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SPACE TECHNOLOGY REQUIREMENTS AND INTERDEPENDENCY FOR NATIONAL COMPETITIVENESS

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ABSTRACT

Space technology requirements have been identified primarily by NASA and the Department of Defense. In addition, independent studies conducted by academic, research, and industry institutions have also developed technology requirements needed for the national space program. Another source of technology identification and prioritization for both space and national competitiveness is the March 1991 report issued by the National Critical Technologies Panel. In this paper, a review of the various requirements generated by the sources mentioned earlier will be presented. One critical objective of this review is to identify common technology requirements. Areas of technology discussed will include automation and robotics; materials; information acquisition, processing and display; communications; human support; life sciences; energy generation and storage; superconductivity; propulsion; and nano-technology. The present space technology interdependency programs, aiming at cost-effective development, will then be discussed. The paper will emphasize technologies needed for fast, cost-effective operations with high safety and reliability. Technologies needed for the conduct of scientific research associated with space exploration and utilization will also be included. The key contribution of this paper is the exposition of the advantages of the space technology interdependency for the benefit of competitiveness abroad. Interdependency applies to development of critical technologies in a cooperative manner using resources available at government agencies, academic institutions, and industries. The paper will conclude with a proposed vision and a set of recommendations for the implementation of the space technology interdependency infrastructures.

I. INTRODUCTION

Most nations have recognized technology as a means of reviving their economics and boosting their competitiveness among nations. In the United States, the enormous trade deficit, combined with deficit financing, provide new incentives for pursuing technology development at an accelerated pace. One of the measures of the rise of foreign competition is the number of influential patents issued. The relative patent strength of the United States and Japan is given in figures 1 and 2. As is evident from these data, the U.S. strength has eroded and this trend continues. In 1990, the top four recipients of U.S. patents were Hitachi, Toshiba, Canon, and Mitsubishi. Of particular importance is the fact that U.S. invests only 1.9% of its Gross National Product in non-defense research and development (R&D), in comparison to Germany's investing 2.8% and Japan 3.0%.

Recent acknowledgments of these U.S. trends have resulted in the proposed Clinton-Gore technology policy. This policy terms technology as "the engine of economic growth," and proposes six broad initiatives: (1) investing in a 21st century infrastructure; (2) establishing education and training programs for a high-skill workforce; (3) investing in technology programs that empower America's small businesses; (4) refocusing federal R&D programs on critical technologies that

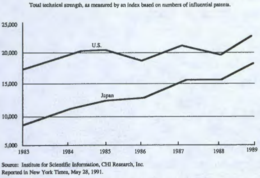

Figure 1.– Japan's rise in patent strength.

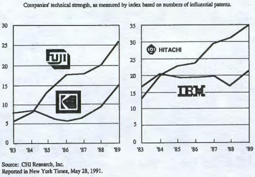

Figure 2.– The surge in Japan's strength.

enhance industrial performance; (5) leveraging the national R&D investment; and (6) creating a world-class business environment for private sector investment and innovation.

Under the Bush administration, the timely development and deployment of technologies were considered essential to satisfy defense, economic competitiveness, public health, and energy needs. The National Critical Technologies Panel issued a report [1] in 1992, detailing six broad areas: materials, manufacturing, information and communications, biotechnology and life sciences, aeronautics and surface transportation, and energy and environment. Twenty-two national critical technologies identified in this report were: materials synthesis and processing, electronic and photonic materials, ceramics, composites, high-performance metals and alloys, flexible computer integrated manufacturing, intelligent processing equipment, micro- and nano-fabrication, systems management technologies, software, microelectronics and optoelectronics, high-performance computing and displays, sensors and signal processing, data storage and peripherals, computer simulation and modeling, applied molecular biology, medical technology, aeronautics, surface transportation technologies, energy technologies and pollution minimization, remediation, and waste management. The Department of Commerce (DOC) issued a report in the spring of 1990 entitled, "Emerging Technologies: A Survey of Technical and Economic Opportunities," in which twelve emerging technologies contributing to new development or improved products by the year 2000, were identified. The specific areas identified are advanced materials, advanced semiconductor devices, superconductors, flexible computer integrated manufacturing, artificial intelligence, high-performance computing, optoelectronics, digital imaging, sensor technology, high-density data storage, biotechnology, and medical devices and diagnoses. The US. Department of Defense (DOD) Critical Technologies Plan, issued March 15, 1990, identifies the following technologies for DOD: composite materials, semiconductor materials and microelectronics circuits, superconductors, machine intelligence and robotics, software productivity, photonics, parallel computer architecture, data fusion, signal processing, passive sensors, sensitive radar, simulation and modeling, computational fluid dynamics, biotechnology materials and processes, air-breathing projectiles, pulsed power, signature control, and weapon system environment. The technologies identified by the DOD, DOC, and the National Critical Technologies Panel (NCTP) have in most cases similar basic development steps. Furthermore, the development of applications of a basic technology also constitutes a distinction in cases of defense and commercial applications. There are 726 federal laboratories with a collective budget of 23 billion dollars. For this reason, considerable overlap and duplication is possible without adequate coordination and cooperation between Government agencies and federally sponsored research and development at academic and research institutions and industry. One of the critical challenges for the future is, therefore, to develop and implement management structures that will make it possible to achieve coordination between federal agencies, as well as, with industry and universities. In this paper, we shall discuss the Space Technology Interdependency (STI). with such structure that has proved very productive in developing interdependencies between DOD and NASA. It is more recently being extended to include the Department of Energy (DOE) and DOC. We will also present management structures that would extend this concept to industry and academia. The discussion of commonalty between space technologies will be presented first to set the stage for cooperative efforts leading to interdependencies.

