France and Japan in Space: Niche Market Players, with Evolving Assets and Roles

by

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Abstract

This thesis examines the nature, capabilities, and growth policies of the increasingly successful French and Japanese space programs, with an emphasis on their strategies for competing with the larger U.S. and Soviet programs. Toward that end, information and analyses are first presented with respect to the context and policy environment for the programs, including such issues as program structure, funding patterns, overall program goals, and the more general trends in each nation regarding high technology policies. The U.S. program is used throughout this portion of the research as a base of reference for the characteristics and capabilities of a large public sector program. Following this analysis of general program characteristics and policies, evaluations of the specific technological capabilities and strategies of the two programs are provided in relation to a range of space technology areas.

Through the evidence presented in this work, it is shown that the French and Japanese space programs have achieved notable levels of success through the pursuit of specific niche capabilities and related niche markets, particularly in areas where the U.S. position is weak. Despite this general similarity in overall nature, it is also demonstrated that the niche development strategies of the two programs have been different in both form and outcome, with the Japanese program emphasizing value-added markets and positioning for future applications of specific niche technologies, and the French program focusing on the attempted near term commercialization of integrated systems. The implications of these approaches for longer term growth are also considered, with the eventual conclusion that the programs will remain niche market players for the foreseeable future.

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Contents

List of Tables

Chapter 1

Introduction and Basic Argument

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.

Two particularly notable examples of this trend are the French and Japanese space programs, which have progressed from their initial satellite launches in 1965 and 1970, respectively, to participation in the current international space station Freedom project. Such progress is impressive, particularly given the relatively small amount of governmental funding allotted to both programs. Moreover, in the interim the French government has emerged as the driving force in many of the activities and projects of the thirteen-nation European Space Agency (providing nearly 1/4 of the agency's funding), while the Japanese program has nearly completed the development of an indigenous, high capacity launch vehicle and has successfully developed capabilities in communications and direct broadcasting satellite technologies. Both programs have also recently placed a high priority on the eventual attainment of autonomy in space activities. From the perspective of Japan, with its heavy reliance on trade and high technology resources, the desire for some level of independent capability in a potential high technology growth area is understandable and perhaps even expected. Similarly, as part of established de Gaullian policies for French autonomy and security, France has long sought the capacity for independent development and planning in space-related areas such as weapons delivery systems and technologies for communications, broadcasting, and surveillance satellites.

Despite the apparent agreement within both governments regarding the value of some level of national capability in space-related technologies, however, true political consensus has not yet been established in either country regarding the extent of autonomy or level of capability necessary for attaining national objectives. As in the U.S. and other countries, the overall commercial potential of the space marketplace remains uncertain. Moreover, the expenditures required for systems-level research and development in space technologies continue to rise, generating further uncertainty and increasing the inherent risks involved in space-related investments. As a result, the government funding for both programs has remained low and conservative relative to the funding for the much larger U.S. and Soviet programs.

In view of these historical and current funding policies, the accomplishments of the French and Japanese space programs become all the more notable. Indeed, various aspects of the capabilities, strategies, and policies of the two programs merit further analysis. For example, which policies have these two governments utilized to attain their current status as space powers, and how have these policies differed from those of a larger, more ambitious public sector program such as that of the U.S.? Further, and perhaps more importantly, how do both countries intend to continue competing in an arena still dominated by the activities of the U.S. and Soviet Union, which support significantly larger public sector programs and substantially higher levels of funding? Though inherently difficult to answer within the scope of a Master's thesis, such questions provided the initial impetus and context for this work and were the focus of the research throughout.

A. The Argument

From its inception, the U.S. space program has sought the mantle of leadership in space development and exploration, while maintaining a presence in a wide range of activities and some level of capability in virtually all space-related technologies. Blessed with comparatively high levels of funding and initial public support, the program has long been a source of technical innovation and revolutionary achievements in space activities. Although the goals of the U.S. program have often been poorly articulated, with little justification beyond leadership and discovery, it has nevertheless continued to enjoy a relatively high level of public support for its efforts. At the same time, space technologies and activities have seemingly become associated for many Americans with U.S. prestige and technological ability in general.

