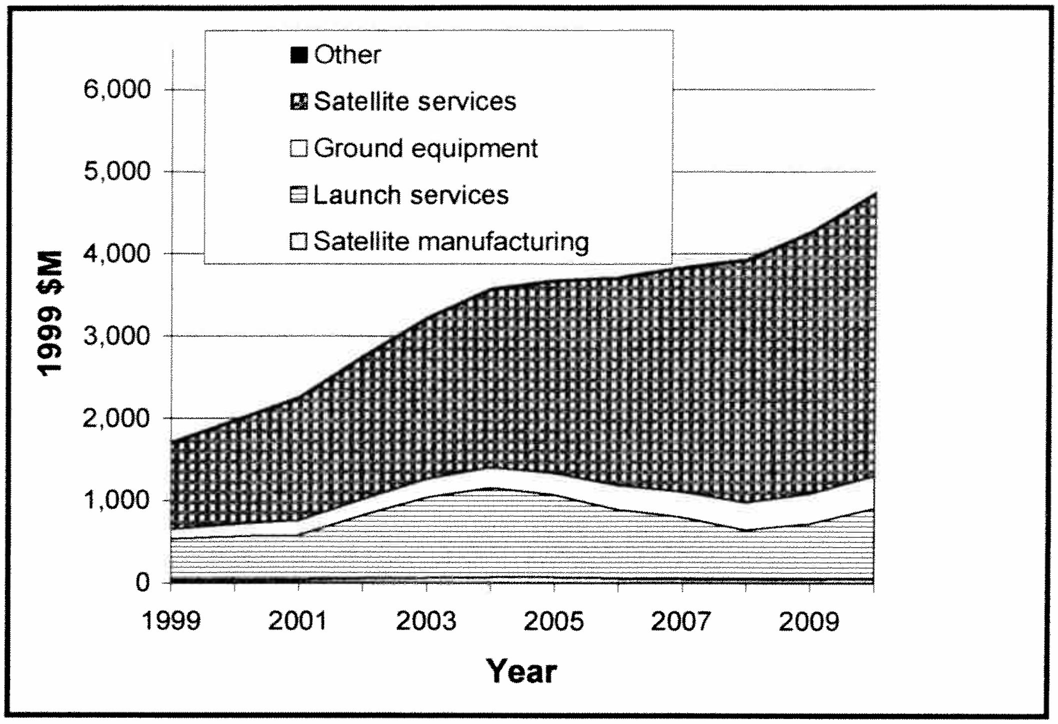

Figure F.10: Forecasted Colorado Space Revenues from Commercial Customers by Industry Segment [1999 M$]

significant increase in on-orbit satellites. Moreover, an anticipated new market for launch services—low-Earth orbit [LEO] satellite constellations—has yet to be fully realized. These two factors have combined to create a launch industry faced with over capacity and a need to consolidate operations in order to reduce costs.

Federal Space Expenditures Forecast

If historical trends continue and federal procurement plans are realized, federal space expenditures in Colorado will likely increase at a comparatively modest real, compound annual growth rate of 2.4 percent. These expenditures reflect moderate growth in federal space budgets and a slightly increasing share of that budget taken by Colorado. DoD space expenditures are by far the largest component of government space spending in Colorado, contributing more than $1.4 billion in 1999 alone. NASA contributed a more modest amount, $206 million, but with heavy emphasis on university-based research.

National M&S procurement fell both in absolute terms and as a percentage of total DoD procurement from 1994 through 1998. Missile programs were hardest hit with the funding decrease, although space procurement shared the burden. DoD space procurement fell by almost $2 billion through the mid-1990s, reaching a low

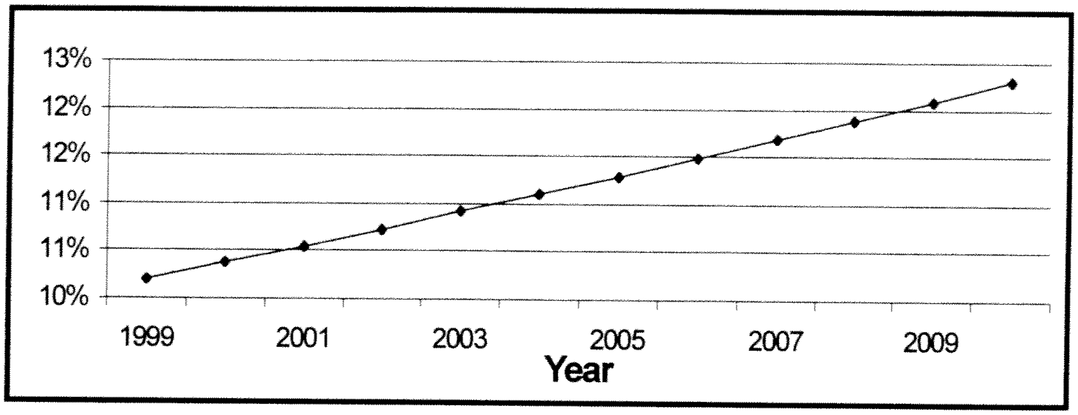

Figure F.11: Forecasted Colorado's Percent Share of National DoD Space Procurement

of $6.4 billion in 1998. 1999's space procurement total of $6.7 billion was the first in what is projected to be a modest but steady increase [at a real compound annual growth rate of 2.5 percent] in DoD space spending throughout the forecast period.[28]

Extending Colorado's historically competitive position in the DoD space procurement market, the state's share of the DoD space procurement budget is forecasted to rise a couple of percentage points over the forecast period [see Figure F.11]. DoD space procurement dollars flowing into Colorado should increase at a real, compound annual growth rate of slightly more than 4 percent throughout the forecast period, although year-to-year growth may vary. Comprising slightly under half of Colorado's $1.4 billion in DoD space dollars in 1999, space procurement will likely overtake DoD's almost constant expenditures on personnel and base activities and grow to more than $1 billion [real dollars] by 2010 [see Figure F.12]. These are conservative estimates of the valuation of Colorado's military space market; classified expenditures [including much of NRO procurement] are not included in the DoD published procurement data. The reported Colorado space firm survey results suggest that Colorado firms capture a significant share of classified space spending; the actual value of DoD space procurement to Colorado may be twice the figure cited herein.

