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The US and Japanese Space Programs:
A Comparative Study of Goals and Capabilities

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1 Introduction

In the early years of space exploration, few nations were willing or able to expend the resources necessary for large scale national space programs. Indeed, at that time only the United States and Soviet Union supported such programs, while developing capabilities in areas ranging from interplanetary probes to manned spaceflight. Both countries subsequently rose to positions of unchallenged pre-eminence in space technologies and activities. In more recent years, however, the level of international interest and activity in the space arena has risen substantially. Various factors have contributed to this change, including the ongoing maturation of industries and markets for communications satellites and launch services, and the increased accessibility of developed, transferable space technologies. Furthermore, the potential benefits from space development and the advantages of assured access to space have become increasingly characterized in strategic terms, both for high technology growth and national security. As a result, various nations have begun to foster promising and successful space programs, with steadily increasing capabilities and ambitious goals. A particularly notable example is the Japanese space program, which has progressed in less than twenty years from the 1970 launch of its first satellite to participation in the ongoing international space station Freedom project. Such progress is impressive, particularly given the relatively small amount of governmental funding allotted to the program. Moreover, the Space Activities Commission (SAC) of Japan has proposed additional (and even more ambitious) national goals for space exploration, including the development of a space infrastructure for autonomous space activities and an eventual manned spaceflight capability. Although these objectives may not be achievable in the near term, they seem to indicate an increase in the national priority assigned to the development of space technology in Japan.

From the perspective of Japan, with its heavy reliance on trade and high technology resources, such an interest in a potential high technology growth area is understandable and perhaps even expected. Indeed, for related reasons, the Japanese program has long sought a state of autonomy in space activities, free from the constraints of technology licensing agreements for imported technologies and capable of independent planning and action should a market for space technologies develop. Despite the apparent agreement on the value and desirability of autonomy, however, little true consensus has yet developed regarding the type of program for which autonomy is desired, or even the logical course of action following its attainment. As in the U.S. and other countries, the commercial potential of the space marketplace remains uncertain, at least for the near term. Moreover, the government, daunted by the enormous expenditures required in this unproven arena, has continued to be cautious in its funding of system level space research and development. As a result, government funding for the program has remained relatively low and inconsistent with SAC goals.

In response to this funding policy, space policy-makers and interest groups in Japan have seemingly adapted their goals and methods to the circumstances, aiming for evolutionary development philosophies, greater participation in international projects, and the cultivation of private investment and activity in the Japanese space program. According to the rationale, the available resources of Japan can thus be optimized for growth, while increasing the exposure of Japanese space engineers to new techniques. In addition to the obvious goal of increasing the technological capabilities of the program, however, these objectives represent a concerted attempt to orient the capabilities of the program to private sector demand, with the intent of supporting further growth through commercialization if government funding does not increase. Specific elements of these efforts seemingly include the pursuit of value-added space markets worldwide and the cultivation of potential markets in the Pacific Rim. Although privatization may indeed be crucial to the growth of the program, it nevertheless represents a significant departure from the policies of more exclusively public sector-oriented programs such as that of the U.S.

In the current world of high technology competition and rising costs for space ventures, the emergence of economically powerful Japan as a space-faring nation is significant and merits further evaluation. Such is the case not only because of the potential implications for space-related markets and industries, but also because the evolving privatization policy for the program differs so markedly from the funding policies of the larger scale programs. At the same time, however, the Japanese program has seemingly utilized U.S. technical capabilities as a benchmark for its own capability, creating an interesting conflict in program philosophy. From that perspective, the more established and widely recognized U.S. program provides a particularly useful and instructive standard of measurement for an analysis of the Japanese program. Moreover, a comparison of the two programs is potentially valuable in that their operational philosophies and styles are fundamentally different, and comparative analyses may provide insights into their relative strengths and weaknesses, as well as their long range objectives and configurations.

Therefore, the purpose of this report is to provide a comparative analysis of the U.S. and Japanese space programs, with an emphasis on their respective strategies for growth and current operational philosophies and capabilities. As part of that analysis, particular consideration shall be given to demonstrating the privatization policy of the Japanese program relative to the public sector orientation of the U.S. program (with its less prioritized commercialization efforts), as well as to the relative impacts of those policies on space activities and funding. In that regard, the Japanese program's reliance on evolutionary development philosophies and unmanned space activities shall be established and considered relative to the sharply contrasting activities and philosophies of the U.S. program. Evaluations of program administration and structure are also included, along with an overview of program facilities. Following the analysis of the strategies and objectives of the programs, particular consideration shall be given to the progress of each program in attaining the goals discussed above. Finally, the study includes a detailed evaluation of the relative technical capabilities of the two programs in selected technology areas. Conclusions based on these analyses and data are provided, with particular emphasis given to an assessment of the potential activities and impact of the Japanese program. A brief historical overview of the two programs is included for reference.

2 Program History

United States The U.S. space program was formally inaugurated in 1958 with the launch of the scientific satellite Explorer. Later that year, the National Aeronautics and Space Administration (NASA) was established for the purpose of directing the nation's civilian activities in space. Throughout the ensuing decade, the program concentrated on the development of satellite and launch vehicle technologies, the support of solar system research, and the creation of a manned spaceflight capability (with the ultimate objective of sending a manned mission to the Moon). These launch technology efforts resulted in the early models of the Titan, Atlas, and Delta launch vehicles, which were established primarily on the basis of intercontinental ballistic missile designs developed by the U.S. Department of Defense (DoD); and the powerful Saturn series. Descendents of all but the Saturn remain in operational use today. In addition to such development activities, the program conducted unmanned research missions throughout the solar system, including the Pioneer probes to the Moon and Sun, the Mariner probes to Mars and Venus (with the U.S. achieving the first flyby in both cases), and the Ranger, Lunar Orbiter, and Surveyor missions to the Moon. Following the Mercury and Gemini manned programs, the decade culminated with the Apollo manned lunar landing in 1969.

In the early 1970s, the U.S. conducted additional manned missions to the Moon, followed by the Skylab space station program. At the same time, the program continued its exemplary efforts in space science and applications. For example, interplanetary probes with multiyear mission plans were sent to Mercury (Mariner), Jupiter and Saturn (Pioneer, Voyager), Uranus (Voyager), and Neptune (Voyager), nearly completing the tour of the solar system. The Viking mission to Mars in 1975 involved the first soft landing on the planet's surface. In addition, satellite technologies for communications, surveillance, broadcasting, meteorology, and remote sensing were further developed and evaluated, while scientific satellites for X-ray and infrared astronomy were designed and launched. Finally, in the search for more cost-effective launch technologies and a new agenda for NASA, the U.S. program developed the Space Transportation System (STS, also known as the Space Shuttle), the world's first reusable, manned spacecraft. The STS program gradually became the focal point for NASA's efforts as the program entered the 80s.

During the 1980s and beyond, the program continued the operation of the STS, while beginning the development of the international space station Freedom. Following the STS Challenger accident in 1986, however, the U.S. experienced a period of program reevaluation and launch capacity shortages. Renewed support for expendable launch vehicles resulted from the incident. Despite a significant decrease in the overall number of space science missions, the Magellan and Galileo probes were launched to Venus and Jupiter, respectively, and the Hubble Space Telescope was successfully placed in orbit (further comments on the Galileo and Hubble projects are provided in a later section regarding space science). As of the writing of this report, over 900 successful launches of spacecraft have been conducted.

Japan The Japanese space program formally began in 1955, when a small group of scientists at the University of Tokyo successfully designed and launched a small solid fuel sounding rocket known as the Pencil rocket. This group was led by a medical technology student, who became fascinated with space technologies while studying in the U.S. and ultimately studied rocket technology upon his return to Japan. Within ten years, the National Space Activities Council (NSAC), the Institute of Space and Aeronautical Science (University of Tokyo), and the National Space Development Center (NSDC) had been established for conducting the nation's space activities. Throughout this time period, the program attempted unsuccessfully to domestically design and build a solid fuel launch vehicle for access to Earth orbit.

Due to growing concern regarding the nation's slow rate of space technology development, the Japanese government established the SAC in 1968 and the National Space Development Agency (NASDA) in 1969, replacing the NSAC and NSDC. Shortly thereafter, the program imported (through licensing agreements) Delta 2914 launch vehicle technology from the U.S. to speed the technology development efforts in Japan. Nevertheless, the 1970 launch of the satellite Osumi occurred on a solid fuel vehicle developed by the Institute group at the University of Tokyo. With the launch of the Osumi, Japan became the fourth nation in the world to place a satellite in orbit. After extensive political debate, the university group and NASDA were subsequently allowed to remain separate, with differing responsibilities (more discussion on this administrative framework will be provided in the following section), facilities, and launch vehicles. To avoid conflict with NASDA efforts, however, the Institute's efforts to develop launch vehicles were limited to vehicles with diameters of 1.4 meters or less. The group ultimately went on to develop a series of launch vehicles known as the M-series, all demonstrating slight improvements in capability. On the basis of the Delta technology, NASDA proceeded to develop the N-series of launch vehicles.

Throughout the 1970s, the two organizations gradually developed a national resource base in space technologies. In terms of applications, NASDA concentrated on the development of satellite and launch vehicle technologies. Specific programs included an experimental satellite series for evaluating basic technologies; a series of programs for developing communications, broadcasting, remote sensing, and meteorological satellites; and the efforts to develop an indigenous launch vehicle. Following the N-series of vehicles, these efforts led to the partially indigenous H-I vehicle, which is the primary vehicle in use today, and to the decision to develop the completely indigenous H-II. With regard to space science, the University of Tokyo group continued to design and launch scientific satellites, concentrating its efforts in the areas of X-ray astronomy, upper atmospheric studies, and solar physics. In 1981, the group was reorganized into the Institute of Space and Astronautical Science (ISAS).

Significant program developments in recent years have included the 1985 decision to participate in the international space station Freedom project and the successful completion of flyby missions to Halley's Comet and the Moon. In addition, recent design efforts have included work on an unmanned, reusable spacecraft known as the H-II orbiting plane (HOPE). At the writing of this report, over forty launches have been successfully conducted[2].

3 Administrative Structure and Facilities

Whether comparing absolute size, the number and nature of operating centers, or basic administrative divisions, the administrative framework and structure of the U.S. and Japanese space programs contain fundamental differences. In many ways, these differences are reflective of the unique origins of the programs, as well as the differing expectations and perceptions within each nation regarding the appropriate role for a space program. For example, the U.S. space program was created during a period of intense competition with the Soviet Union in the space technology arena. In particular, the two nations were "racing" to develop the world's first manned spaceflight capability and conduct the first manned landing on the Moon. The result was an early orientation to ambitious, large scale projects involving widespread operations in a variety of field centers and the mobilization of tremendous resources. This initial focus established a precedent for such projects (including manned activities) and influenced the philosophy and administrative organization of the program. Partial evidence of this fact is provided by the composition of the unwieldy array of centers in existence today, most of which were established during this period. Furthermore, space development activities were perceived to have national security implications. Consequently, the U.S. Department of Defense (DoD) was involved in the program from its inception.

In contrast, the initial activities of the Japanese space program were small in scope and oriented to the university by nature. Moreover, these activities primarily consisted of technology development efforts rather than manned spaceflight activities or similarly scaled projects. Although recent Japanese space policy statements call for an enlargement of the sphere and scale of activity, many aspects of the style and administrative structure of the program still reflect this modest beginning and the lower initial priority assigned to the program. For example, the program maintains comparatively few centers and supports a small staff relative to the U.S. program. In addition, the centers currently in existence remain suited to smaller scale technology development projects rather than extended operations. In another area of contrast with the U.S. program, the initial objectives for the program did not include the utilization of space technologies in defense-related activities. Such is still the case today, as the Japanese space program does not formally support any military activities and contains no DoD equivalent in its organizational structure.

Since the operations and objectives of both programs are greatly influenced by their individual structures, further analyses of the structure and administrative framework for each program are provided below. A brief overview of each program's facilities is also included.