In contrast to such broadly defined goals, ambitious charters, and high levels of funding, the French and Japanese programs have historically operated within an environment of severe budgetary and political constraints, gradual development schedules, and more ambivalent public attitudes toward space. Due to such factors, the early development efforts for both programs centered on basic, proven technologies rather than innovation, while growth strategies focused on the eventual penetration of specific space-related markets and technological areas (particularly those in which the U.S. did and/or does not maintain a strong presence). In the process, the two programs have essentially evolved into niche market players, with specialized capabilities and market strengths. In this context, a niche or niche market can be thought of as a particular manifestation or application of space technologies, or the associated market for those technologies. Further development of this concept will be provided in later sections.

Despite this general similarity in end condition and result, however, the paths and motivations for developing these niche capabilities and attributes have actually been quite different. For example, the French program has achieved a measure of success through 1) the multinational framework of the ESA, both for funding and technical assistance; 2) a reliance on a military component of space funding and demand (a characteristic that is nearly unique in Western Europe, with the exception of the United Kingdom, and related to France's desire to be an independent military power); and 3) the cultivation, support, and partial ownership of commercially oriented space organizations such as Arianespace (launch vehicles) and Spot Image Corporation (remote sensing satellites and services). In comparison, the Japanese program has thus far attained an admirable level of progress through 1) a greater reliance on technology importation agreements, primarily with the U.S.; 2) evolutionary development philosophies in highly concentrated areas; and 3) success in certain value-added space industries, particularly those related to existing Japanese technological strengths. These different paths and policies have naturally influenced the niches eventually targeted and occupied by the two programs and will therefore be evaluated as part of the analysis.

With regard to the future direction of the two programs, this work will seek to demonstrate that both nations hope to continue and expand the policies mentioned above, particularly the penetration of space markets and technology areas where the U.S. either has a weak presence or is dormant. In addition, both nations seem to be preserving their focus on basic technology development efforts, with the ostensible intent of positioning themselves for long range applications of those technologies in potential growth areas. However, their space activities and operational practices may be altered drastically by the current objective of establishing autonomous capability in manned spaceflight, which portends higher funding levels and greater concentrations of effort and resources for both programs. To circumvent the constraint of low government funding, both nations (but particularly Japan) will continue to encourage private sector demand and investment, as well as the growth of new markets.

B. The Approach

The primary focus for this work was the evaluation of the funding policies, strategies, and capabilities of the French and Japanese space programs. Nevertheless, the U.S. space program is used throughout the analysis as a base of reference, or standard of measurement, for the policies and capabilities of a larger public sector program. Through such a comparison, the institutional and operational characteristics of the smaller, niche-oriented programs can be more clearly understood and applied to the analysis. In that sense, however, this work is more accurately a three nation study of space program goals and capabilities, particularly in the areas of program structure, funding, and objectives. Although the Soviet program is another example of a larger program (and undeniably a powerful force in the development and exploration of space), its capabilities and characteristics are not included in the study. The reasons for this exclusion consist of 1) the difficulty of acquiring accurate budget and project information for the Soviet program; 2) the nature of the Soviet economy, which is not based on market principles and is therefore less applicable to the economies and related growth strategies of France and Japan; and 3) the fact that the Soviet program is undergoing a period of instability and redefinition due to the economic difficulties and uncertainties within the Soviet Union.

In order to address the questions described above and substantiate the subsequent propositions, it was first necessary to establish a base of information regarding the political origins, early goals and influences, and evolving activities of the French and Japanese space programs. Such issues are critical to an understanding of the current structures and philosophies of the programs, as well as the strategies and capabilities that have evolved for each program over the course of time. Therefore, assessments of each program's origins, evolution, and current structure are provided in the following two sections of this study. The evolution and structure of the U.S. program are also considered in detail, both for the reasons discussed above and because U.S. space activities have profoundly influenced the activities, standards, and goals of other programs. Information sources for these assessments included publicly available studies and histories, as well as interviews with space officials. Although a more detailed analysis of each program's niches will be provided in later sections, the foundations for those analyses are also contained in these sections.

In further relation to the operational environment for the programs, the fourth section of this work contains information and analyses regarding the trends in space funding for the three programs, as well as the general budgetary practices in each nation affecting that funding. Furthermore, an overview of the general policy environment in France and Japan is included for reference, with some consideration of the relations between industry and the state. Such factors clearly influence the nature and efficacy of the development and growth strategies for each program. Finally, trends in program management are considered within the context of these funding patterns, primarily for further understanding of program style. Combined with the earlier information regarding program structure, these issues and factors essentially represent the operational context for the programs. The characteristics of the U.S. program are again provided for comparison.