II. KEY SPACE TECHNOLOGIES

A detailed discussion of space technologies for the DOD and NASA is presented in [2]. The U.S. Air Force Science and Technology Plan [3] identifies key technologies in three areas: current, next generation, and future. In the current area, technologies listed are improved performance space motors, staged combustion cryogenic engine, nickel cadmium batteries. silicon solar cells, satellite cloud analysis, and UHF/SHF satellite up-down links. For the next generation, the list is: composite booster cases, nickel hydrogen batteries, gallium arsenide solar cells, radiation hardened microelectronics, knowledge-based scheduling and planning of space assets, and multi-spectral environment sensors. For the future technologies, the report identifies areas as follows: high-power density batteries and solar cells/technology for autonomy and operational survivability; electric propulsion; high-energy density materials; endothermic fuels, high-temperature/strength materials; hypersonic aerodynamics/computational fluid dynamics; combined cycle propulsion; light detection and ranging wind sensor; low-cost, lightweight EHF technology; and laser satellite cross links.

NASA's integrated technology plan [4] is based on requirements form space science, Earth observation, space flight, space exploration, space and ground operations, and space systems and infrastructure development.

The NASA program consists of two parts research and technology (R&T) base and civil space technology program (CSTP). The discipline areas for the R&T base are as follows: aerothermodynamics, space energy conversion, propulsion, materials and structures, information and controls, human support, and advanced communications. For the CSTP, five disciplines are space science, planetary surface exploration, transportation, space platforms, and operations. The subcategorizes in these five areas and the prioritization is shown in figure 3. The areas identified include: science sensing, observatory systems, science information, in-situ science, surface systems, human support, Earth-to-orbit transportation, space transportation, Earth-orbiting platforms, space stations, deep-space platforms, automation and robotics, infrastructure operations, and information and communications. The prioritization in figure 3 might have changed as a result of funding limitations during FY92 and FY93; however, the general structure of the program still remains the same. More recently the human support technologies, manned transportation systems, space manufacturing, commercial development of space, advanced concepts and integration, and remote sensing have also been reflected in the overall NASA strategy for future implementation and emphasis.

The preceding discussion of DOD and NASA space technology development was presented to point out the commonalty of the R&D efforts outlined in the strategic plans of the two Agencies. It

Space Science Technology	Submillimeter Sensing	Direct Detectors	Active µwave Sensing	Sample Acq., Analysis & Preservation	Passive Microwave Sensing	—	Optoelectrncs Sensing & Processing	Probes and Penetrators	—
		Sensor Electronics	Laser Sensing						
	Cooler and Cryogenics	Microprecision CSI	Telescope Optical Systems	Data Archiving and Retrieval	Data Visualization	—	Precision Instrument Pointing	Sensor Optical Systems	—
Planetary Surface Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	Planetary Rovers	Surface Habitats and Construction	Exploration Human Factors	—	Artifical Gravity
	—	—	Extravehicular Activity Systems	Surface Solar Power and Thermal Mgt.	In Situ Resource Utilization	Laser-Electric Power Beaming	Medical Support Systems	—	—
Transportation Technology	ETO Propulsion	Nuclear Thermal Prop.	Aeroassist/ Aerobraking	Transfer Vehicle Avionics	ETO Vehicle Avionics	ETO Vehicle Structures & Materials	Autonomous Rendezvous & Docking	COHE	Auxiliary Propulsion
		Aeroassist Flight Expt							
	Cryogenic Fluid Systems	Advanced Cryo. Engines	Low-Cost Commercial ETO XPort	Nuclear Electric Propulsion	CONE	—	Autonomous Landing	TV Structures and Cryo Tankage	HEAb
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.	Zero-G Life Support	Platform Materials & Environ. Effects	Station-Keeping Propulsion	—	Spacecraft On-Board Propulsion	Earth-Orbiting Platform Controls	Advanced Refrigerator Systems
	—	—	Zero-G Advanced EMU	Platform NDE-NDI	Deep-Space Power and Thermal	—	Spacecraft GN&C	Debris Mapping Experiment	—
Operations Technology	Space Data Systems	High-Rate Comm.	Artificial Intelligence	Ground Data Systems	Optical Comm Flight Expt	Flight Control and Operations	Space Assembly & Construction	Space Processing & Servicing	Photonics Data Systems
					Flt. Telerobotic Servicer/DTF-1				
	—	CommSat Communicat'ns	TeleRobotics	Operator Syst./Training	Navigation & Guidance	CommSat Communicat'ns Flight Expts	—	Ground Test and Processing	—
	HIGHEST PRIORITY ◊◊◊			2nd-HIGHEST PRIORITY ◊◊			3rd-HIGHEST PRIORITY ◊		