United States The management of space activities in the U.S. is primarily concentrated within two organizations - the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD). Although both are governmental agencies promoting the development and utilization of space, their roles, responsibilities, and styles are quite different. For example, NASA was originally conceived as a research and development agency, with an emphasis on the peaceful exploration and development of space. Consequently, a fundamental objective of the agency is ostensibly the general advancement of science and technology in space-related technical disciplines. With regard to mission philosophy, the agency has historically been oriented to the design and completion of specific missions and projects, as opposed to the operation and continuous support of comprehensive space systems (such as those required in military space activities). With the advent of the STS and the plans for the international space station, however, NASA has begun to add a significant operational element to its sphere of activities and responsibilities. In terms of governmental organization and identity, NASA is an non-departmental agency with a specific charter.

In comparison, the DoD's space activities naturally concentrate on national defense and security. Specific activities in this arena consist of surveillance, meteorological studies, navigational support, mapping, and the maintenance and support of a variety of satellite communications systems. In addition, the Department supports the development and acquisition of launch vehicles and other technologies perceived to be necessary for the fulfillment of national security objectives. Due to the requirement for continuous operational capability and the high number of operational units in many military space systems (such as the communications or surveillance satellite systems mentioned above), the procurement process of the DoD generally involves the acquisition of multiple - and often redundant - units of various space systems and system components. Although this "stockpiling" approach is frequently necessary to ensure the operational capability of these systems, it also provides the benefit of sustaining the industrial base for those technologies.

Despite such differences in operational objectives and philosophy, joint projects between the agencies sometimes occur. A current example is the National Aerospace Plane (NASP) project, involving the development of technologies and designs for a craft capable of taking off and landing horizontally and operating under power in both the atmosphere and space. Furthermore, DoD technology initiatives have frequently been of benefit to NASA, particularly in the areas of satellite technology and launch vehicle development. Indeed, most of the Expendable Launch Vehicles (ELVs) in the U.S. inventory are derivatives of launch vehicles originally developed by the DoD for military purposes. Although the ELV example is more of an exception than a general rule, some technology transfer is almost inevitable, since the companies developing the technologies for both agencies are often the same. Nevertheless, stringent security restrictions and mission incompatibilities have often served to discourage a more complete or institutional transfer of technology.

In terms of larger facilities, NASA currently maintains ten field centers, which are involved in a variety of activities. These facilities consist of three research centers, including the Langley, Ames, and Lewis Research Centers; the Goddard Space Flight Center, oriented to space science and technology applications; five primary space flight centers, including the Kennedy, Johnson, and Stennis Space Centers, Marshall Space Flight Center, and Wallops Station; and the Jet Propulsion Laboratory (JPL), involved in scientific missions and planetary studies[3]. A variety of smaller facilities exist for testing and data acquisition. In addition, the U.S. program has access to Vandenberg Air Force Base, a launch center affiliated with the DoD. The number of people directly employed by NASA at these installations is approximately 23,900, while private contractors provide the services of roughly 33,000. Private contractors involved with the program include production firms as well as smaller companies providing support services. The total number of employees affiliated with the NASA portion of the program is approximately 56,900.

Of the space flight centers mentioned above, three - Kennedy, Vandenberg, and Wallops (used primarily for the launch of sounding rockets) - provide actual launch facilities to the U.S. program. These installations contain a wide array of launch complexes and pads, although many are currently inactive. At the present time, however, only the Kennedy Space Center provides active launch services for the STS. Although Vandenberg currently has "mothballed" STS facilities, the facilities are scheduled to be converted for Titan IV use in the early 1990s. The Vandenberg facility allows access to polar orbit without overland flight. In terms of launch rates, these facilities can presently support approximately ten Delta, ten Atlas I/II, six Titan IV, and ten to twelve STS launches per year. After the conversion of the Vandenberg STS facilities, the Titan IV pads should be capable of ten launches per year.

Japan The management of Japanese space activities is also divided among two distinct organizations - the National Space Development Agency (NASDA) and the Institute for Space and Astronautical Sciences (ISAS) - both operating within the policy guidance of SAC. However, the similarity to the multiorganizational structure of the U.S. ends there, as neither Japanese organization is oriented to defense applications. More accurately, the Japanese program structure represents a division of NASA's responsibilities into two separate bodies. With respect to objectives, NASDA is responsible for the development of application satellites and launch vehicles and the acquisition and utilization of system data[4]. On a much smaller scale, its organizational responsibilities are comparable to the combined responsibilities of the Kennedy, Johnson, and Stennis Space Centers and the Marshall Space Flight Center within NASA. The organization operates under the governmental authority of the Science and Technology Agency (primarily), the Ministry of Posts and Telecommunications, and the Ministry of Transport.

In comparison, ISAS is oriented to the launch and development of scientific satellites and the general promotion and support of the space science field, including space science projects and relevant research[5]. Although smaller and lesser funded than NASDA, ISAS nevertheless benefits from this administrative separation through the ability to protect its appropriated funding from the budgetary needs of NASDA projects. As shall be discussed in more detail in the funding section, such budgetary "raids" have long been a handicap for space science activities within the U.S. program, as science funding has frequently been channeled to the manned programs in times of budgetary need. In terms of identity, ISAS is primarily associated with the university community (due to its origins in the University of Tokyo). Its organizational responsibilities are comparable to the functions of the Jet Propulsion Laboratory and some aspects of the Goddard Space Flight Center within NASA. The Ministry of Education holds governmental authority over the Institute.

At the present time, the two organizations are completely independent, maintaining their own funding, projects, management, and launch facilities and vehicles. Indeed, their operational style and philosophy are separate and distinct. Nevertheless, a new policy objective of SAC is the promotion of greater cooperation and interaction between the organizations. This initiative would necessitate improved interorganizational communication.

In the area of installations, the Japanese program maintains six large facilities, with a variety of smaller testing, data acquisition, and tracking stations providing support services. The major installations include the Tanegashima and Kagoshima Space Centers, utilized for H-series and M-series launches, respectively; the Tsukuba Space Center, oriented to research; the Kakuda Propulsion Center, central in the development of Japan's launch vehicle capability; and the Earth Observation and Space Data Analysis Centers, oriented to the acquisition and analysis of satellite data[2]. The number of individuals directly employed by NASDA and ISAS at these installations is approximately 1,280, while the private sector provides the services of roughly 9,100 employees to space development efforts. The corporate employees consist primarily of technical personnel, who also work on defense and corporation-specific projects in their area of expertise[6]. The total number of employees affiliated with the Japanese space program is approximately 10,380, or less than 1/5 the number of U.S. space-related employees. Although the U.S. figure includes support services personnel, this dramatic difference in staffing nevertheless reflects a much smaller resource base in terms of experienced technical personnel. Without a significant increase in trained personnel or an influx of outside expertise, the low number of employees with experience in space technologies, systems, and operations could limit the growth and future activities of the program.

With regard to launch capacity and the potential for growth, both of the Japanese launch sites suffer from severe launch restrictions due to limited physical area. For example, the Tanegashima site currently has only one pad for the H-I and will have just one pad for the H-II when construction is completed. In comparison, the Delta launch vehicle of the U.S. has three pads, the Atlas has three pads, and the Titan IV will have four pads (when the conversion is completed). In addition, the launch activities at the two sites are constrained to the periods of January/February and August/September by an agreement between the government and Japanese fishermen. The fishermen believe that the launching of rockets disturbs the fish and thereby lessens their catch. As a result, NASDA pays the fishermen an annual stipend for compensation. Although the possibility of negotiating higher launch rates has been discussed in MITI and program position papers, the problem may remain somewhat intractable given the political strength of the fishing lobby and the reluctance of the members of the dominant Liberal Democratic Party (LDP) to aggravate a critical portion of its constituency. In the near term, both factors impose a serious constraint on Japan's launch capabilities and potential to gain greater operational experience in launching.

Although the program's existing launch capacity has thus far been sufficient for its low requirements, an increase in launch demand due to the addition of commercial launch commitments or more ambitious program initiatives would necessitate a growth in capability. In view of the limitations in land area and the normal restrictions regarding launch pad safety zones (particularly for commercial launches and their related insurance stipulations), such facilities would almost surely have to be located off the Japanese mainland, possibly through a launch site agreement with another nation. Such agreements are possible in principle, as evidenced by the recent agreement between the Soviet Union and Australia to launch the Zenit rocket from Cape York (under the supervision of an American firm and the Australian government). However, the costs of an offsite launch agreement could be prohibitive, and a substantial increase in launch demand would be necessary to balance the expense. Until sufficient demand has been established, these factors will likely limit both Japan's entrance to the commercial launch arena and the frequency and scale of its future manned activities.

4 Program Objectives and Strategy

Both the U.S. and Japanese governments have recently released policy statements regarding space development and exploration. As official guidelines for development and indicators of national interests in space, these statements provide a useful frame of reference for evaluating the potential objectives and capabilities of the two programs. Furthermore, the official positions merit review in that they partially reflect each nation's strategies and institutional mechanisms for development. Despite the usefulness of the statements, however, they only partially enumerate the more fundamental goals and motivations seemingly associated with each program. To the extent possible, therefore, such factors shall also be considered in the following section, along with the observable strategies for development. Detailed analyses of each nation's progress in achieving these goals will be provided in later sections.

United States In order to understand the current goals and philosophies of the U.S.

space program, one must first consider the program's origins and initial objectives. As discussed previously, these initial activities were fundamentally shaped by the evolving superpower conflict with the Soviet Union, and the related race to place a man on the moon and establish superiority in military space systems. Additional shaping influences on U.S. space policy consisted of the basic national perceptions at the time regarding the prestige and appeal of space exploration, combined with the proudly held image of the U.S. as a technology pioneer and world leader. The combination of these factors predictably created an early orientation to national security and the publicly visible manned activities, as well as to ambitious, large scale projects and extended operations in general. In the process, institutional and societal precedents and expectations for such activities and projects were established.

Although much has transpired since the successful Apollo program and the public enthusiasm of those early years, including the somewhat regrettable focus on the STS in the 1970s and the relative stagnation of the 1980s, the policies of the U.S. space program are still largely influenced by the same basic precepts. Indeed, many of the primary goals defined in recent policy statements are essentially the same as those of earlier years, including the increased human exploration of space (through the international space station and a potential manned journey to Mars), the support of national security related requirements, and the renewed support of a diverse range of activities in space science. More specific (and significantly lesser funded) initiatives consist of the rejuvenation of basic research in space technologies, the development of a high capacity launch system, and the somewhat revitalized efforts to encourage private sector involvement. Though such objectives contain elements of pragmatism for an established space faring nation, they nevertheless seem more closely linked to an overriding desire to perpetuate U.S. leadership in space activities and preserve the form and nature of the current program. A more concise and directed plan does not seem to exist. Furthermore, as evidenced by the current Mars initiative, the U.S. view of space leadership is still largely defined in terms of public sector projects of the scale and nature of the Apollo program.

With regard to financing strategies, the U.S. space program has historically been supported through government funding and procurement. In view of the high risk (and longer term) nature of space investment and the type of U.S. project envisioned for the near future, the funding and support for U.S. space development activities will almost certainly remain in this form. Consequently, the primary mechanisms for development will continue to be NASA and the DoD, acting as administrators and project managers for contracts awarded to various corporations. Although private sector investment and involvement in the space program have been the subject of much discussion and some experimentation, further incentives and guarantees will apparently be required before private sector organizations invest at a level sufficient to sustain development activities (more analysis of the status of these efforts will be provided in a later section). Moreover, company consortia designed to promote, manage, and utilize space technologies, such as those seen in Europe and Japan, for the most part do not exist.