Following the assessment of program funding patterns, thorough evaluations of French and Japanese program objectives and strategies are provided, along with a review of the current status of those initiatives. The purpose of this section is to provide an understanding of the stated and apparent goals for the programs, the non-technical strategies for growth, and the related strategies for stimulating markets and demand for space products. Assessments of the space-related private sector organizations and activities in France and Japan are also included. These issues can be thought of as the remaining factors defining the policy environment for each program, as well as the more general indicators of strategic orientation and (in some cases) niche position. Specific technologies and development strategies are referenced in this section when appropriate but not evaluated in detail. The objectives of the U.S. program are again summarized briefly for comparison.

On the basis of the general policy and operational information described above, the sixth section of this work addresses the specific niche capabilities of the French and Japanese space programs relative to the overall space arena. The capabilities of the U.S. program are utilized only as a technological standard of measurement or a means to clarify specific French or Japanese development strategies. The current development strategies of the two programs are evaluated on the basis of ongoing projects and these existing capabilities, with particular emphasis on the identification of sectorial niches that have seemingly been targeted. This section is intended to further establish the niche orientations of the two programs and substantiate the central proposition of this work through technical analysis. Although many of these capabilities and technologies are not yet of a commercial nature, some have resulted in clear niche markets for the two programs relative to the overall arena (and the market positions of other programs and organizations). These specific capabilities and markets are further evaluated in the next section on the basis of revenue data, market supply and demand information, and estimates of current market positions.

In the final section, conclusions regarding these analyses are presented, along with evaluations of the implications for the longer term growth of the French and Japanese space programs. The potential impacts of the recent efforts regarding manned spaceflight are also briefly addressed.

Chapter 2

The Evolution of Three Programs

Before the central issues of this research can be addressed, an understanding of the origins, early influences, and subsequent evolution of the French and Japanese space programs must first be acquired. Such factors have undeniably had a profound impact on each program's philosophies, structure, and capabilities, as well as the priority placed upon space activities in both nations. Therefore, assessments of the political origins and evolution of the two programs are provided below, along with a brief summary of the major projects and initiatives occurring in each program's history. A complete review of the origins and early activities of the U.S. program is also included, since its accomplishments and goals have influenced the other programs and often set the standards for space development. More detailed evaluations of current program administration and strategies are provided in later sections.

A. United States

Perhaps the most critical factor in the early activities and development of the U.S. space program was its early association with the evolving superpower conflict between the U.S. and Soviet Union. Indeed, as both nations sought to attain a position of technological and political superiority in the years immediately following World War II, space and space-related technologies became increasingly associated with national security objectives, as well as international prestige. In a more abstract sense, space exploration and development also became linked with national pride, national identity, and technological prowess, particularly for the U.S., which prided itself on its image as a technology pioneer and world leader. The somewhat inevitable result was a "race" to establish supremacy in military space systems (particularly launch vehicles and surveillance satellites) and manned spaceflight technologies. The events in and philosophical impact of this race on the U.S. space program will be considered in the following paragraphs, along with a summary of later U.S. space achievements, capabilities, and milestones.

The Years of Discovery Motivated by the German demonstration of V-2 rocket technology in World War II, the early development efforts for both nations focussed on the technologies for medium range and intercontinental ballistic missiles. Success was attained by the U.S. in 1954, while the Soviet Union successfully completed its first development efforts in 1957. By mid-1955, the U.S. had announced its plans to use such technologies for the launch of an Earth orbiting satellite in the eighteen month time period between July, 1957 and December, 1958 (known as the International Geophysical Year). Designated as the Vanguard project, the plan included the development of a new launch vehicle specifically for the satellite. Despite this apparent head start, however, the U.S. development efforts for the new vehicle suffered repeated setbacks and extended well into 1957. In the meantime, the Soviet Union simply utilized a slightly modified missile design for a satellite launch vehicle, thereby reducing the required development time and shocking the world with the launch of the Sputnik 1 in October of 1957. Galvanized by this event, the U.S. employed a ballistic missile known as the Jupiter C for the launch of its first satellite, the Explorer 1, in January of 1958. From this time forward, the space race was viewed by the American government and public as a fundamental challenge to its identity as a world pioneer and leader.