Colorado's military procurement patterns are unique. While only slightly more than 5 percent of national defense procurement is space-related, almost 30 percent of Colorado's military procurement dollars come from space programs.[29]

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[28] General Accounting Office, *Defense Acquisitions: Improvements Needed in Military Space Systems' Planning and Education*, GAO/NSIAD-00-81, May 2000.
[29] Data extrapolated from M&S proportion of Colorado procurement.

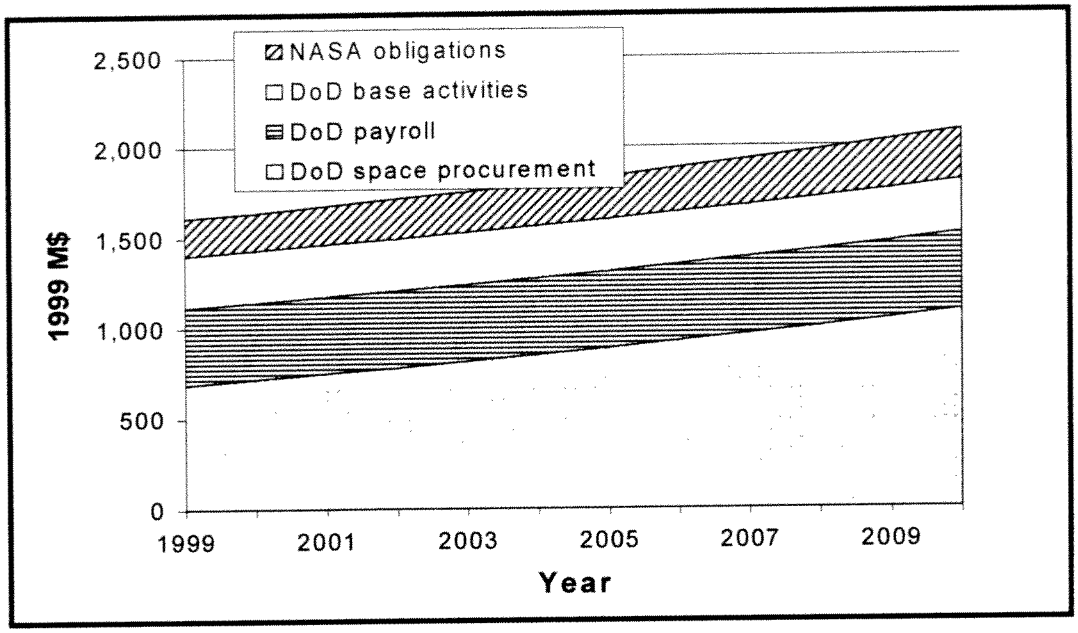

Figure F.12: Forecasted DoD and NASA Space Spending in Colorado [1999 M$]

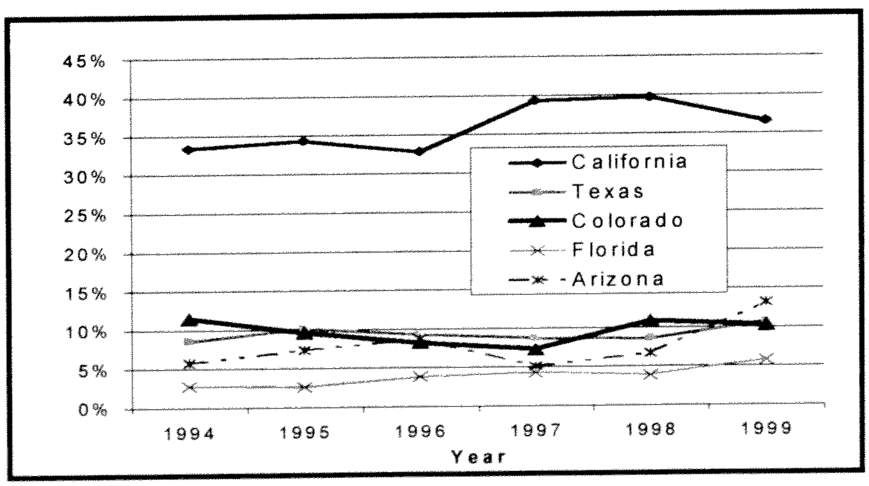

Figure F.13: Historical Percent Share of DoD Space Procurement, by Major State Recipient

Moreover, while research, development, test, and evaluation [RDT&E] activities comprise only 17 percent of national DoD procurement, they amount to more than 53 percent of Colorado's DoD procurement. These numbers that approximately 36 percent of the more than $1 billion the DoD spent on space-related RDT&E in 1999 went to Colorado-based firms. Therefore, while Colorado ranked 4th in the