In the meantime, incentives for the private sector will be provided through government commitments to employ U.S. firms for certain services and to act as "anchor tenants" for space-related private firms. For example, the U.S. government has made a commitment to use only U.S. launch vehicles for government payloads. As one effect of this reliance on government contracts and initiatives, however, the capabilities of the U.S. program may ultimately be tailored to the larger scale and more expensive requirements and projects of NASA and the DoD, rather than those of companies interested in accessing or developing markets for space technologies. For example, the original plan to divert materials research to the space station could have made the costs of experimentation prohibitive for smaller companies, as opposed to less costly methods such as drop towers, sounding rockets, balloons, or even unmanned orbiting platforms. This orientation to larger scale public projects may limit the number of residual technologies emanating from the program, in addition to slowing the transfer of technologies between the public and private sectors.

Japan From its inception the activities and goals of the Japanese space program have focussed on the gradual development of basic space technologies and the pursuit of autonomy in space. Current initiatives resulting from these objectives include the development efforts for satellite technologies and the completely indigenous, potentially world class H-II launch vehicle. As mentioned previously, such objectives in a potentially strategic growth area are easily fathomed for Japan, particularly in view of its dependence on trade and high technology resources. Despite the general agreement on the end objective, however, true consensus has not yet developed with regard to the appropriate process for the required development. Some groups (represented by such notable spokesmen as Ryuji Kuroda, the General Manager of NEC) have favored a combined public and private sector program supported through substantial government funding, while others have recommended the more typical Japanese approach to fostering technological growth in high risk areas - the reliance on the private sector to tailor its development efforts and emerging capabilities to existing (and potential) markets[7]. The more prominent view within the government has seemingly been to provide low yet stable near term funding for establishing initial capabilities, while encouraging private sector investment and involvement for sustaining long term growth. Within the resulting budgetary limitations, Japanese space policy-makers have been forced to rely on a combination of evolutionary development philosophies and the importation of technologies through licensing agreements.

By the mid-1980s, however, a combination of factors had evolved which enhanced the commercial appeal of space technologies and ultimately increased the emphasis on space development activities within Japan. Firstly, certain industries and markets for space technologies, such as those for communications satellites and satellite systems, had matured to levels sufficient for self-support and profitable entry. Furthermore, other arenas, such as the areas of materials research and remote sensing, had begun to demonstrate clear promise for growth. Finally, the U.S. space program proposed the international space station project, providing a valuable opportunity for the Japanese to gain from the knowledge and experience of other programs, as well as to acquire international visibility and prestige in this high technology arena. Such factors led to renewed political and corporate interest in the development of indigenous technologies and the potential commercialization of space. On the basis of that enthusiasm, program planners began to actively seek methods to enlarge the scope, range of capabilities, and funding of the space program. These efforts are reflected in the recent policy statements for the program, which center on the now familiar issue of autonomy, Japanese participation in and support of international space projects and activities, the cultivation of private investment and involvement in the space program, and the furtherance of activities in space science[8].

The common theme in these objectives is the underlying goal of increasing the scope, capabilities, and commercial appeal and value of the program, without a corresponding increase in government funding. That is to say, the underlying goals for the program are self-sufficiency and privatization, with an associated reduction of government responsibility for the program. From this perspective, the rationale for the stated policy objectives can be demonstrated in various ways. To begin with, the state of autonomy creates obvious advantages for long term planning, decision-making, and growth. This remains true whether or not the Japanese program ultimately supports manned activities or larger scale projects. For example, the related development of indigenous capabilities would enable the program to cultivate existing and potential markets for space technologies in the Pacific Rim, thereby stimulating potentially critical demand for the private sector. Moreover, indigenous capabilities increase the appeal of the Japanese space program as a partner in international space ventures. Participation in such projects should enable Japanese engineers and scientists to acquire knowledge and experience in advanced space technologies for a fraction of the cost of truly autonomous development. Finally, indigenous technologies and capabilities should allow greater access to value-added industries and markets for space subsystems. Both the potential to access value-added industries and the possibility of supporting and interacting with regional space industries constitute the prerequisite elements for the ultimate strategic objective - an increase in private sector investment and involvement. As discussed by Eberstadt in a related study, the strategy for obtaining that objective can be generally characterized in terms of 1) the creation of private sector organizations to develop and market commercially-relevant space technologies and capabilities, and 2) the encouragement of markets and demand for these products and services[9].

In terms of creating private organizations for managing space technologies, the program has already made some notable progress. Specific examples will be dealt with in more detail in a later section regarding the current status of the initiatives described above. As a brief overview, however, policy-makers in Japan have recently fostered the creation of corporate consortia for providing launch services (the Rocket Systems Corporation); developing and marketing the technologies and equipment for the Japanese portion of the international space station (the Japanese Manned Systems Corporation); and managing the utilization of the reusable experimental platform known as the Space Free Flier, scheduled for launch in the mid-1990s (the Institute for Unmanned Space Experiments with free Fliers - USEF). Each of these organizations represents a significant step towards privatization and the reduction of government responsibility for the space program. More importantly, the organizations and corresponding structure constitute an effective positioning of Japanese space industries for developing and marketing space technologies and services in the event that commercial markets emerge.

With regard to the stimulation of demand, the various strategies center on two separate efforts - 1) the creation of organizations and consortia to facilitate the growth of markets and demand for space technologies, and 2) the cultivation and support of potential markets in the Pacific Rim. Although further detail will again be provided in the later section mentioned above, notable examples of foundations and company consortia in this area include the Japanese Space Utilization Promotion Center (JSUP), and the Space Technology Center (STC). As a non-profit foundation, JSUP is intended to discover and promote potential uses for the space station, in addition to serving as a representative for the interests of space industries as users. In comparison, the STC was created to conduct research and development activities for electronics-related materials processing in the microgravity environment. In terms of stimulating programs in the Pacific Rim, the program intends to concentrate on communications technologies and possibly launch services, with the assistance of existing governmental mechanisms such as the Japan International Cooperation Agency(JICA)[11]. If successful, this initiative would further provide a means of growth and sustenance to the program and its related space industries.

However, it should be noted that such growth assistance agencies in Japan are often understaffed and inadequately prepared for providing such aid. For example, JICA, which is responsible for technical feasibility studies and assistance, has fewer staff persons now than in 1977, when it was already poorly staffed relative to such admittedly overextended operations as the World Bank. Moreover, many of the experts in the agency are not fluent in other languages[10]. Consequently, the effectiveness of the agency in facilitating space program growth in other countries may be limited for the near future.

5 Funding and Program Management

The evaluation of funding practices and budgetary trends is critical to the comparison of the two programs, since these factors directly impact program effectiveness, internal policy, and management. Moreover, the trends in funding are significant in that they reflect and illustrate the different origins and long term strategies of the two programs. For example, the U.S. program has traditionally relied on public sector management and demand, while basing its activities on a large operating budget. In contrast, the planners for the Japanese program have hoped to stimulate private demand and establish commercial utility, with only minimal government investment. Furthermore, the U.S. program places a higher priority on manned space activities and large scale projects (as already discussed), whereas the Japanese program has typically focussed on gradual technology development efforts and smaller scale, unmanned activities. As a result of such factors, the U.S. space budget is substantially larger than the space budget in Japan. Further evaluations of these characteristics and their effect on program management are provided in the following sections, along with funding histories for the last decade and a brief overview of the politics of space funding in each country.

United States Although high in comparison to other nations, the funding for the U.S. space program has often been inconsistent with program goals and unstable on the project level. Various factors have contributed to these trends, including the disparity of views within the government regarding the activities and objectives of the space program, the inability of program planners to adapt to longer term shifts in political and public support, and a tendency within the program to underestimate costs for potential projects. In addition to their individual importance, however, the significance of these factors is magnified by the budgetary process of the U.S. In particular, the U.S. government reviews its budget annually, but without systemic guarantees or commitments to items in budgetary areas considered to be discretionary (such as the space program) rather than essential. Consequently, changes in administration and/or political priorities can have a dramatic impact from year to year on the existing and proposed funding for such categories.

With regard to the space program, which exists on moderate and relatively unstable levels of political and public support, the level of governmental funding and commitment for specific projects is often highly variable. Evidence of this characteristic is plentiful, though an extreme example is the Galileo project (discussed in the technology assessment section), which was canceled four times and revived five times in less than twelve years. Moreover, the political conditions producing this state of budgetary instability are reinforced and often provoked by the program's frequent difficulties in project management and cost estimation. As a result, project cancellations and funding reductions are common. Since the activities of the space program frequently involve multiyear research and development schedules and long production lead times, these fluctuations and uncertainties in the annual operating budgets for projects typically have a deleterious effect on the management efficiency of the program.

In addition to these trends in project management, however, the perpetual discrepancies between the institutional (and societal) expectations for the program and the politically available budget have profoundly affected the philosophy and selection of projects within the space program. The resulting effects can be loosely summarized as 1) a fundamental orientation toward revolutionary, or technologically unique, projects, and 2) a propensity for the creation of "megaprojects" (or projects large in scale and scope), in both manned and unmanned programs. Both types of project have typically been portrayed as necessary to generate public and political support for the program and thereby maintain funding. They have also been defended as productive overall, since the U.S. space program has established a spectacular record of "firsts" through this approach.

Despite the relative benefits in such respects, however, this style of operation has also limited the overall efficacy of the program in the use of public resources. For example, one result of the orientation to revolutionary projects has been a corresponding tendency to discard or underutilize proven technologies in the perennial search for such projects. Indeed, the history of the U.S. space program is replete with examples of this behavior, including the Saturn V launch vehicle, the Skylab project, and the X-15 experimental rocket plane, to name but a few. Other projects, such as the Landsat remote sensing satellite series, have only narrowly avoided this fate. In terms of the efficient use of government investments, a tendency of this nature is extremely wasteful, providing few opportunities to reduce unit costs through long term usage and lessen the effects of initial development costs. Nevertheless, it should also be noted that the U.S. has made evolutionary improvements to existing systems when funding for the development of new systems was unavailable. Some examples of this approach are the Titan, Delta, and Atlas series of launch vehicles and many of the early space science projects conducted by NASA. The success and relative cost-effectiveness of these systems strongly supports the wisdom of further incorporating evolutionary development philosophies into the development activities of the program.

The effect of the political and institutional orientation to megaprojects has also been pronounced, though perhaps somewhat contrary to expectation. According to the prevailing belief, an increase in project scope involves more production facilities and regions of the country in the procurement process, thereby enhancing a project's chance of political acceptance and survival. By their very nature, however, such projects are more prone to design and management complications and related cost overruns, which in turn often *increase* the risk of cancellation. In addition, the functional compromises inevitably entailed in the design of large, multifunction spacecraft often lessen the effectiveness of individual mission components and instruments. Finally, the development of the megaproject requires much more time than that of a smaller project, creating long periods of inactivity within the disciplines depending on the project for new scientific data. These periods have a very detrimental impact on university research and education in space-related fields.

As another undesirable result of this operational focus on discrete, large scale projects and the more publicly visible manned programs, basic research and development efforts within NASA have seemingly been deemphasized (despite the nature of NASA's charter). Indeed, the megaprojects and manned programs have often survived during funding shortages on the basis of funds appropriated from smaller projects and basic research. This trend can be illustrated by the funding history of NASA's Advanced Research and Technology division, which is responsible for the management of basic engineering research. The division's funding has decreased from six percent of the total space budget during the Apollo era to two percent of the current budget. Such trends indicate a significant decrease in basic research and a poor commitment to the long term requirements of the program[13]. In recognition of this problem, however, NASA has recently begun the five-year $773 million Civilian Space Technology Initiative (CSTI), with the intent of supporting basic technology development efforts in areas such as automation and robotics, propulsion systems, and information technology. The CSTI has been designed to cultivate technologies with many potential applications, as opposed to the traditional method of relying on individual projects to generate residual technologies[14].