Figure 3.– Integrated Technology Plan Investment Prioritization.

is this commonalty of technology base that becomes the ground for developing interdependencies and sharing of resources and results to realize cost-effectiveness and quality products that have wide applications, not only in these Agencies, but also in industry and the commercial sector.

III. SPACE TECHNOLOGY INTERDEPENDENCY

The Space Technology Interdependency Group (STIG) was established in May 1982 to identify and promote the pursuit of new opportunities for cooperative relationships between the National Aeronautics and Space Administration (NASA) and the U.S. Air Force Systems Command (AFSC). In addition, STIG is chartered to monitor ongoing cooperative activities and identify areas of overlap and duplication. The Air Force responsibility now is located in the Materiel Command after the reorganization of the Air Force became effective in 1991. The goal of STIG is to provide advocacy, oversight, and guidance to facilitate and encourage cooperative development programs and to avoid duplication of effort and resources on space technology activities. Three categories of programs have been defined by STIG to characterize interaction. The dependent program is the one in which a single set or subset of mutually constructed program goals is planned. Dependency connotes coordinated management, shared resources, and strong agency executive management support. An interdependent program is one in which some degree of overlap is stated in the agency program and/or technical goals, as outlined in a jointly developed program plan. It is assumed that there are complementary synergistic results beneficial to the participating agencies. Interdependent programs are conducted by one agency, with minimal or no cooperation from other agencies.

In July 1992, the U.S. Army and Navy formally jointed STIG and, in 1992, the participation was extended to the DOE, SDIO, and DARPA. The STIG was organized and is implemented by direction from a Steering Committee. The AF Materiel Command Deputy Chief of Staff for Technology, and the NASA Associate Administrator for the Advanced Concepts and Technology Office serve as co-chairpersons and are responsible for designating members to the Steering Committee. The Steering Committee currently has members from the Army, Navy, SDIO, DARPA, and DOE. Steering Committee members are from the Headquarters' executive staff to provide technical expertise needed for direction and evaluation or programs.

The STIG program is implemented through eight technical committees. These committees are established by the Steering Committee. The members are selected from participating field centers and laboratories. The co-chairpersons for the technical committees are nominated by members of the Steering Committee (SC) and approved by SC co-chairpersons.

The STIG Information Collection, Transfer, and Processing Committee's technical scope includes microwave and millimeter wave electronics, microelectronics, photonics and optical communications, image processing, sensors and coolers, and large optical systems. The Propulsion Committee deals with chemical boost, solid rockets, air breathing, chemical transfer, electric (solar and nuclear) propulsion, and reaction control. The scope of Flight Vehicle Systems Committee includes aerothermodynamics, aeromaneuvering, guidance, navigation and control, thermal protection systems, and vehicle synthesis and design concepts. The Space Structures Committee concentrates on structural dynamics/control, and structural concepts and materials. The Space Power Committee deals with solar power generation, energy storage, power management and distribution, nuclear energy, thermal management, and power beaming. The charter of Space Environments and Effects is in the following areas: vehicle environments-radiation, effluents, plasmas and fields, meteoroids and debris, and environmental effects materials, equipment and biological systems. The Operations Committee is focused on robotics and telepresence, automation and intelligence, human factors, life sciences, and space maintenance and servicing. The Flight Experiments Committees concentrates on experiments coordination and launch opportunities.

The STIG committees have the responsibilities to: (1) identify and characterize interdependent activities, (2) encourage interdependent programs, (3) interchange technical and programmatic information and share lessons learned, and (4) identify critical voids and non-productive overlaps in technology programs. In the 1990-91 time frame, STIG had a total of 93 cooperative programs shared by DOD and NASA. In 1992, this number exceeded 120 and involved other agencies in many of these projects.