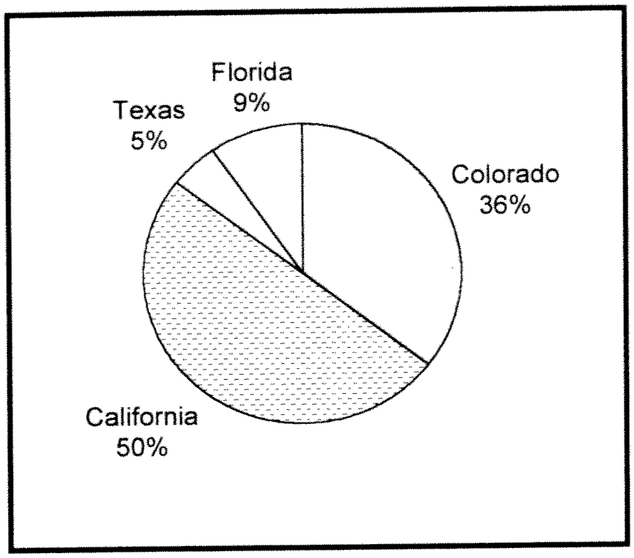

Figure F.14: 1999 Apportionment of DoD Space-related RDT&E Procurement [$1.04 B][30]

nation in total DoD space procurement [see Figure F.13], it appears that the state was second only to California in space-related RDT&E [see Figure F.14].

As noted in Section 3.5, NASA funds in Colorado very heavily reflect the strength of Colorado's university research capabilities. Colorado ranks first in total NASA receipts among states without a major NASA facility. Moreover, Colorado is the third largest recipient of NASA funds to education institutions [see Figure F.15]. Despite decreasing NASA budget authority since 1997, funding to Colorado has *increased* in absolute terms, growing from 1.3 percent in 1997 to 1.5 percent in 1999 of NASA budget authority. As the International Space Station proceeds with on-orbit assembly, NASA plans to step down its construction expenditures as the agency increases its investment in research activities. Given Colorado's historic strength in securing NASA research funds, Colorado may capture up to 2 percent of NASA's budget authority by 2010. A continued investment in Colorado's university system, with appropriate research emphasis, could lead to a growth in Colorado's NASA funding from the state's 1996 figure of $206 million to slightly more than $280 million [real dollars] in 2010 [see Figure F.12]. A difference of more than $70 million in research funding could support a large cadre of highly qualified, actively publishing research faculty, who in turn would support quality graduate students in the institutions, all garnering national and international recognition for Colorado's space economy.

[30] Note: Space RDT&E to states other than the four shown here is not included in the total space RDT&E figure above.

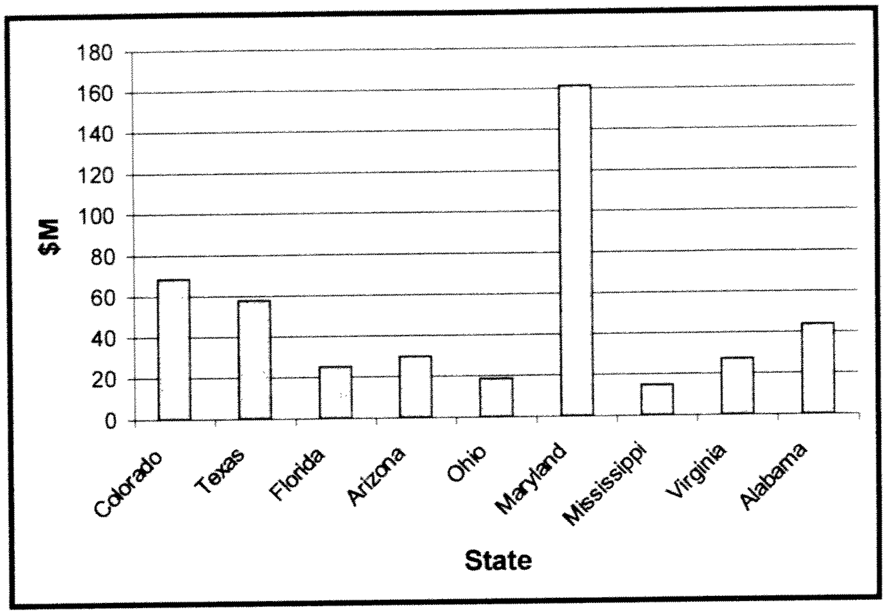

Figure F.15: 1999 NASA Obligations to Educational Institutions, by State, Excluding California[31]

Conclusion

Colorado is well positioned to take advantage of anticipated growth trends in both the government and commercial space marketplaces; the state is particularly strong in satellite services and military space procurement, two large sectors of the space economy. Colorado also has a foothold in the rapidly growing ground equipment manufacturing segment.

As noted above, these forecasts presume Colorado maintains its competitive position vis-à-vis other states. The space industry presents itself as an increasingly attractive marketplace for states shopping for new businesses. Both traditional space states and those states that can offer particularly appealing incentives [such as low labor costs and less burdensome taxation] are casting lures for space start-ups and/or consolidations. Many of Colorado's major space firms already have a presence in competing states. Appendices H and I depict how states like Florida, California, Texas, and Virginia already have a significant lead on Colorado in terms of government support for their space industries. Colorado must present advantages to the space industry's continued presence and expansion within the state. As with other space states, those advantages can take the form of a new state office supporting the space industry by coordinating with state economic and technology agencies to devise business incentive, infrastructure, and workforce strategies.

[31] Note: California total of $1.6 billion excluded for scaling purposes.