Despite these disturbing patterns in the support for individual space projects and basic research, the total funding for NASA has increased during the last five years (in terms of constant 1985 dollars). These increases were largely due to the addition of development funding for the space station Freedom and an increase in STS operational costs following its 1986 grounding and subsequent renewal. Lesser factors consisted of the increased allocations for space science in the late 1980s and the 1988-89 budgetary provisions for en-

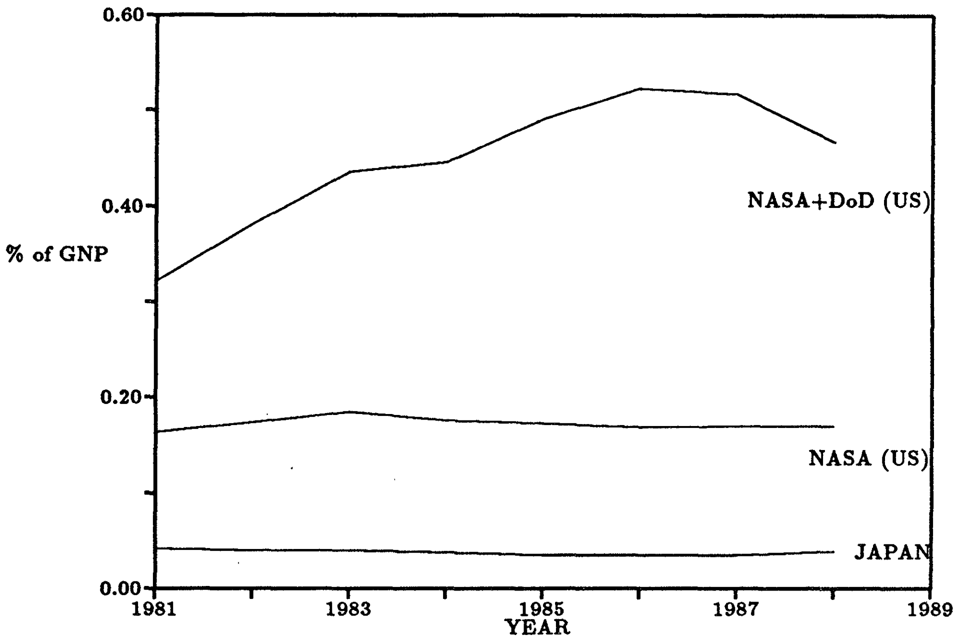

Figure 1: Space Program Funding as a Percentage of GNP

hanced networks for data transfer and communications[15]. For the same time period, the DoD's space-related funding fluctuated slightly[16]. Both funding histories are presented in tabular form in Table 1, along with the combined funding for the space activities of the Departments of Commerce, Energy, Interior, Agriculture, and Transportation. The 1987 funding value for NASA does not include the replacement costs for the new STS orbiter.

As a function of the U.S. Gross National Product (GNP), however, the level of space funding for NASA has remained relatively constant throughout the last decade, while the level for the DoD has risen significantly (Figure 1). On the basis of the GNP data, one can conclude that the priority attached to the civilian portion of the U.S. space program

	Constant 1985 Dollars(millions)		
FY	**NASA**	**DoD**	**Other**
1985	$ 6,925	$ 12,768	$ 474
1986	$ 6,976	$ 14,614	$ 359
1987	$ 7,241	$ 14,815	$ 330
1988	$ 7,317	$ 13,138	$ 403
1989	$ 8,743	$ 13,867	$ 555

Table 1: U.S. Space Program Funding

during that time period did not change relative to the national hierarchy of priorities. In comparison, the priority for defense-related space funding has increased relative to other budgetary items. This trend primarily reflects the increased defense funding of the 1980s and a greater awareness of the operational and tactical benefits of military satellite systems.

However, some important clarifications must be added regarding the nature of U.S. space program funding for defense activities. The DoD funding data presented in Table 1 are merely estimates for the DoD's yearly disbursements for space activities. In actuality, the DoD does not have a formal "space budget" within its overall budget, and the yearly estimates are simply the aggregated results of numerous accounting judgments regarding the applicability of specific DoD program outlays to military space activities[16]. These judgments often entail the determination of a percentage of space applicability for specific DoD expenditures. Consequently, the space funding data available for the DoD are somewhat subjective and uncertain. Furthermore, a significant portion of the DoD's annual spending for space is devoted to the procurement of multiple items in large scale space systems and the purchase of replacement units and components for those systems. In terms of the effects of funding, such expenditures are quite different from disbursements for the design and development of space technologies. Indeed, their primary benefit (other than ostensibly enhancing the national security of the U.S.) lies in the sustainment of industrial capabilities in the space technology area. Due to such dissimilarities and uncertainties, the overall impact of defense-related expenditures on the activities and capabilities of the U.S. space program is difficult to ascertain and quantify, whether the basis of measurement is funding effectiveness or amount. Regardless of that fact, however, defense-related space funding has unquestionably been significant in the development of U.S. capabilities in space technologies and the sustainment of U.S. space-related industries.

Japan In direct contrast to the U.S. program, the funding for the Japanese space program has historically been very steady, though comparatively small (Table 2)[2]. These characteristics are primarily due to 1) the nature of the Japanese political process, which relies on consensus and political precedent for decision-making, and 2) the strategy of relying on the private sector for long term growth. With regard to the relationship between stability and the funding process, political consensus between relevant government officials must be established before a project concept can become a budgetary reality. This process is inevitably long and arduous, requiring extensive negotiation and compromise (particularly since the planning authority for a given area is often intentionally distributed among many organizations in the interest of stability and consistency). Moreover, the cancellation of a budgetary item entails similar difficulties. As a result, deviations from the budgetary *status quo* are infrequent, both in terms of specific projects and proportional funding levels. Although this approach to stability certainly makes relative funding increases for a given area difficult to obtain, it also has the benefit of making cancellations of an ongoing budgetary item extremely rare.

With regard to program strategies and government funding, the small operating budget for the Japanese program clearly reflects the decision within the government to avoid a large public sector program, at least for the near term. As mentioned previously, the current growth policies are instead based on the assumption of increased private sector activity and low, but steady, government investment. Both the funding level and operational focus of the program reflect a basic conflict in the Japanese view of the potential of space - although space industries are considered a strategic area for technological growth, they are also viewed as high risk in nature, capital intensive on the systems level, and difficult to enter as a late-comer. As stated by Morino and Kodama in an analysis of Japanese space policy, the current policies indicate that space technologies are considered important to technological growth in Japan, yet space industries overall are not necessarily viewed as primary industries for the future[17]. In such scenarios, the Japanese government has typically relied on the private sector to develop its capabilities in relation to exting markets. In any event, the government funding for the program has remained low, while private investment has only begun to emerge in the last five years.

In terms of program management, one desirable effect of these factors has been an increase in stability and efficiency, both for specific projects and the overall budget. Indeed, project cancellations in the program have been virtually nonexistent, as have cost overruns (although this last fact is at least partially due to the equal rarity of increases in governmental funding beyond negotiated levels). Through these practices the system has avoided the inefficiency that generally results from unstable short term funding, while encouraging the responsible estimation of costs. Moreover, as a function of GNP the budgetary allotment for the program has remained essentially constant (though comparatively low) for the last decade (Figure 1). Combined with the practice of maintaining stable support on the project level, this consistent level of overall funding has enabled patience and long term commitment in the development of basic space technologies - characteristics consistent with those in other areas of Japanese industrial development. Five-year funding histories for NASDA and ISAS are presented in Table 2, along with the combined funding for the space-related activities of the Ministry of International Trade and Industry, the Ministry of Transportation, and the Ministry of Posts and Telecommunications.

In combination with the initial scarcity of indigenous technical experience in space-related fields, however, the small operating budgets for the program have also virtually mandated an evolutionary approach to development rather than revolutionary. Indeed,

FY	Dollars(millions)($ 1 = 140 Yen)			
	NASDA	**ISAS**	**Other**	**Total**
1985	$ 635	$ 78.3	$ 90.7	$ 804
1986	$ 648	$ 88.4	$ 102	$ 838
1987	$ 662	$ 84.4	$ 125	$ 871
1988	$ 690	$ 141	$ 182	$ 1,013
1989	$ 763	$ 91.8	$ 152	$ 1,007

Table 2: Japanese Space Program Funding

Japanese space projects have typically involved only incremental advances in technology in concentrated areas, thus entailing relatively low development costs while generating the highest return on investment. When necessary to further reduce development costs and time (or overcome a technical obstacle), the Japanese program has frequently imported "off-the-shelf" technology from other nations for adaptation to project requirements. The N-series of launch vehicles, which utilized U.S. Delta 2914 engine and guidance technology, is an excellent example of this approach. Another example is the Ginga X-ray astronomy satellite, which will be discussed in more detail in a later section regarding space science. Moreover, Japanese space projects have often been significantly smaller in scope than their U.S. equivalents. Through this methodology, the program has avoided not only unnecessary development costs, but also interruptions in the flow of scientific data to the university and research communities. For example, ISAS has successfully launched nineteen scientific satellites in just twenty years. Although the missions have often been conceptually basic, they have provided valuable and continuous data, sometimes during periods of international inactivity within specific scientific fields[12]. The Ginga project is again an excellent case in point, as it provided the only new data in the field of X-ray astronomy during the late 1980s.

However, the licensing agreements for the imported technologies have also imposed restrictions on any Japanese space activities involving those technologies. In particular, commercial space activities and international technology transfers are prohibited by such agreements. Moreover, the reliance on imported technologies to achieve short project turn-around times (and thereby "catch up" to other programs) has perhaps stunted the growth of an indigenous technical base for systems level technology development efforts. In effect, this practice has simply postponed the technical growing pains and expenses associated with the autonomous development of systems level technologies. Although this factor will be discussed in more detail in the technology assessment section, evidence of this problem has already been seen in the development efforts for the H-II launch vehicle. The project has suffered through numerous technical setbacks and unprecedented (for the program) scheduling delays during development. Such facts suggest that the rapid expansion of the program's capabilities through technology importation may be misleading.

Finally, in terms of research, the structure and funding stability of the Japanese program have enabled high levels of consistency and efficiency in the support of space science and basic research. Indeed, the charter of ISAS specifically calls for such research, allowing ISAS to develop a style emphasizing creativity and self-sufficiency and minimizing bureaucracy (very little of the ISAS budget is spent on internal paperwork). For example, ISAS typically operates without a prime contractor for launch vehicles, completing its own designs and inspections while consigning the actual manufacturing to Nissan Motors[12]. Moreover, Japanese corporations have been active in funding research efforts, both in Japan and elsewhere. The same corporations also invest time and money in employee development through educational funding and leaves. To some degree, these initiatives may be related to the emphasis placed on stability and commitment within Japanese society. Regardless of the source, however, this approach allows a longer term view of resource development.

6 Status of Program Initiatives

In prior sections, information and analyses have been provided with respect to the structure, management, funding, and philosophy of the U.S. and Japanese space programs. Each area constitutes a critical portion of the overall comparison of the capabilities of the two programs. To further understand the potential for each program, however, these characteristics must be further evaluated and judged within the context of the objectives and strategies for each program. Therefore, the purpose of this section of the report is to consider the status of the objectives and efforts described previously.

United States As earlier established, the current goals of the U.S. space program revolve around the increased human exploration of space, the support of national security requirements, a rejuvenation of space science and basic research, the development of a higher capacity, more responsive launch system, and the cultivation of private sector involvement in the space program. More generally, the U.S. program is interested in preserving its status as a leading world power in space exploration and development.

In terms of progress in these areas, the program has achieved varying levels of success. For example, the objective of increased exploration is being partially fulfilled through the design and development of the space station Freedom, with the cooperation of Japan, the European Space Agency (ESA), and Canada. However, great uncertainty exists with regard to the usefulness of the current station configuration and the feasibility of supporting the project's operating costs in the current budgetary environment of the U.S. Furthermore, in contrast to the Japanese plans for their portion of the station, U.S. program planners no longer envision the station as a materials processing laboratory, since costs were considered prohibitive. Rather, the onboard experiments are expected to focus on life sciences research and some space science. Other initiatives in the area of human exploration, such as the potential manned mission to Mars and the possible lunar base, have been the subject of much public and political debate, but are nevertheless still in the study phase. Moreover, government funding for the Space Exploration Initiative, as the two missions are collectively known, has been reduced significantly by the U.S. Congress in the last two years. Despite such setbacks, however, manned activities of the scale and nature of the STS and the space station remain a cornerstone of current U.S. space policy and planning.