We will briefly describe the implementation strategy for the STIG Operations Committee (SOC) to illustrate the organization and products that come from each of the STIG technical committees. The SOC is co-chaired by Dr. Kumar Krishen of the NASA Johnson Space Center and Dr. Carter Alexander of the USAF Armstrong Laboratory. There are five subcommittees under SOC on the Robotics and Telepresence, Automation and Intelligent Systems, Human Factors, Life Sciences, and Space Maintenance and Servicing. These five subcommittees are jointly co-chaired by technical experts from the two organizations, NASA and USAF. The membership of the SOC includes Army, Navy, DOE, and SDIO, in addition to NASA and the USAF. The SOC has 65 members. The members of SOC were nominated by their laboratories, research centers, or organizations and approved by SOC cochairpersons and the STIG Steering Committee. The SOC conducts two meetings on a yearly basis to (1) review operations R&T plans, resources and progress within NASA, DOD and DOE; (2) develop and maintain list and descriptions of current interdependent programs; and encourage and recommend future interdependent programs. One key area of SOC work involves facilitating communication of R&T results in the operations area across agencies and various centers within these agencies involved in the operations R&T. This technical interchange is facilitated through STIG Operations, Applications and Research (SOAR) Symposium and Exhibition on a yearly basis. Six such symposia and exhibitions have been held in the past. The SOAR features technical review of interdependent programs, identification of future interdependent programs and concerns. It includes industry and academia. The proceedings are published to document progress made in operations R&T. The SOC activities include both ground and space operations. Another activity of SOC concentrates on providing interface with NASA, DOD, and DOE Operations Technology Thrusts and the remaining seven STIG technical committees. A SOC recent survey showed more than 40 projects being coordinated across agencies and many more on which active communications are continued on a periodic basis [5]. Furthermore, SOC has been successful in modifying many project plans of DOD and NASA to effect enormous cost savings. The SOC has also linked the industry and academia in an active manner in the joint development of the identified and prioritized R&T technical areas.

IV. VISION, BENEFITS, AND IMPLEMENTATION FOR SPACE TECHNOLOGY INTERDEPENDENCY

This author has participated in the STIG for a number of years. Furthermore, the author maintains very active interface with academia, industry, and R&T agency of the State of Texas. On the basis of many years of experience, the author proposes the following vision for STI: "Create and promote STI infrastructures to encourage and coordinate cooperative projects in R&T for mutual benefits to the organizations involved." The benefits of STI are numerous and can be summarized as follows: (1) increasing interagency communications at all levels; (2) creating national technology cohesiveness through interaction with industry and academia; (3) sharing of expertise and facilities across agencies, industry, and educational institutions; (4) avoiding undesired duplication and reinventing through sharing of lessons learned; (5) developing cost-effective approaches through interdependent programs; (6) facilitating the identification of technology requirements for specific applications; and (7) creating an environment to gain a substantial edge in international competitiveness thorough technology transfer.

The STI management infrastructure should be easily implementable with a minimum impact to cooperating organizations. Furthermore, such a structure should be least affected by frequent reorganizations of the cooperating agencies/organizations. One such organization is proposed in figure 4 and is patterned after the STIG discussed earlier in this paper.

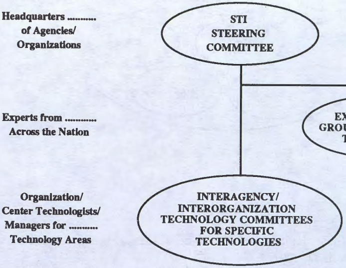

Figure 4.– Proposed STI Management Infrastructure.

V. CONCLUSIONS

The Space Technology Interdependency (STI) is a manageable task since space technology needs are relatively understood and there is a mechanism to periodically update the list of high priority space technologies. The STI would facilitate identification of technology requirements with realistic specifications. The foremost requirement for the management structure for STI should be its ability to provide motivation to personnel to implement and promote cooperative efforts. Communications should be effective at all levels and decisions should incorporate both top-down and bottom-up inputs. There should be clear guidelines for measurement of success. The implementation of successful management infrastructure provides a challenge. It should be a process oriented and flexible approach. There should be emphasis on team work, and not on preconceived results. Most important, it should incorporate rewards and incentives for those who produce desirable results.

The goal of STI should be to bring together Federal and state agencies with Small Business Innovation Research (SBIR), Industry Internal Research and Development (IR&D), commercial enterprises, and educational institutions to cooperate in the R&T development for space programs and ensure timely transfer of new innovations to industry for commercial development (see Figure 5). Thus, STI can play a major role in the revitalization of the space program, as well as our commercial sector. It would be a significant contribution to the implementation of the National Technology Policy for America issued by President Clinton and Vice President Gore on September 11, 1992.

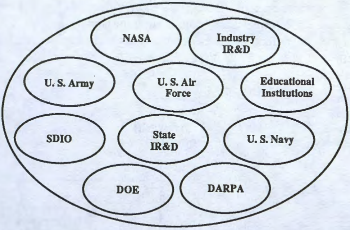

Figure 5.– Domain of STI.

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