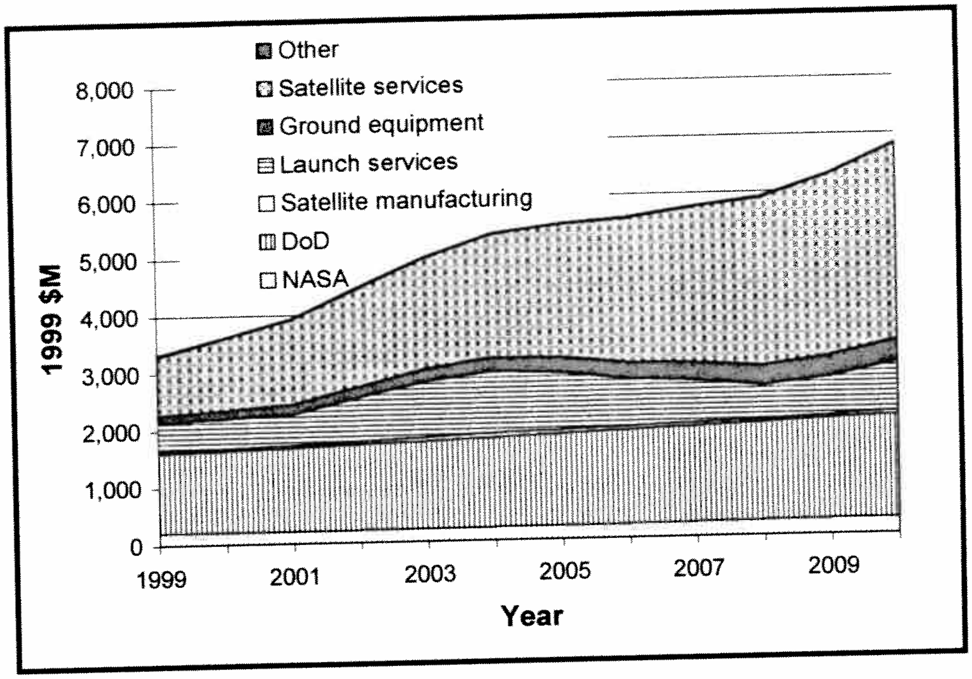

Figure F.16: Forecasted Federal Space Spending in Colorado and Colorado Space Revenues from Commercial Customers, by Source and Industry Segment

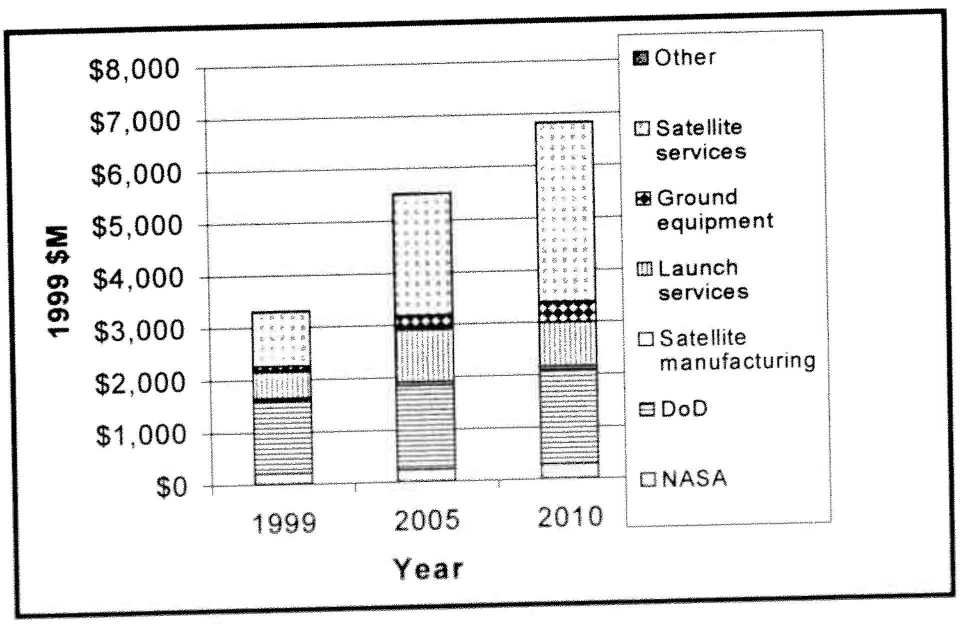

Figure F.17: Snapshots of Colorado's Space Economy, by Source and Industry Segment

Appendix G: Space Education in the State of Colorado

G.1 K-12 Education

Workforce Strategy #2 aims to improve K-12 space education through enhanced curriculum and expanded learning opportunities. The strategy notes:

> …an aggressive K-12 space education program must be implemented to educate the Colorado workforce. A high-tech workforce needs to be created from the bottom up. In other words, Colorado must focus on the education of the children in the state to prepare them to be the workforce of the future.

A solid K-12 foundation underlies a qualified high-tech workforce and successful matriculation through higher education. The state currently has educational standards in place that support a basic space curriculum. Six content standards for Science in the public school systems specify "what all students should know and be able to do in science as a result of their school studies," and reflect the "high expectations and outline the essential level of science knowledge and skills needed by all citizens to participate productively in our increasingly technological society." Two of these standards, Standards 4 and 5, directly relate to space education. Standard 4, Earth and Space Science, stipulates that "Students [will] know and understand the processes and interactions of Earth's systems and the structure and dynamics of Earth and other objects in space." A subsection of this standard, Standard 4.4, specifically focuses on "the structure of the solar system, composition, and interactions of objects in the universe, and how space is explored." The Standards delineate specific topics of space education for elementary, middle, and high school. The other subsections of Standard 4, while relating to general Earth science, may also be incorporated into a space-based curriculum through cross-disciplinary lessons [e.g., astrobiology, Earth observation, planetary geology].