In terms of the support of national security requirements, the program has greatly increased the scale and range of its activities. This trend can be demonstrated qualitatively through the sharp increase in defense-related space funding as a function of GNP in the mid-1980s. In addition to establishing the policy of maintaining an alternate supply of Expendable Launch Vehicles (ELVs) following the STS Challenger disaster, the DoD has recently given particular attention to the upgrade of satellite systems and technologies in navigation, weather forecasting, and communications. The highly valued systems for military surveillance have also been emphasized and continually upgraded. Recent launch initiatives of critical importance to the overall capabilities of the program include the support of the Advanced Launch System Technology Development Project (ALS), the National Aerospace Plane (NASP), and the new high capacity launch system currently under discussion. Each of these projects entails joint funding from NASA and the DoD. The new launch system is expected to be a derivative of the STS, with the inclusion of propulsion, computer-aided casting, and parts-reduction techniques developed in the ALS project. This vehicle may enable the more efficient launching of space station components (including the international modules), as well as constituting a critical element of a potential Mars mission. Initial funding for the project is expected in this fiscal year. Despite their importance to program capabilities, however, these technologies may not be easily transferable to the private sector in the near future, due to security restrictions and incompatibility. For example, many of the satellite technologies developed by the DoD are driven by mission performance rather than cost. Such factors generally limit the usefulness of these technologies as private sector systems.

With regard to space science, the program has achieved an increased level of funding and established an extraordinarily ambitious agenda for the 1990s. A summary of recently

Project	Estimated Cost (billions)
Galileo	$ 1.3
Hubble Telescope	$ 1.9
AXAF	$ 1.6

Table 3: Total Cost of Selected Space Science Projects

launched and forthcoming missions includes the Magellan and Galileo probes to Venus and Jupiter, respectively, the Hubble Space Telescope, the Mars Observer mission, the Comet Rendezvous/Asteroid Flyby mission (CRAF), the Cassini project, and the three remaining elements of the Great Observatories series (excluding the Hubble). As will be discussed in more detail in the space science section of the technology assessment, each mission represents a significant step forward in space exploration and technical capability. Indeed, the potential of the Great Observatory series, if realized, would simultaneously provide a quantum leap in capability for the visible, ultraviolet, X-ray, gamma ray, and infrared wavelengths of the spectrum. At the same time, however, many of these projects signify the U.S. program's continued focus on revolutionary, large scale projects, often at the expense of stable, continuous activities in a given area. Moreover, the estimated mission costs for these projects are staggering, as illustrated by Table 3. All three estimates are larger than the entire annual budget of the Japanese program. In addition, the U.S. program has suffered from the management complications often associated with such projects, as demonstrated by the Galileo scheduling problems and the well-known deficiencies in the Hubble Space Telescope. Nevertheless, the U.S. should maintain its unparalleled renown in space science through these projects.

In the area of basic engineering research, the U.S. program has initiated various measures to counteract the proportional decline in research funding relative to manned programs. The most notable measure of this nature is the Civilian Space Technology Initiative (CSTI) mentioned in the previous section. The importance of the CSTI resides in its attempt to develop technologies with multiple applications (a building-block approach) rather than relying on the mechanism of discrete missions or projects to automatically generate residual technologies. This approach will be a significant departure from many previous NASA ventures and should prove invaluable in future development efforts. Moreover, it has the potential to be advantageous for the private sector, since these technologies will be more easily transferable and will represent fundamental technical capabilities rather than mission-oriented capabilities. Areas of emphasis in the CSTI include automation and robotics (areas of strength for the Japanese program), propulsion systems, and information processing technologies (critical to the improved management of satellite data).

With respect to private sector involvement, the U.S. program has recently shown signs of rejuvenation in what had become a rather dormant initiative. The preceding period of inactivity was at least partially due to a government tendency to discourage private sector initiatives that competed with federally funded, large scale space projects. An example of this behavior is the early 1980s policy of forcing commercial launches onto the STS, at the expense of the emerging U.S. commercial launch industry. Such activities illustrate the sometimes destructive results of the need to justify public sector investment, in addition to providing an interesting contrast to the policies of the Japanese program. More recently, however, the program has sought an increase in private sector investment to supplement the funding for the program and provide justification for its existence through demonstrating the commercial and competitive value of space technologies. An example of this effort is the ongoing Commercial Experiment Transporter (COMET) project, created to provide launch services and round-trip transportation to space for small payloads. Funding for the program would be comprised of 45 million from NASA and contributions from vehicle providers and payload owners. The payloads for the vehicle will primarily consist of projects developed at NASA's sixteen Centers for the Development of Space, which are consortia of academia and industries oriented to the development of space-related products. Although the funding levels are still low, the Centers and the Comet project both represent truly significant departures from previous NASA policies regarding private sector activities and may signify a legitimate increase of support for such efforts. However, these activities do not represent a step toward privatization of the program. Rather, they seem to point to the supplementation of the public sector funding and activities of the program with some lower level commercial efforts.

Less recent quasi-private initiatives consist of the financially and politically troubled Earth Observation Satellite Corporation (EOSAT) and the management scheme for the Jet Propulsion Laboratory (JPL), which resembles the schemes for other U.S. national laboratories. The responsibilities of EOSAT include the management of the two remote-sensing satellites in the U.S. Landsat system and the sale of Landsat data to commercial users. It was originally intended to be self-sustaining. However, EOSAT has required continuous financial support from the government and has often faced termination due to low political support and interest. Nevertheless, the organization remains one of the two dominant remote sensing corporations in the market, along with SPOT Image of France. In comparison, JPL is significant among NASA field centers in that it is operated and managed by the California Institute of Technology under a NASA contract, as opposed to management through government personnel and systems. The advantages of this system include greater flexibility in terms of procurement and hiring, and greater independence in the use of project funding. However, the funding for the Laboratory (approximately 1.1 billion per year) is still provided through NASA, the DoD, and Department of Energy. Although not commercially oriented, JPL nevertheless represents an attempt to increase the flexibility and efficiency of some portions of NASA's operating structure. The JPL model is also under consideration for other NASA centers, particularly those involving only unmanned activities.

Despite the promise of the COMET program, the somewhat equivocal success of EOSAT, and the quasi-private facility experiment with the JPL, however, the U.S. program remains a public sector program, with ambitions and activities unsuitable for most commercial markets. Nevertheless, these projects and initiatives signal an increase in the effort to supplement such activities with legitimate private sector projects and commercially relevant products. If that trend were to continue, the U.S. program and its related industries would represent a powerful combination of public investment and activities and commercially motivated funding and efforts.

Japan As established earlier in this report, the fundamental goals of the Japanese space program consist of increasing the scope, capabilities, and commercial utility of the program in the short term, and attaining self-sufficiency and a state of privatization in the long term. With regard to increasing system-level technical capabilities, the program has already attained a certain measure of success. For example, smaller payloads can now be reliably launched on the H-I at low launch rates, and scientific and commercial satellites can be produced indigenously if needed. In addition, the program has established successful satellite systems for direct broadcasting and remote sensing, as well as world class capabilities in certain component and subsystems technologies.

As will be discussed in detail in the technology assessment section, however, these satellite and launch capabilities are generally not yet comparable to U.S. (and world) standards of performance and cost on the integrated system level. Moreover, the 1985 and 1990 agreements between the U.S. and Japan (allowing increased competition for public-sector satellite contracts) will further slow the rate of satellite technology development in Japan. This situation will also be exacerbated by the relatively low domestic demand for such technologies and the competition with land-based fiber optics networks. Nevertheless, the commercial potential for satellite technologies and subsystems in the world market, as well as the desire for advanced indigenous capabilities, should provide an impetus for further development. In comparison, the prospects for Japan's future launching capacity are less clear (particularly for larger payloads), since they will ultimately depend on the progress and unproven performance of the H-II launch vehicle. In terms of launch rates, the program's capabilities will also be contingent on the construction of additional launch sites, either on the Japanese mainland or somewhere in the region. Both options would be costly, necessitating a substantial increase in demand from some source. In view of the highly competitive nature of the current world market for launch services, the probability of this occurrence in the near future is somewhat low.

In terms of subsystems and value-added industries, the Japanese program and its related industries have achieved more notable success and seemingly established much greater potential. The strongest evidence for this statement exists in the areas of communication satellite ground stations and component technologies. According to recent MITI figures, Japanese industries (led by NEC in this case) now supply over 60 percent of the ground stations for INTELSAT, as well as many of the satellite antennas and transponders for both INTELSAT satellites and many U.S. manufacturers[7]. Although the ground station exports are the only current case of an export surplus for Japanese space industries, these technology areas are nevertheless classic examples of the familiar Japanese value-added approach to market entry. Such activities are also one of the cornerstones of the Japanese strategies for space commercialization and privatization. However, it should also be noted that the expertise in ground station technologies was acquired during the design and construction of microwave communication networks in Japan in the 1950s. Similarly, Japan's competitive edge in transponder production corresponds to its national strength in the production and design of miniaturized electronics. These facts strongly suggest that future Japanese strengths in space technologies will evolve from and conform to current areas of Japanese technical advantage. In addition, such evidence indicates that Japan will further benefit from these attributes if the current miniaturization trend continues in space-based broadcasting and communications systems. For example, Japanese corporations could be expected to prosper in the markets for Very Small Aperture Terminals (VSATS) and mobile communications systems hardware. An additional area with market potential could be the sale of the indigenous LE-5 cryogenic rocket engine designed for the H-I. U.S. firms such as McDonnell Douglas (the manufacturer of the Delta launch vehicle) have already expressed interest in purchasing the LE-5. Each of these areas has legitimate promise as a value-added industry for Japan.

With regard to the cultivation of markets in the Pacific Rim, Japan's efforts have thus far involved more preparation and diplomacy than actual business or planning. Nevertheless, the region has tremendous potential as a market for communications technologies and systems, particularly in view of the geography of such widespread island nations as Indonesia. Indeed, Indonesia has already established a small scale space program, with an emphasis on satellite systems and a need for launch services. In addition, the region may contain opportunities to construct an additional launch site for less cost. Finally, through contractual packages providing technical assistance, financial aid, and technology infrastructure items (such as ground stations), the Japanese program could induce demand for its launch services and satellites. This demand could be crucial to stimulating growth and development in Japanese space industries and services. Despite the obvious benefits of creating such a market and the apparent government interest in doing so, the activities in this area seem somewhat minimal at the present time.

Perhaps the most critical objective in terms of the future of the program, however, is the goal of stimulating private sector investment and involvement in space activities, with the intent of eventual privatization and self-sustainment. In this respect, the Japanese program has also made some progress, particularly in terms of establishing a private sector infrastructure for the promotion, management, and utilization of space technologies. As already discussed, this infrastructure is primarily composed of foundations and company consortia created for technology management and cost optimization in areas of potential Japanese corporate activity. For example, the Rocket Systems Corporation (RSC) was created to manage the production and sales of the H-II launch vehicle, following the example of Arianespace in Europe. The potential benefits of this arrangement could include an increase in vehicle reliability and a reduction in vehicle cost through the application of mass production techniques and quality control methodologies. In particular, the RSC could reduce vehicle cost through operating on the basis of bulk orders for parts and subsystems.

Although this system remains untested (and may prove successful), the point must again be made that a significant increase in launch vehicle demand and production, followed by an increase in launch site capacity, would be necessary before these benefits could truly be realized. This increase in demand is simply not likely in view of the increasingly competitive market for launch services and the high estimated cost for the H-II (approximately 120 million dollars[19]). In essence, a new market would have to develop in which the Japanese maintained a strong presence for reasons other than cost. The only possibility of such a market is the Pacific Rim, where the RSC would be forced to compete with another local supplier - the highly subsidized Chinese space program. Such subsidies would be politically infeasible for the Japanese program in the current international trade environment. As an added drawback, the Japanese operational experience base of forty launches is simply insufficient to prepare the RSC for a higher launch rate in the near term. Nevertheless, the organization represents an important step toward privatization of the Japanese space program. In addition, it demonstrates the desire of Japanese corporations to position themselves for potential launch services markets of the future. This desire also explains the decision to invest in a sophisticated, modern launch vehicle such as the H-II rather than a "dumb booster" based on older technology.