In response to popular demand for accelerated efforts in space, the Eisenhower administration established the National Aeronautics and Space Administration (NASA) in April of 1958 for the purpose of directing the nation's civilian activities in space. Within days, the Mercury project was approved, with the objective of placing a man in Earth orbit. A few months later, NASA engineers initiated nonrelated studies aimed at a manned space station in low Earth orbit. Despite such ambitious planning, however, the Soviet Union again prevailed, successfully launching the first human into space (for a one-orbit flight) in April of 1961. Although the U.S. program was at that time planning longer Mercury missions for the late 1961 or early 1962 timeframe (the first U.S. manned spaceflight actually occurred in February, 1962), the reaction in the U.S. was swift and pronounced. Less than two months later, the newly elected President of the U.S., John F. Kennedy, issued the now famous challenge to place a man on the Moon within the decade (the Apollo project). The U.S. program achieved a successful manned lunar landing in July of 1969[1].

The Impact of Apollo In terms of technological achievement and national prestige, the Apollo project was an unequivocal success, ultimately resulting in four successful manned lunar landings. Moreover, the project produced the largest launch vehicle ever developed (the Saturn V vehicle) and contributed to a variety of technological spinoffs, including microchip technologies, synthetic fibers, ceramic materials, and biotechnologies. In comparison, the Soviet Union was never able to mount a manned lunar mission and later claimed to have never attempted one (Soviet space officials recently admitted that a manned lunar project was in fact initiated and later cancelled). By the rules of the superpower conflict, the U.S. had won the first chapter of the race to space.

In the process, however, an indelible imprint was left on the structure and operational philosophy of the U.S. space program, as institutional and societal precedents and expectations for such projects and activities were established. Indeed, the Apollo project seemingly became the standard by which the success and worth of U.S. space efforts were judged, while U.S. program planners became increasingly oriented to large scale, ambitious projects (often involving manned flight) and extended operations in general[2]. This trend, which still exists today, can be illustrated by the budget allocations for the Office of Space Flight, which was created for the management of the Mercury, Gemini, and Apollo programs immediately after the 1961 Apollo announcement. From 1965 onward, this division (or its successors) has received a majority of NASA' annual budget, while the corresponding division for instrumented spacecraft (the Office of Space Science and Applications) has typically received less than twenty percent of the budget. The orientation to manned programs and Apollo-scale projects can be further demonstrated through a review of the focal points of NASA's agendas following the Apollo project. A summary of these agendas includes 1) the never realized 1971 plan for a manned mission to Mars, which was coupled with a low Earth orbit space station; 2) the Space Transportation System (STS, also known as the Space Shuttle), which was the compromise post-Apollo agenda ultimately supported by the Nixon administration; 3) the concurrent but vastly simplified Skylab project, which consisted of a manned orbiting laboratory constructed from unused Saturn stages; and 4) the ongoing international space station Freedom project.

Many analysts believe that such projects are essential to the continued funding and preservation of the U.S. space program and support them on that basis. Perhaps this is true, as the Apollo-scale projects have certainly generated revolutionary accomplishments and excitement for the U.S. program. Without question, however, these projects have also had a profound impact on the allocation of U.S. space funding and the usage of space-related resources.

Other Capabilities and Achievements In addition to the more visible and highly funded manned programs, however, the U.S. space program has throughout its existence sustained significant efforts in the areas of solar system research and general space science and applications. Although a complete review of such activities and efforts is beyond the scope and intent of this work, a brief chronological summary nevertheless provides some insight into the range and nature of U.S. activities in these areas. Throughout the 1960s, for example, basic technology development efforts concentrated on satellite and launch vehicle technologies, with particular emphasis on the expendable launch vehicles (ELVs) for the manned programs and the technologies for surveillance, meteorological, and communications satellites. These efforts resulted in the early models of the highly successful Delta, Atlas, and Titan launch vehicles, which were established primarily on the basis of intercontinental ballistic missile designs developed by the U.S. Department of Defense (DoD); the powerful Saturn series mentioned earlier; and the Centaur, the world's first cryogenic rocket engine. Descendents of all but the Saturn series remain in operational use today.

In terms of satellite technologies, efforts in the program's first decade resulted in the world's first operational photoreconnaissance satellite, launched in 1960 by the DoD, and operational, systems-level technologies for direct broadcasting, satellite communications, and meteorological analysis. Furthermore, U.S. technologies and policy efforts in this period formed the basis for what eventually became Intelsat, an international telecommunications consortium (with 115 current member nations) that is currently responsible for virtually all of the international voice data and video traffic transferred by space. Finally, in the area of space science, 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.