Contractor	Number of Contracts	FY Obligations	Total Award Value
Colorado School of Mines [a]	4	$1,859,000	$10,439,641
Colorado State University [b]	37	$2,171,307	$12,064,709
University of Colorado-Boulder [c]	230	$39,411,566	$252,451,419
University of Colorado-Denver [d]	1	$0	$1,000
University of Denver [e]	14	$927,971	$9,040,687
University of Southern Colorado [f]	1	$22,000	$44,000
TOTAL	287	$44,391,844	$284,041,456

[a] Research funding from GSFC, JSC, GRC, MSFC
[b] Research funding from LaRC, GRC, GSFC, MSFC
[c] Research funding from LaRC, ARC, GRC, GSFC. Non-research, non-education contracts: ISS hardware [JSC], conferences [GSFC]; book [MSFC]. Education & Outreach: $3.1 million for National Space Grant College & Fellowship Program [HQ], $1.8 million Space Grant [GSFC], $57K for Teacher Training [GSFC], $44 thousand for Graduate Student Research Program [GSRP]
[d] Research funding from GSFC
[e] Research funding from ARC, GSFC, LaRC, MSFC
[f] GSRP funding from LaRC

Figure G.1: NASA Spending in the Colorado University System, FY 2000[32]

In addition, Standard 5 of the Science Education Standards stipulates that "Students [will] know and understand interrelationships among science, technology, and human activity, and how they can affect the world." This particular Standard presents additional opportunities for a space-related curriculum, through lessons and programs on Earth-Sun interaction, space-related careers, technology transfer, and the ethics of new technology. These two Standards, in conjunction with other subject standards, serve as a conduit through which teachers may incorporate space education into the K-12 classroom.

G.2 University Education

The second stage in creating a qualified, high-tech workforce for the space industry is higher education. In addition to boosting direct educational programs, Colorado universities are also essential to Workforce Strategy #3: the establishment of co-operative education programs between Colorado space firms and Colorado universities. These "co-ops" supply and attract a skilled personnel pool, while increasing Colorado's output of high value-added products and services.

[32] NASA Acquisition Internet Service, 2000.

To date, at least fourteen Colorado universities currently offer space-related curricula and/or departments. Six Colorado universities have received a total of $44 million FY 2000 funds from NASA as of December 31, 1999 [Figure G.1]. By the end of the fiscal year, awards to Colorado universities should come in close to the 1999 total of more than $68 million. These grants funded research, the construction of International Space Station hardware, teacher training, and two Graduate Student Research Programs.

The University of Colorado at Boulder plays a significant role in university space education. The Aerospace Engineering Sciences department, which holds 73 faculty members, 147 graduate students, and 290 undergraduate students, received $10 million in research funding last year alone. U.C.-Boulder is also home to the Space Science Institute and serves as headquarters of the Colorado Space Grant Consortium [CSGC].

The NASA-funded CSGC integrates the resources of 15 member institutions.[33] The Consortium supports three goals:

- **Research**: The CSGC provides students with hands-on experience in designing, flying, building, operating, and analyzing space experiments;
- **Training**: CSGC campuses support undergraduate and graduate curriculum at consortium schools
- **Outreach**: CSGC programs enter communities and encourage young students to explore math and science.

The Colorado School of Mines also has a significant role in space education. In addition to membership in the CSGC, the Colorado School of Mines is home to the Colorado Advanced Materials Institutes and the Center for Commercial Applications of Combustion in Space, a NASA Commercial Space Center.

G.3 Colorado Utilization of NASA Programs

In addition to funding various university departments, NASA also sponsors several educational programs aimed at university students, K-12 students and educators, and the general public. These programs include teacher workshops, student internships, teacher internships and fellowships, and educational workshops. Figure G.2 lists Colorado participants in NASA programs for FY 1999.

[33] UC-Boulder, UC-Colorado Springs, Colorado State University, USAF Academy, Pikes Peak Community College, University of Southern Colorado, Mesa State College, Space Foundation, University of Northern Colorado, Western State College, Adams State College, Colorado School of Mines, Ft. Lewis College, Metro State College, Front Range Community College

Program	Teachers/Faculty Participants	Total K-12 Students	Total Higher Ed Students	Total Students	Total Others	Total Participants
Space Grant	3,399	46,365	1,620	47,985	1,415	52,799
Aerospace Education Services Program	436	4,686	0	4,686	108	5,230
Educator Resource Center Network at Space Foundation	1,793	0	0	0	952	2,745
Teaching With Space	2,277	0	0	0	0	2,277
Space Discovery	359	0	0	0	0	359
Curriculum Support	80	150	0	150	31	261
Earth, Science, Education - Education Product Workshop	31	0	0	0	155	186
Classroom of the Future	27	0	0	0	25	52
Jet Propulsion Lab TOPEX/POSEIDON Education Outreach	0	0	0	0	52	52
Earthworks	21	0	3	3	0	24
Teaching From Space	23	0	0	0	0	23
PESTO	18	0	0	0	4	22
Unassigned	0	0	0	0	20	20
Graduate Student Researchers Program	0	0	17	17	0	17
NASA Educational Workshops	10	0	0	0	0	10
KC-135 NASA Reduced Gravity Student Flight	0	0	14	14	6	20
Summer Faculty Fellowship Program	4	0	0	0	0	4
NASA Opportunities for Visionary Academics	2	0	0	0	0	2
Mission Geography Workshop	0	0	0	0	1	1
Summer High School Apprentice Research Program Plus	0	1	0	1	0	1
International Space Camp	1	0	0	0	0	1
TOTALS	8,481	51,202	1,654	52,856	2,769	64,106

Figure G.2: Colorado Participation in NASA Programs, FY 1999
[Source: Provided by NASA-JSC with the caveat that it may not be a comprehensive list.]