In the area of materials research and microgravity experimentation (other than on the space station), two organizations have been established, including the non-profit Institute for Unmanned Space Experimentation with free Fliers (USEF) and the Space Technology Center (STC). As stated previously, USEF is expected to manage the experiments for and use of the reusable Space Free Flier, scheduled for launch in the mid-1990s. The Institute was initially organized through the efforts of MITI, which has seemingly identified microgravity research as a priority for the private sector activities of the program. MITI also contributed government funds to the development of the platform itself, along with ISAS and NASDA (for a combined total of approximately 180 million dollars at 140 yen per dollar). However, the funding for the Institute was provided by its thirteen member companies (roughly seven hundred thousand dollars)[17]. USEF clearly represents an effort by the government to transfer the management responsibilities for these experiments to the private sector.

In comparison, the STC was founded in 1986 to conduct research and development activities on electronic material processes in the microgravity environment. Six companies contributed approximately 12.1 million dollars to the consortium, while the Key Technology Center (a government organization supervised by MITI) has provided 28.5 million dollars[17]. The activities of the STC have thus far consisted of several small scale microgravity experiments on small German rockets and will eventually involve participation in German Spacelab projects. Although the funding levels for the STC are somewhat low, the consortium nevertheless illustrates the strategy of establishing a private sector infrastructure for developing and managing space technologies. It also signals the interest of Japanese industries and MITI in microgravity research and materials processing. In their present form, however, the STC (and USEF) are more significant and viable from the standpoint of positioning for future activities than current technological impact.

An additional area of consortia and activity involves the utilization of the space station and its residual technologies. For example, the Japan Manned Space Systems Corporation (MSSC) was recently established to develop and ultimately market the experimental capabilities of the Japanese Experiment Module in the space station. The MSSC will also be responsible for planning and coordinating the use of the module. In terms of privatization strategies, the MSSC signals a major effort to establish private sector organizations for facilitating growth, as well as an attempt to supplement the lean government staffing of the Japanese space program. Despite the significance of this event, however, the consortium is not expected to be self-sustaining and will remain government supported to cover the projected disparities between costs and receipts. In this sense the MSSC is similar to the quasi-private framework for EOSAT of the U.S. program. Furthermore, this organization, like the RSC, may suffer setbacks due to a lack of experience in the operation of space systems.

The other example of a space station-related organization is the non-profit Japanese Space Utilization Promotion Center (JSUP), founded (and co-supervised) by MITI and the Science and Technology Agency to discover and promote potential uses for the space station. Established partly on the basis of contributions from 42 space-related companies, JSUP is also intended to serve as a "consensus forum" for its corporate members - an organization representing the interests of space industries and companies as users. Both the MSSC and JSUP again demonstrate the interest of Japanese companies in the potential benefits of microgravity research and space-based materials processing. In addition, they further signify the strategy of privatizing the infrastructure for managing the development of space technologies and stimulating demand. As has been stated previously, this philosophy is in sharp contrast to the public sector-oriented activities and growth and demand philosophies of the U.S. program.

However, it should be reiterated that USEF, the STC, and JSUP are primarily significant as indicators of current Japanese strategies for developing and utilizing space technologies, rather than true privatization. At their current funding level, these organizations will only be capable of feasibility studies, small scale experimentation, and minimal development work. Such activities can be important to development in its early phases, and without question the organizations reflect the interest of Japanese corporations in the potential long term benefits of microgravity experimentation and spaced-based materials processing. Nevertheless, their actual activities primarily represent an investigation of possibilities and the support of initial studies. Until the level of funding and effort increases dramatically, the results of these activities will likely remain scientifically useful but not commercially viable. Moreover, the willingness of Japanese corporations to actually contribute the needed capital remains unclear. Indeed, according to Tohru Haginoya, the senior executive director of JSUP, Japanese manufacturers seem disinclined overall to invest in comprehensive microgravity research at this time[18]. This view coincides with recent statements by German researchers, who also see the commercial prospects of microgravity research as dim in the near future. Given such trends, the emerging Japanese infrastructure for private sector space activities signals an important step toward privatization (and perhaps ultimately commercialization), but not privatization itself.

7 Technology Assessment

In view of the technically advanced and complex nature of most space technologies, an assessment of the relative technological capabilities of the two programs is an essential component of the analysis. Such an assessment is significant not only because of the relationship between technical capabilities and the attainability of program objectives, but also because the Japanese space program has assigned a high priority to the development of an autonomous national capability in space technology that is comparable to the U.S. level of capability. Indeed, through a combination of focussed development efforts and international licensing agreements, the program has produced a variety of technical successes in space technology fields. Recent accomplishments include the indigenous development of the LE-5 cryogenic rocket engine, the design and production of an inertial guidance system, and the establishment of Japanese capability in three-axis-stabilization techniques for large geosynchronous (GEO) satellites[24]. In addition, the program has shown substantial progress in developing such key technologies as the LE-7 (an advanced cryogenic rocket engine similar to the U.S. Space Shuttle Main Engine, or SSME), and the ETS VI, a two ton experimental communications satellite scheduled for launch on the H-II in 1993. Both of these technologies have potential commercial applications.

Despite the significance of such progress, however, the U.S. has maintained similar or superior capabilities for some time. For example, the U.S. program developed the Centaur, the first cryogenic engine, in 1966 and produced inertial guidance and three-axis-stabilization technologies in the 1960s and 1970s, respectively. The U.S. experience base in these areas is well established. Furthermore, in developing proprietary technologies the Japanese have encountered technical difficulties similar to those experienced years ago by U.S. engineers during the development of the same technologies. An excellent example of this scenario is the repeated occurrence of blade failures during the testing of the impeller shroud and turbine blades in the LE-7 turbopumps[20]. Similar problems were encountered by U.S. engineers during the design of the SSMEs in the mid-1970s. Such evidence indicates that the autonomous development of advanced space technologies entails certain difficulties, even with the knowledge gained from observing and interacting with other programs. Moreover, accomplishments in one area of space technology do not necessarily lead to the attainment of an equal level of capability in other space technology disciplines. Therefore, the comparative analysis of the technical capabilities of the two programs ultimately requires an evaluation of each area of space technology. Since a complete analysis of that nature is not feasible within this format, the assessment shall instead concentrate only on the comparative analysis of selected U.S. and Japanese launch vehicles, communication satellites, and

Rocket	GLOW	Payload Capability	Launch	Cost
	(Tonnes)	to GEO (kg)	Success(%)	(Million $, 1989)
H-I	139.3	550	100	100
Delta 3920(PAM-D)	192.3	730	98.3	50
H-II	256	2000	96 (est)	117 (est)
Titan IV/Centaur	862	4536	100	180 (est)

Table 4: Comparison of the H-I,H-II, Delta 3920 and Titan IV

scientific spacecraft.

Launch Vehicles With regard to launch vehicles, Japan has recently initiated the H-series of launch vehicles to replace the highly successful N-series and improve the launch capabilities of the program. Of this series, the H-I is currently in operation, while the initial launch of the H-II is scheduled for 1993. Since the medium capacity H-I was first launched in 1986, a suitable U.S. vehicle for comparison is the Delta 3920 PAM-D[23], also of medium capacity and first available in 1982. When fully operational, the H-II will provide the program's maximum payload launch capacity. Therefore, an appropriate U.S. expendable vehicle for comparison is the Titan IV, which provides the largest launch capacity in the U.S. fleet of expendable launch vehicles. A summary of launch vehicle characteristics is provided in Table 4[1].

Representing the largest launch vehicle in the current Japanese family of vehicles, the H-I is a three stage launch vehicle utilizing the U.S. Delta MB-3 engine as the first stage, the LE-5 engine as the second stage, and an indigenous solid fuel motor for the third stage. The MB-3 burns a storable propellant, which is a hypergolic fuel (a fuel that ignites upon mixing), while the LE-5 uses the liquid hydrogen/liquid oxygen combination. As is typical for engines using liquid hydrogen/liquid oxygen rather than storable propellants, the 450 second specific impulse of the cryogenic LE-5 is much higher than that of the first stage (258 seconds). Nine solid rocket boosters (SRBs) are included in the design for augmented thrust at liftoff. In addition, the vehicle has a restart capability provided by the LE-5. Vehicular guidance is accomplished with a tuned, stable platform inertial guidance system. Although the LE-5 is cryogenic and regeneratively cooled, it utilizes an open loop cycle and incorporates a gas generator for the turbopumps, rather than using the hydrogen bleed technique[22]. As a result, the reliability of the restart function is lower than otherwise possible.

In comparison, the Delta 3920 PAM-D is a three stage launch vehicle utilizing storable propellant engines for the first and second stages and the spinning, solid fuel PAM-D as the upper stage. The first stage consists of a Rocketdyne RS-27, rather than the less powerful MB-3 used in earlier Deltas and the H-I. In addition, the second stage has a restart capability. As with the H-I, nine SRBs are provided for thrust augmentation. Guidance for the vehicle is accomplished with a strapdown inertial unit.

Both vehicles provide a restart capability and the navigational accuracy of an inertial guidance system, thereby adding versatility and efficiency to mission design and operation. Although the H-I utilizes sophisticated cryogenic technology in the second stage, the first stage consists of the 1960s vintage, less efficient MB-3 engine. Therefore, the H-I does not demonstrate the large reduction in liftoff weight typically associated with cryogenic technology (relative to the Delta). Moreover, the Delta delivers a larger payload to GEO for a lower cost. In terms of reliability, the Delta offers a long and successful operational record, with 188 successful launches out of 200 attempts for various Delta models over a thirty year period, and a 98.3 percent launch success rate for the last fifteen years. Although the H-I has not failed in five launch attempts, its reliability has not yet been statistically established. On the basis of such evidence, the conclusion is that the overall technology level of the two vehicles is comparable, despite the superior sophistication of the LE-5 engine. From the standpoint of performance, however, the Delta is superior, particularly in view of its higher payload capability and significantly lower launch cost. Although the H-I has not been proposed as a commercial launch vehicle, its performance limitations relative to such vehicles as the Delta would lessen its appeal in a competitive market for medium class launch services.

With regard to the H-II and Titan IV comparison, the fully indigenous H-II launch vehicle is a two stage design using the cryogenic LE-7 and LE-5A engines as the first and second stages, respectively. Two large, thrust-vectored SRBs are included in the design for thrust augmentation and control. Since both engines burn the combination of liquid hydrogen/liquid oxygen, the H-II will have a low liftoff mass. In terms of engine technology, the LE-5A is similar to the LE-5, except for the incorporation of a hydrogen bleed cycle to drive the turbopump. As mentioned previously, this method is more reliable during restart. The LE-5A also provides a hydrazine thruster Reaction Control System for control in the coast phase, while employing its gimbal-mounted thrust chambers for control in powered flight. Although currently still under development, the LE-7 engine is a closed cycle, staged-combustion design similar in concept to the SSME. However, the LE-7 utilizes one turbopump for the fuel mixture rather than two, while operating at lower chamber pressures (and therefore generating less thrust). Vehicular guidance will be accomplished with a strap down inertial guidance system incorporating ring laser gyros. Both the LE-7 and the guidance system involve the use of sophisticated technology[21]. Although the first launch of the H-II will not occur until 1993, the initial reliability estimate for the vehicle is 96 percent.