Throughout the 1970s, the U.S. space program continued these exemplary (and often unrivaled) 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[5]. Finally, in the search for more cost-effective launch technologies and a new agenda for NASA (as described above), the U.S. program developed the STS, the world's first reusable, manned spacecraft. The STS program gradually became the focal point for NASA's efforts as the program entered the 1980s.

During the 1980s and beyond, the program continued the operation of the STS, while beginning the development of the 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 U.S. support for expendable launch vehicles resulted from the incident. Moreover, the resulting worldwide capacity shortages created an opportunity for other world suppliers of launch vehicles (particularly the French through Arianespace) to establish a strong presence in the world commercial launch market. 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.

B. Japan

A Modest Beginning The Japanese space program formally began in 1955, when a small group of scientists at the University of Tokyo successfully designed and launched a miniature solid propellant 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. It should be noted that prior development work had been prohibited by the Allied Occupation Forces following the end of World War II. Over the course of the next year, the group experimented with a variety of technologies for small rockets, while gradually increasing vehicle size and performance.

On the basis of this work, the group convinced the Nissan Motor Co. in 1956 to participate in subsequent efforts as their primary contractor. In addition, the

Japanese government allocated a modest amount of funding for the development of a larger, two-stage sounding rocket with a twenty kilogram payload capability and fifty kilometer design altitude. This new governmental interest was at least partially due to discussions within the Japanese Science Council regarding possible Japanese participation in the space-related activities of the International Geophysical Year. Later that year, the Science and Technology Agency (STA) was established for the purpose of promoting and guiding the nation's high technology policies in the areas of space technology, nuclear power, and some aspects of the research and development for aviation and biotechnologies. By 1960, the Prime Minister's Office had also established the National Space Activities Council (NSAC) for studying and promoting the possible uses of space, while the STA had created the Space Science and Technology Preparation Office for the same purposes[6].

Despite this initial level of interest and relatively early start, however, the funding for the University's activities remained modest, and development efforts continued to focus primarily on the basic technologies and uses for upper atmospheric sounding rockets. Although construction activities for an orbital launch vehicle facility began in 1962 in the Kagoshima Prefecture (constituting the beginnings of the Kagoshima Space Center), the vehicle itself remained in the planning and early development phases for the next two years. This early reluctance to fund additional or more rapid development efforts was almost certainly related to the resource constraints faced by both the government and industry in rebuilding the nation's war-torn economy. Furthermore, Japanese government policies at that time focussed primarily on "catching up" to the U.S. in certain targeted industries. The list of targeted industries included such areas as heavy machinery, steel, and chemicals, which had proven growth potential and strategic value to production, rather than technology areas involving substantial investment and uncertain commercial possibilities. Although the prestige value of space development activities was unquestionably recognized, the leadership role in these activities was conceded to the more ambitious programs in the U.S. and Soviet Union.

In 1963 and 1964, however, various events combined to produce a change in Japanese perceptions regarding the potential benefits of space activities. Principal among these were the first successful occurrence of television signal transmission between the U.S. and Japan in 1963 (via the U.S. satellite RELAY-1), the 1963 signing and enactment of the interim agreements for Intelsat, and the broadcast of the 1964

Tokyo Olympic games throughout the world via the U.S. communications satellite SYNCOM-3. By mid-1964, the Institute of Space and Aeronautical Science had been established within the University of Tokyo for basic technology development and research, and the National Space Development Center (NSDC) had been organized by the STA for the purpose of studying and promoting the potential benefits of space technologies and activities. From that time forward, the Institute's efforts to develop an orbital launch vehicle proceeded in earnest, resulting in increasingly powerful sounding rockets. Moreover, the overall goal of developing an autonomous capability in launch vehicles and satellites began to emerge in policy discussions, particularly as the U.S. broadened its commercial satellite applications and France and West Germany began the Symphonie project for communications satellites. Such considerations were presented in a report written by the NSDC in 1967 - an event that also eventually served to define the role and territory of the NSDC and its successor, NASDA[6].