G.4 Additional Colorado Space Education Activities

A number of private and non-profit organizations within Colorado also support space education. These institutions provide educational programming, professional development programs, and educator resources. Two of the major institutions involved in the advancement of space education are the Space Foundation and the Space Science Institute.

Part of the mission of Space Foundation, located in Colorado Springs, is "to passionately provide and support educational excellence through the excitement of space." To accomplish this, the Foundation offers professional development programs and educator resources. Professional development programs include

"Space Discovery Graduate Courses" and "Teaching With Space." The Space Discovery Graduate Courses offer lesson plans and activities for classroom learning and are available to educators for continuing education credit. Previous graduate courses have included *A View from the Top—Space Basics and Earth Studies, To the Moon and Beyond—Living in Space & Basic Rocketry, and Beam Me Aboard—Advanced Space Technologies*. The Teaching With Space programs, which are sponsored by individual school districts, provide educators with one-, two-, or three-day in-service programs designed to teach teachers how to incorporate aerospace concepts into their curricula. Subjects include space "basics," aviation and flight, global positioning systems [GPS], math and space, and advanced space basics. In addition, the Foundation hosts the NASA Educator Resource Center. This web-based database links educators to NASA and Federal Aviation Administration [FAA] space-related materials.

The Space Science Institute [SSI], located at the University of Colorado at Boulder, has a two-fold mission: a more active and effective involvement of the space and earth science research community in K-12 education, and a balanced program of research and education. Like the Space Foundation, SSI also holds workshops for educators, which focus on curriculum development and other aspects of professional development. Past workshops have included *the Space Storm Educator Workshop*, the *Earth and Space Science Technological Education Project*, and the *Stardust Educator Workshop*. SSI also assists teachers with the development of K-12 Earth and space sciences curriculum.

Appendix H: State Incentives

Selection of an incentive package in response to a relocation opportunity often requires extensive economic analysis that considers competing states and customer perspectives. A development agency analyzes competing states' likely offerings in response to customer preferences, and inputs these assumptions into a forecast model covering several scenarios to determine the agency's optimal incentive package. [Often tax and subsidy incentives offered by a state are less important than less controllable cost drivers like labor rates or supplier proximity.] It is outside the scope of this plan to evaluate competing states' incentives to support such an analysis.

Nonetheless, in preparing a package of state incentives, Colorado should consider basic benchmarks offered by other space states—whether targeting a particular industry like space, or hardware and service items in many industries. Sales tax exemptions, for example, have been implemented by states such as Florida and Virginia with spaceports, but they can be applied also to services across industries. Foreign trade zones are also a popular item for states whose spaceport authorities wish to avoid incurring a federal duty on foreign satellites imported for launch. Enterprise zones can be structured for both subsidies and tax breaks in areas where growth is needed--e.g., in remote or underdeveloped areas. [See Business Strategy #4 for more incentive details.]

Florida appears to offer the most complete package of space-focused incentives. Figure H.1 is an incentive list that can be considered a menu of items for Colorado to evaluate.

To qualify for incentives, companies may have to meet conditions relating to private investment and job creation. For example, Florida's investment tax credit requires a minimum investment of $25 million and the provision of 100 new jobs.

On July 1, 2000 a lease tax exemption went into effect in Florida. Renting, leasing, or granting of a license for the use of real property is now exempt from the state's 6 percent sales tax when property is used primarily for space flight business. ["Space flight business" includes the manufacturing, processing, assembly, or operation of a space facility, space propulsion system, space vehicle, satellite, or ground control.] In January 2001 a machinery and equipment exemption will also

Incentives for Space Companies	Florida
Sales Tax Exemption	Satellites Launch vehicles [with components & fuels] Machinery & equipment and for producing new items used at spaceport Electricity used in aerospace manufacturing
Fuels Excise Tax Exemption	Fuel in satellites + launch vehicles
Ad Valorem Tax Exemption	Space flight hardware used for research
Investment Tax Credit	Up to 20 years equal to 5 % of capital costs for facility growth
Foreign Trade Zones	Import of foreign payloads + components for test & integration
Industry Grants	Up to $12 million for growing R&D firms or manufacturers
Infrastructure Grants	Up to $2 million to improve access to transportation
Job Credits	Up to $5000 per new job created, 7500 in an Enterprise Zone
Training Grants	Work force grants for growth companies

Figure H.1: Florida State Incentives for Space Business Development

go into effect. Companies planning to establish or expand their space industry manufacturing or R&D operations in Florida will be able to exempt 25 percent of state sales taxes on such expenditures.

Appendix I: Space Strategic Plans in Other States

I.1 State Space Authorities & Strategic Plans

As shown in Figure I.1, a number of other states have chartered authorities to guide and promote space activities. In some cases companies, such as Virginia's DynSpace or California's Spaceport Systems International. have contracted with the state to conduct launches. California does not appear to have a single authority, but instead a public-private, non-profit partnership on which the state depends for policy and planning advice in space matters: the California Space & Technology Alliance/California Spaceport Authority. Generally other state agencies, especially economic development offices, assist the authority--for example, in arranging incentives for space development. Most states have developed strategic plans to coordinate their development of space.