In comparison, the Titan IV can be launched as either a two or three stage launch vehicle, with the first and second stages utilizing storable propellant and the third stage (when applicable) consisting of either the cryogenic Centaur or the Inertial Upper Stage (IUS) developed for the Shuttle. The basic vehicle design includes two large SRBs for thrust augmentation and an inertial guidance system. In addition, the engine thrust chambers are gimbal-mounted for vehicle control. Although neither the first or second stages have a restart capability, the Centaur and IUS upper stages offer mission versatility within the transfer orbit. Despite the inefficiency of the high liftoff weight, the Titan IV is an excellent performer in terms of GEO payload capability and relative launch cost, particularly in the Centaur configuration[1]. The Titan IV/IUS combination is less cost-effective, since the GEO payload capability of the configuration reduces to 2,313 kilograms for only slightly less cost. In 1991, however, the SRBs on the vehicle will be replaced by lightweight, filament-wound graphite composite boosters with a higher performance solid propellant. As a result, the GEO payload capability will increase to 5,670 kilograms in the Centaur configuration, and approximately 2,890 kilograms in the IUS configuration. Although the current launch record of the Titan IV consists of three successful launches out of three attempts, the long term reliability estimate for the vehicle is 95 percent.

Both vehicles provide mission versatility, albeit through different methods. In terms of technology sophistication, the guidance package of the H-II is more advanced and unique, although not necessarily more effective in the performance of the mission. In addition, the cryogenic technology of the LE-5A and LE-7 engines is efficient and advanced, particularly in comparison with the older propulsion technology of the Titan IV first and second stages. Despite the more modern propulsion system in the H-II, however, the technology for vehicular control is comparable for the two vehicles. With respect to further development, both vehicles have future growth potential, although the growth options defined for the H-II are dependent on the eventual success of the LE-7 engine design.

Nevertheless, the performance of the TitanIV/Centaur is substantially superior, particularly with respect to GEO payload capability and related cost. Moreover, the addition of the new SRBS will only increase the differences in capability. On these bases, the conclusion is that the H-II will generally utilize more sophisticated, modern technology than the Titan IV, while providing significantly less payload capability at a higher cost per pound of payload. In exchange, the H-II is expected to provide greater reliability, primarily through the overall reduction of parts and the incorporation of simplifying system design philosophies (such as the use of two stages in the vehicle rather than three). It should also be noted, however, that the H-II provides sufficient launch capacity for the larger commercial satellites in the current generation, while the Titan IV is not expected to be used in a commercial capacity. Therefore, the difference in cost per pound of payload between the vehicles may be less significant to a potential commercial user than the overall launch cost and related payload capability. In that case, the H-II would compare favorably to the Titan IV.

Satellite Technology In view of the recent Super 301 trade negotiations between the U.S. and Japan regarding the Japanese satellite market, a comparative analysis of the satellite technology of the two programs is particularly relevant. Indeed, the central themes in the ongoing satellite controversy have been the recognized superiority of U.S. communications satellite technology, and the apparent efforts within Japan to establish a comparable level of domestic satellite technology through various means (some of which were questioned by the U.S.)[25]. In some respects, such efforts have already produced significant results, as the Japanese have demonstrated operational capabilities in three-axis-stabilization of GEO satellites and xenon-fueled ion propulsion techniques and will launch the two ton experimental satellite ETS VI in 1993. In addition, the Japanese program has placed an operational series of direct broadcasting satellites (BS-2a and b) in orbit and is developing the BS-3 replacement series for launch in late 1990. Although the U.S. established the early technology standard for broadcasting satellites in 1974 with the Applications Technology Satellite VI (the ATS series was initiated by NASA in 1966), the current Japanese efforts are comparable to the present level of U.S. technology.

Nevertheless, the U.S. capabilities in communications satellite technology are still substantially greater, particularly in terms of craft size and the number of transponders (and thus the number of video and voice channels) per craft. Moreover, U.S. satellite technology companies still dominate the world satellite market. For example, the Hughes Corporation of the U.S. supplies nearly half of the world's satellites and satellite systems[1]. A comparison of satellite characteristics is presented in Table 5 for the current CS-3 series developed in Japan, the U.S. Comstar series, and the Intelsat 6 satellite developed by the Hughes Corporation[1]. In view of such evidence, the U.S. clearly maintains a lead in system performance, even in the comparison of the 1976 U.S. technology with the 1988 CS-3.

In recent years, however, the Japanese program has developed a relatively strong technical base in terms of Ka-band transponders. The Ka-band frequency, which is higher than the Ku or the even lower C-band frequencies, has attracted interest within the satellite communications arena because it requires less orbital space for operation and provides more resistance to microwave interference. On the negative side, the Ka-band suffers from

Satellite	Launch date	Mass	Transponders	Voice	Life
		(kg)		Circuits	
US Comstar	1976	811	24 (C/Ku)	18000	7
Intelsat 6	1989	1700	48 (C/Ku)	33000	14
CS-3	1988	550	12 (C/Ka)	6000	7

Table 5: Comparison of US and Japanese Satellites

signal obscurement due to rain attenuation. Despite the potential benefits, the U.S. has just begun the experimental development and application of Ka-band technology with NASA's Advanced Communications Technology Satellite, scheduled for launch on the STS in 1992[26].

In terms of overall system capabilities, however, the issue remains the same - the U.S. maintains a substantial lead in many of the technologies necessary for the design and production of large scale communications satellites. Although the Japanese efforts have been significant, U.S. levels of technology and cost efficiency in production have not yet been attained. Nevertheless, the Japanese have achieved impressive levels of capability in the production of components and the design and implementation of supporting hardware. For example, as has been discussed, Japanese companies provide many of the world's transponders and satellite ground stations. In the near term, these trends in relative satellite technology strengths will most likely persist.

Scientific Spacecraft A comparative evaluation of U.S. and Japanese capabilities in space science is also particularly relevant, since the space science arena has been an area of emphasis for both programs for many years. Moreover, the Japanese program has recently produced a number of accomplishments in space science, including (as already mentioned) a flyby of Halley's Comet in 1986 and the 1990 Muses-A lunar probe. In comparison, however, the U.S. space program has for many years produced notable (and often spectacular) accomplishments in the space science arena. Furthermore, the U.S. program is currently entering a particularly ambitious phase of space science and exploration, with an agenda for the 1990s including interplanetary probes to Mars and Venus and the four observatories in the Great Observatories series. From that perspective, a comparison of the technological capabilities of the two programs is indeed timely. For the purposes of this analysis, the comparison shall be limited to a detailed assessment of a few representative missions for both programs. Conclusions regarding each program's scope and level of technical capability in space science are provided following the assessments of these missions.

In terms of program scope, the space science activities of the Japanese space program have primarily been concentrated in the areas of X-ray astronomy, upper atmospheric studies, and solar physics[2]. Notable exceptions to this general rule include the Halley's Comet and lunar missions mentioned above. As of the present time, no Japanese interplanetary missions have been conducted, although interplanetary missions in space science are listed as a policy objective in the SAC policy document discussed earlier. Of the general areas of concentration, a particularly productive field of study has been that of X-ray astronomy. Beginning with the launch of the Hakucho in 1979, three craft have been developed and launched for X-ray studies, with the most recent being the 1987 Ginga (Astro-C). Development is underway for the Astro-D, scheduled for launch in 1992. The Hakucho was designed for a panoramic survey of X-ray bursts, while the Tenma (Astro-B) was developed to observe X-ray sources in the cores of active galaxies. Neither craft involved particularly unusual or sophisticated technology. Such was also the case for the Ginga, which was based on existing, "off-the-shelf" technology from both domestic and international sources (the large area proportional counter, or LAC, was supplied by Leicester University of the United Kingdom, while the all-sky X-ray monitor and gamma burst monitor were provided by the Los Alamos National Laboratory of the U.S.)[1]. Nevertheless, the timing of the Ginga launch proved to be highly fortuitous, as the supernova SN87A was discovered just after the launch date. Valuable observations of both the supernova and the galactic core were provided by Ginga throughout 1987, filling an important gap in global activity in X-ray astronomy.

Although the Japanese program has conducted many other successful projects in the space science area, the flyby missions to Halley's Comet (the Suisei) and the Moon (the Muses-A) perhaps best exemplify the current level and applications of Japanese technology in space science. With regard to the Halley's mission, the Suisei was designed to study the activity of the comet's hydrogen coma and investigate the bow shock generated by the interaction between the coma and the solar wind. The craft, which was identical to another comet rendezvous craft (the Sakigake) launched seven months earlier, contained a Lyman-alpha imager and a plasma analyzer for these purposes. The Suisei constituted a valuable element of an international effort to study Halley's Comet. In comparison, the Muses-A mission, although certainly not revolutionary by current world standards of space technology, was also significant in that the project represented the only lunar mission conducted by a nation other than the U.S. or Soviet Union. The Muses-A craft was designed to demonstrate orbit control and data transmission capabilities. The mission included the release of a small lunar satellite[27]. Despite the occurrence of certain technical difficulties with the satellite, the mission provided valuable experience and practice for future Japanese endeavors in space science. In addition, both the Suisei and Muses-A missions greatly enhanced the public reputation and visibility of the Japanese space program.

With regard to the space science activities of the U.S. space program, a compact summary such as the one provided for the Japanese program is difficult to develop, primarily because of the wide range of U.S. activities and the impressive number of noteworthy U.S. accomplishments in the space science arena. The range and number of these accomplishments can be partially demonstrated by the fact that the U.S. program actually conducted its first successful lunar flyby in 1964 with the seventh craft of the Ranger series. During the period of time between the Ranger 7 mission and the launch of the comparable Muses-A mission from Japan in 1990, the U.S. program produced an impressive array of accomplishments and "firsts" in space science, including the first soft landings on the Moon and Mars (Surveyor and Viking), a variety of flyby and orbiting missions to Mercury, Venus, Mars, and the outer planets (the Mariner, Pioneer, and Voyager series), and extensive studies in solar physics, X-ray astronomy, and other fields of space science[29]. It should also be noted, however, that most of these achievements occurred prior to 1980, while the decade of the 1980s represented a period of relative inactivity for the U.S. program in space science. Indeed, due to budgetary constraints and a temporary shortage of launch vehicles, no interplanetary missions or major space science projects took place between the two 1978 Pioneer Venus probes and the launch of the Magellan probe in 1989 (also to Venus). In view of these facts and the ambitious U.S. agenda outlined for the 1990s, the assessment of U.S. capabilities in space science shall concentrate on current U.S. projects and plans rather than past accomplishments. As with the analysis of Japanese space science activities, a few representative U.S. projects will be evaluated in the following sections.

Although many space science projects on the current U.S. agenda are worthy of consideration, the Galileo mission to Jupiter and the four observatories in the Great Observatories program are perhaps best representative of the range of current activities in the U.S. program. With regard to the Jupiter mission, the Galileo craft, which was launched in 1989 for a projected arrival at Jupiter in 1995, was designed to 1) release a probe into the Jovian atmosphere for atmospheric studies and 2) establish an orbit around Jupiter for further studies and the initiation of a series of flybys of the major Jovian moons. Due to the insufficient thrust of the Shuttle/IUS combination used to launch the craft, however, the plans for the mission also incorporate a gravity assist technique for the development of the energy necessary to reach Jupiter. This technique entails an initial pass around Venus and two subsequent loops around the Earth, with a two year intermediate pass around the Sun inserted between the two Earth passes. In addition to providing an opportunity to study the dark side of Venus, the gravity assist scheme will allow the craft to study various asteroids and conduct infrared observations of the far side of the Moon[1].

To support such studies, the Galileo craft contains a highly sophisticated diagnostic device known as the Near-Infrared Mapping Spectrometer (NIMS), which is capable of classifying surface mineralogies through the application of the solar reflection spectrum. The NIMS has never been flown before and represents a significant advancement in technology. In addition to the NIMS, the Galileo craft contains a variety of other instruments for measuring and observing characteristics such as thermal surface properties, atmospheric composition, magnetic fields, and plasma. In view of these instruments and the atmospheric probe (which was designed to survive for 75 minutes through pressures up to twenty Earth atmospheres), the Galileo mission does indeed represent an impressive advancement in the level and quality of space science technology[30].