Space Plan Elements	Florida	California	Texas	New Mexico	Virginia	Alaska
Organization	Spaceport Florida Authority received FAA license in 1997.	Spaceport Systems International received a license in 1996, and operates spaceport at Vandenberg.	Texas Aerospace Commission is coordinating local efforts to attract RLVs and create spaceports. A Texas Spaceport Authority has been proposed, modeled on airport boards.	New Mexico Office of Space Commercial-ization has applied to FAA for spaceport license.	Virginia Space Flight Authority won FAA license and contracted with DynSpace to operate spaceport at Wallops.	Alaska Aerospace Development Corp. received a license in 1996, and developed Kodiak Launch Complex.
Plan Status	Strategic plan (Volpe Report) was released in December 1999.	CSTA's strategic plan was released in August 1998.	Plan is being written for state legislative review.	1997 spaceport plan has been put aside during reconsideration of public-private partnerships, funding, and incentives.	Plan is being updated; copy of Dynspace operating contract has been requested.	Copy of business plan has been requested.

Figure I.1: Space Organizations and Strategic Plans of Selected States

Florida's and California's plans address a range of space opportunities, while other states shown in Figure I.1 focus on spaceports alone. States not shown that are evaluating spaceports include Idaho, Montana, Nevada, Oklahoma, and Utah. Also not shown in the table are other states with significant federal facilities such as Alabama, Maryland, Mississippi, and Ohio.

Following are strategic inputs from Florida's and California's plans, as their space plans are the most comprehensive benchmarks available. Despite these plans' emphasis on leveraging the states' spaceport infrastructure, the reader may notice resemblance's to Colorado's inputs from Sections 3 and 4.

I.2 Strategic Plan Benchmarks: Value/Vision/Mission

Florida:

- *Vision*: To become the world's most competitive location for international space enterprise [per "The Place for Space" brochure; vision not found in strategic plan]

California:

- *Vision:* California leads the world in space education, research, technology, manufacturing, services, and transportation
- *Mission:* Support, enhance, and expand California space development to benefit California space companies, entrepreneurs, public-sector space stakeholders, and California's workers and residents statewide

I.3 Strategic Plan Benchmarks: Goals

Florida:

- Maintain and strengthen Florida's leadership position in space transportation.
- Diversify Florida's space economy.

California:

- Increased market share and greater profitability for California space companies, operations and entrepreneurs.
- Responsive, flexible, industry-friendly business environment with trained workforce availability.
- Attraction of world-class workers/companies through creation of a statewide network of synergistic, entrepreneurial "centers of excellence" for 21st century space.
- Long-term state and federal investment in California space development.
- Increased revenues for California programs and services.
- Sustained leadership position for California space in global space arena.

I.4 Strategic Planning Benchmarks: Objectives/Priorities/-Actions

Florida:

•Leadership in space transportation
Improve communications and strategic planning.
Incrementally invest in the Cape Canaveral spaceport.
Address institutional impediments to commercial launches.
Partner with stakeholders in developing new vehicle and spaceport concepts.

•Diversify the state's commercial space economy

- Conduct strategic market assessments.
- Align Florida's key economic and technology sectors with the space economy.
- Strategically partner with NASA.
- Support the Florida Space Research Institute and the Florida Space Institute.

California:

- Public awareness/interest in space
- State policymaker support/advocacy
- Federal policymaker support/advocacy
- Workforce programs/partnerships with education & industry
- Guidelines for performance standards in education
- Space-related incentive projects
- Capitalizing on California's space assets
- Governor's support for space technology
- Space information/referral interface
- Regulatory streamlining/single interface approach
- Performance guidelines/incentivization: manufacturing
- Marketing of California space capabilities
- Science/research/technology development
- Collaborative forum/space stakeholders
- Rewrite: Commercial Space Launch Act
- Implementation of strategic plan
- Enhancing California spacelift capability
- Revolutionary technology transition

- Investment community interest
- California space economic impact
- Convergence: space/other industries

I.5 Strategic Planning Benchmarks: On-going Planning Processes

Florida:

- Master transportation plan for ground infrastructure at Cape Canaveral is being updated jointly by Spaceport Florida Authority [SFA], Kennedy Space Center [KSC], and the Air Force's 45th Space Wing
- Plan includes five-year forecast identifying future space transportation needs, and will be supported by a newly-established Spaceport Management Council with members representing FDOT, SFA, KSC, 45th Space Wing, and Naval Ordnance Test Unit

California:

- California Space Infrastructure Program [CSIP] is a two-year, federal-funded effort to draw up a space infrastructure master plan coordinated by CSTA/California Spaceport Authority and Booz Allen.
- Outreach includes regional presentations and hundreds of stakeholder interviews, as well as encouragement and evaluation of space infrastructure funding requests.
- Year 2000 marketing plan for CSTA's promotion of California space is also underway.
- Governor's Aerospace Summit was held on November 15, 1999.
- Space-Related Economic Development Collaborative has been created.

New incentives include $1000 tax credit for new space vehicle & satellite

Appendix J: Resources

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www.ball.com
www.boeing.com
www.csc.com
www.fas.org/spp/military/budget
www.hughespace.com
www.lmco.com

www.peterson.af.mil
www.raytheon.com
www.schriever.af.mil
www.senate.gov/-allard
www.spacecom.af.mil/hqafspc
www.spacenews.com
www.ssti.org
www.trw.com

Companies surveyed:
A & A Satellite
ACS Defense Inc.
Advantage Light & Sound
Advantage Wireless
Aeroflex UTMC
Aerojet Electronic Systems Division
Aerospace Design & Development Inc.
Aerospace Marketing Consultants, Inc.
AKR Communications
Analex
Analytical Graphics
Analytical Surveys, Inc.
Anser
AntennaPro, Inc.
Apogee Scientific, Inc.
Applied Research Associates
Arcadis, Geraghty & Miller
ASI Technologies
Automated Systems Engineering
Autometric, Inc.
Ball Aerospace & Technologies Corp. *
Berkeley Software Design
Blue Line Engineering
Boeing Aerospace *
Brite Star Satellites
CACI
Channel 2000
Ciber, Inc.
CMPROS
Colorado Video, Inc.
Computer Sciences Corp. *
Constell Inc.
Cooperative Institute for Atmospheric Research
Crosslink, Inc.
Cullimore and Ring Technologies

D & D Electronics, Inc.
Dames & Moore Group (Division of URS Radian)
Decisive Analytics Corp.
Delfin Systems
Denver Space Systems
Denver Technological Laboratories
Denver Uplink
DIRECTV
Eagle Picher
Earth Space Transport Systems Corp.
EarthWatch, Inc.
Electric Propulsion Laboratory
Emergent Information Technologies
Estes Satellite & Communications Inc.
Fablink
General Dynamics
GRC International
Harris Corp.
Honeywell, Inc.
Hughes Space & Communications, Inc. *
Infinity Systems Engineering
Instar Engineering & Consulting
Intecon, LLC
ITT Systems
Kornelly & Associates
Left Hand Design Corporation
Lockheed Martin Astronautics *
Loctite Corp.
Magnum Tool company
Meadowlark Optics Inc
Merrick & Company
Metrum-Datatape, Inc.
MITRE Corp.
Nanomaterials Research Corp.
National Renewable Energy Lab
Navsys Corporation
Northern NEF, Inc.
NSN Network Services
OAO Corporation
PanAmSat
Pikes Peak Satellite
PRC Inc.
Primestar
Q-Dot, Inc.
Raytheon Systems Company *

RT Logic
Satellite Broadcasting, Inc.
Satellite Pro, Inc.
Schafer Corp.
SEAKR Engineering Inc.
Software Technology Inc.
Space and Satellite Control
Space Imaging (A Lockheed Martin joint venture)
Space Launch Tech Co.
Spectrum Astro, Inc.
SRS Technologies
Stanley Aviation
Starbird Satellite
Starsys Research Corp.
STC-Metsat
Stratton Park Engrg.Co. Inc.
Systems Technology Associates
TASC
Teledyne Brown Engineering
Telewire Supply division of Antec Corp.
Tri-gon Precision
TRW Space & Missile Systems *
TUV Product Service
Unique Mobility Inc.
Universal Spaceware
Vanguard Research Inc.
Vexcel Corporation
Virginia A. Ostendorf, Inc.
Woodmoor Group

All firms participated in a phone survey. Companies followed by "*" participated in a more extensive interview process.

Individuals contacted/interviewed in addition to company surveys:

Steve Connair	Air Force Financial Mgmt. Office
	Air Force Public Affairs Office
Elaine Test	Alaska Aerospace Development Corporation (Kodiak spaceport)
Rod Brickson	Army Comptroller's Office
Nancy Ray	Army Public Affairs Office
Marco Morales	Army Space & Missile Defense Command
Ed White	Army Space Command
Mary Ford	Colorado Department of Labor and Statistics
Jim Kenyon	Colorado Economic Development Commission
Gail Brody	Colorado Office of Economic Development

Sue Piatt	Colorado Office of Economic Development
	Colorado Springs Chamber of Commerce
Ray Morris	DoD Directorate of Information and Operations Reporting
Charles Ergen	Echostar
Chad Delong	Greater Denver Chamber of Commerce
	HQ AF Space Command Competition Advocate Office
Nancy Champagne	HQ AF Space Command Finacial Mgmt. Office
Ed Parsons	HQ AF Space Command public affairs
Rich Smith	KPMG Consulting (for New Mexico Office of Space Commercialization)
Janet Clark	Lockheed Martin
Thad Maddan	Lockheed Martin
Barbara Berstein	NASA Headquarters, Legislative Affairs
Larry Spencer	NASA Headquarters, Legislative Affairs
Kathy Nado	NASA Headquarters, Office of Space Flight
Beverly Smith	NASA Headquarters, Procurement
Jim Bradford	NASA Marshall Space Flight Center, Procurement
David Miller	National Oceanic and Atmospheric Administration
Beverly Carter	NOAA Legislative Affairs
Jerry Slaff	NOAA Public Affairs
Larry Combs	NOAA Space Environment Center
Mike Crumley	NOAA Space Environment Center
Doug Flanders	Office of Senator Wayne Allard
Doug Flanders	Office of Senator Wayne Allard
Scott Pace	RAND Corporation
Sarah Hoyt	Raytheon
Edward Ellegood	Spaceport Florida Authority
Fred Johnson	Texas Aerospace Commission
Mary Noelle Benson	TRW
	U.S. Senate Armed Services Committee
Major Birmingham	U.S. Space Command Public Affairs
Colonel Pete Worden	US Air Force
Michael Swiek	US GPS Industry Council
Wayne Woodhams	Virginia Space Flight Authority