At the same time, however, the Galileo project illustrates the sometimes inefficient management of the U.S. program, as the ambitious project ultimately required twelve years to propose, design, and launch. Moreover, the project involved numerous cost overruns, scheduling delays, and conceptual design changes during that time period (the project was canceled four times, revived five times, and fundamentally redesigned seven times). Although different factors contributed to these difficulties, most were related in some way to the decision to launch the craft on the STS. For example, some delays were due to technical complications and budgetary constraints in the concurrent development of the STS and IUS, while others were a result of the STS downtime and the confusion regarding safety criteria following the 1986 Challenger accident. By the time of launch, the estimated cost of the Galileo project had risen to 1.3 billion dollars, despite the fact that the design of the craft will represent twenty year old technology upon its arrival at Jupiter[31].

With regard to the Great Observatories series, the four observatories in the series consist of the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO), the Advanced X-ray Astrophysics Facility (AXAF), and the Space InfraRed Telescope Facility (SIRTF). When fully operational, the series should be capable of providing simultaneous observations of cosmic sources in infrared, visible, ultraviolet, X-ray, and gamma ray wavelengths. Relative to the overall U.S. space science agenda, the series constitutes the centerpiece of an already ambitious decade[28]. Moreover, each facility involves significant advancements in the level of space science technology. For example, the HST (launched in 1990) is expected to eventually provide a quantum leap in visible wavelength capability relative to the best Earth-based instruments. At full capacity the HST should allow observations of objects 50 times fainter than those presently discernible, with additional improvements of a factor of ten in resolution capability and a factor of seven in observable distance.

In addition to the Optical Telescope Assembly (consisting of a 2.4 meter in diameter primary mirror arranged in the Cassegrain style with a Ritchey-Chretien folded optical system), the HST contains five instruments for scientific studies, including 1) the Faint Object Camera, for the detection of visible and ultraviolet light from objects that are invisible from Earth; 2) the Faint Object Spectrograph, for measuring the chemical composition of faint objects; 3) the High Speed Photometer, for measuring the intensity and variations of light emitted from stellar objects; 4) the High Resolution Spectrograph, intended for studies in the ultraviolet portion of the spectrum; and 5) the Wide Field/Planetary Camera, for both wide field and focussed (narrow field) photography. Each of these instruments involves highly sophisticated technology[32].

In consideration of the complexity and scale of the instrument, some technical difficulties should be expected. Nevertheless, the HST has thus far proven to be a disappointment for the U.S. program, as production flaws were discovered in the primary mirror after launch and some of its expected capabilities have therefore not materialized. Until the scheduled STS repair flight in 1993, certain instruments on the HST will unfortunately continue to perform well below their design expectations. In combination with the 1.9 billion dollar cost of the project (nearly twice the entire 1988 budget of the Japanese space program), the unfortunate HST developments again illustrate the frequent inefficiency of the U.S. space program.

The second observatory in the series is the GRO, originally intended for launch on the STS in April 1990 but postponed due to complications. The purpose of the GRO is to observe and measure sources of gamma rays (the most energetic form of radiation). On the basis of such data, U.S. scientists hope to gain understanding of the high energy processes in quasars, pulsars, supernovas, and radio galaxies. Furthermore, the observatory will facilitate the ongoing studies of the origin of the Universe and the search for antimatter. The GRO contains various instruments for these observations, including a pair of scintillation spectrometers, a highly sensitive Compton telescope, an "energetic" gamma ray telescope for high resolution observations, and a set of eight wide-field detectors (covering the entire celestial sphere) for monitoring and locating bursts and transient sources. Combined in one platform, these instruments constitute one of the largest observatories ever launched. As with the HST, the GRO represents a significant advancement in space science capability and technology[1].

Following the HST and GRO, the third observatory in the series is the AXAF, intended for the measurement and observation of cosmic X-ray sources. The observatory is tentatively scheduled for launch on the STS in 1996. Although the total cost for the program should ultimately be about 1.5 billion dollars, NASA has implemented a phased funding and development program to avoid the cost overruns encountered in the HST program. The AXAF is expected to operate for at least fifteen years, with maintenance and services provided by STS astronauts. The primary instrumentation of the AXAF consists of a 1.2 meter in diameter (ten meter focal length) X-ray telescope and six pairs of nested focusing mirrors. With these instruments, the AXAF will have ten times the spatial resolution and 100 times the sensitivity of its 1970s era predecessor, the HEAO-2[1].

The fourth member of the series is the SIRTF, scheduled for initial finding in 1992 and intended for launch on the STS in the late 1990s. In terms of objectives, the purpose of the SIRTF is to provide detailed observations of faint cosmic sources in infrared wavelengths, thereby continuing the work of its NASA predecessor IRAS and the European Space Agency's ISO. In particular, the SIRTF is expected to expand the analysis of sources detected by IRAS but not evaluated due to insufficient capability. The instrumentation plan for SIRTF includes a 0.85 meter in diameter telescope with detectors and optics cooled below seven degrees Kelvin by liquid helium, as well as an infrared camera, an imaging photometer, and a spectrograph[33]. Maintenance, servicing, and instrument replacement will be accomplished through STS missions. Due to budgetary constraints, initial funding for the SIRTF has been postponed for many years.

On the basis of a detailed assessment of the current space science projects of the U.S. and Japanese space programs, certain conclusions regarding program objectives and capabilities can be drawn. For example, the Japanese program certainly produces "world class" projects and data in the realm of space science, in the sense that the program has contributed greatly to the global scientific community and is capable of participating in meaningful and ambitious space science initiatives. At the same time, however, the Japanese activities in space science reflect the program's emphasis on pragmatic scope and conservative technical objectives. As a result, the Japanese program has not attained a level or range of capabilities in space science technology equal to that of the U.S. program. In return, the Japanese program has maintained greater continuity within its areas of concentration. The development and launch of three X-ray astronomy craft in less than ten years illustrates this approach. Moreover, the program has in general demonstrated greater efficiency and frugality in the management of space science projects.

In comparison, the current activities of the U.S. program demonstrate a continuation of its customary emphasis on revolutionary technologies and achievements. Although these activities should eventually make tremendous contributions to the space science community, an additional result thus far has been the frequent occurrence of the technical and logistical complications often associated with such projects. In addition, the U.S. program is spending a significantly higher amount of money for those projects. For the near term, however, the policy objectives and funding patterns for both programs indicate no significant changes in operational philosophy, although the activities of the Japanese program may gradually increase in scope.

8 Conclusions

Through a combination of international licensing agreements and evolutionary development efforts in concentrated technology areas, the Japanese space program has progressed from the 1970 launch of its first satellite to participation in the current international space station program. In the process, the program has achieved many worthy accomplishments, including the contribution of valuable scientific data to the space science community, the development of a satellite technology base, and the design and production of modern launch vehicles. Although these technologies and systems have often not been comparable to world (or U.S.) standards of performance, capacity, or cost, particularly on the integrated system level, they nevertheless represent a significant step toward the establishment of indigenous capabilities and the attainment of autonomy for certain activities. Both objectives have long been a feature of the Japanese space program. Significantly, these efforts were primarily based on low, yet stable, government support and funding.

On the basis of these accomplishments, Japanese program planners have sought to further increase the capabilities, scope, and commercial utility of the space program. However, these efforts have been constrained by the reluctance of the Japanese government to sustain a larger public sector program and its corresponding levels of funding. As established in this report, the commercial potential of space activities remains unclear. Moreover, as a late-comer to this high risk technology area, the government has seemingly chosen to rely on the private sector for long term growth. Consequently, the goals of the Japanese space program have further evolved to include privatization and self-sufficiency. In both respects, the program and its related industries have made some notable progress. For example, the private sector organizations evaluated in this report constitute an important step toward privatization, as do the efforts to cultivate markets and demand in the Pacific Rim. However, at their present level of funding, activity, and experience, these organizations truly represent just a step in that direction rather than privatization itself. Their activities could more accurately be characterized as an investigation of technological and commercial possibilities with government support, as opposed to legitimate commercial ventures. Nevertheless, the growing private infrastructure should allow corporations to acquire greater operational and management experience with space systems, while positioning them for increased activity should markets for space technologies continue to develop. With respect to the potentially critical markets in the Pacific Rim, the efforts of the program have thus far focussed on attaining visibility as a potential service provider and demonstrating interest and capability. Although the plans for the region have not yet progressed beyond this phase, the region will almost certainly be a focal point for future marketing efforts.

In terms of commercial demand for space technologies and services, the Japanese program and its related industries have achieved their greatest success in the markets for value-added industries, particularly in areas of established Japanese strength. Indeed, such activities seem to represent one of the true cornerstones of current Japanese strategies for benefiting from space-related markets and space technologies. This approach seems quite consistent with the established Japanese government practice of achieving growth in high risk areas through relying on the private sector to tailor its capabilities and efforts to existing markets and strengths. Specific examples of value-added activity outlined in this report include satellite ground stations, transponders, and antennas, as well as the potential sale of the LE-5 rocket engine. In addition, Japanese manufacturers should prosper in the markets for miniaturized broadcasting and communications system components and hardware. These industries represent the true focal point of Japan's private sector activities in space-related markets and technologies. Due to the cost and capacity constraints evaluated in the report, other Japanese technologies, particularly those on the integrated system level, have not yet become commercially viable and remain more oriented to self-reliance and the pursuit of autonomous capability. Moreover, liabilities such as the comparatively low operational experience base of the program and Japan's late entry to many of the systems markets will continue to limit the commercialization efforts for those systems.

Despite the promise of the value-added industries and the long term strategy of privatization, however, the research and system level activities of the Japanese program remain largely reliant on public sector funding and management. Based on the evidence provided by the program's funding history as a function of GNP, this funding is not likely to increase dramatically in the near future. As a result, the program will probably continue to utilize evolutionary development philosophies and participate in international projects when possible. In effect, it will remain a small, public sector-oriented program for the near term, but with a strong value-added industrial sector and a slowly evolving private infrastructure for developing and managing space activities. With regard to privatization strategies, the program will almost certainly continue to rely on private sector activities and the emerging private sector infrastructure for long term growth. Although the level of private sector activity remains low at this time, these activities and organizations nevertheless signify a positioning of Japanese space industries for the space technology arena. In that respect, the Japanese space program will almost certainly continue to emerge as one of the world's leading programs, and will without question be a factor in the future development of space.

With regard to the capabilities and future of the U.S. space program, a dramatic reduction in the capabilities of the program will probably not occur in the near future. Public support for the existence of a space program remains moderately high in spite of the current budgetary dilemmas of the U.S. Moreover, most government officials seem to believe that a space program in some form is justifiable and politically acceptable. Consequently, the probability of draconian reductions in space program funding is relatively low. Nevertheless, in the near term the U.S. program will face increasing public and governmental scrutiny as a result of the poor management and disastrous failures of recent years. In addition, the current fiscal difficulties of the U.S. will almost certainly preclude substantial increases in space program funding.

In view of such factors, the U.S. space program will face a significant and fundamental challenge in the 1990s - the search for an acceptable compromise between its propensity for large scale, revolutionary projects and the funding constraints resulting from the current budgetary and political climate in the U.S. The philosophical alternative is to ignore such fiscal realities in the selection of projects, thereby risking the onset of another period of project delays and cancellations, technical failures, and potential accidents as a result of inconsistencies between program goals and program funding. At the same time, policy makers for the U.S. program may be forced to reconcile the differences between quality science and revolutionary science in the evaluation of potential projects, while recognizing that sustained research and development will be necessary to preserve the capabilities and leadership of the program. Although the U.S. space program will continue to be a leading innovator in the space technology arena, some changes in its operational style and philosophy will probably become necessary. One such change may very likely be the development of a policy to participate more frequently in major international projects, particularly those involving a genuine distribution of funding and managerial responsibilities. In that event, the gradual emergence of Japan as a space-faring nation will indeed be of significance to the U.S. space program, as well as to the other space-faring nations of the world.

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