Despite these accelerated development efforts and growing bases of governmental support, the Institute suffered repeated setbacks and failures in its efforts to domestically design and build a solid propellant launch vehicle for access to Earth orbit. By 1967 the Institute's capabilities and competence in launch vehicle technologies had been called into question by government observers. In response to growing concern regarding the nation's slow rate of technology development, the Japanese government subsequently established the Space Activities Commission (SAC) in 1968 and the National Space Development Agency (NASDA) in 1969, replacing the NSAC and NSDC, respectively. SAC was intended to proactively coordinate and guide the space development activities of various agencies, while NASDA was oriented to the development of applications technologies. It should be noted that the law creating NASDA expressly forbade the development of military or defense-related technologies. After extensive political debate, the Institute group and NASDA were allowed to remain separate, with differing responsibilities (more discussion on this administrative framework will be provided in the next section), facilities, and launch vehicles. To avoid conflict or overlap with NASDA launch vehicle efforts, however, the Institute's efforts to develop launch vehicles were limited to vehicles with body diameters of 1.4 meters or less. Shortly thereafter, the program imported (through licensing agreements) Delta 2914 launch vehicle technologies from the U.S. to speed the technology development efforts in Japan. In addition, NASDA imported NASA management systems to facilitate the development and operation of large scale space systems. The Institute group proceeded to develop a series of launch vehicles known as the M-series, all demonstrating slight improvements in capability, while NASDA developed the N-series on the basis of the Delta technology. Ironically, the 1970 launch of the technology demonstration satellite Osumi occurred on a solid propellant vehicle developed by the Institute group. With the launch of the Osumi, Japan became the fourth nation in the world to place a satellite in orbit. NASDA's first satellite launch occurred in 1975[8].

An Evolving Power Throughout the 1970s, the two organizations gradually developed a national resource base in basic 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). The HOPE is considered a possible precursor to an eventual manned reusable spacecraft. At the writing of this report, over forty launches have been successfully conducted[7].

C. France

As with the U.S. program, the early technology development efforts of the French space program originated in the drive to develop ballistic missiles for strategic nuclear forces. In particular, at the end of World War II the French government made the decision to establish a national strategic nuclear force that was independent of the forces and command structures of the North Atlantic Treaty Organization (NATO).

Such a force required a national capability in rockets as well, and by 1950 a small liquid propellant rocket (known as the Veronique) based on the German V-2 design had been designed and launched, attaining an altitude of three meters. Various versions of the Veronique were developed over the course of the next twenty years, with steadily increasing performance and improved reliability. After observing U.S. success with the more logistically flexible solid propellant designs, however, French military planners also initiated a project for the development of solid propellant vehicle technologies in 1959. These efforts were further galvanized by the successful testing of the first French atomic bomb in 1960. Nevertheless, proposals for space launchers remained in the conceptual stages throughout most of this time period[10].

Following the successful launches of U.S. and Soviet satellites in 1957 and 1958, with steady launches occurring in both nations thereafter, French officials began to take notice of space technologies and their potential applications. A government committee was formed to evaluate the potential benefits of space development in 1959 (as in Japan), and by mid-1960 designs had been completed for a small, three-stage launch vehicle utilizing indigenous liquid and solid propellant technologies as the first and upper stages, respectively[10]. Encouraged by these events, the French government established the Centre National d'Etudes Spatiales (CNES) in 1962 for conducting the nation's activities in space. Immediately thereafter, development work was initiated on a larger variant of the earlier proposed launch vehicle, known as the Diamant A, with CNES and the defense-related agencies sharing the cost for development (although the military maintained responsibility for managing the early development activities). Three years later, in November of 1965, and only four months behind schedule, the Diamant A launched the technology demonstration satellite Asterix from the Hammaguir Army Center in Algeria. With the launch of the Asterix, France became the third nation to launch an artificial satellite into orbit[3].

The Influence of De Gaulle As these efforts to develop an indigenous launch vehicle proceeded, certain political events transpired that seemingly came to have a dramatic impact on the objectives and activities of the French space program. Principal among these was the 1958 reelection and rise to political dominance of President Charles de Gaulle. From the end of World War II onward (and both during and after his brief stint as head of the provisional French government in 1945 and 1946), de Gaulle had been an outspoken proponent of a strong and independent French state, capable of acting autonomously in matters of the economy or national security.

Indeed, his views almost certainly influenced the drive to establish nuclear independence from NATO following the war. By the time of his reelection, however, such views had evolved into a belief that France could restore its former status as a great power and, more specifically, maintain its independence from the policies and activities of the two superpowers - the U.S. and Soviet Union. Moreover, de Gaulle believed that France could ultimately assume the role of the leader in a "Europe stretching from the Atlantic to the Urals"[12]. Although such views obviously never came to complete fruition, de Gaullian policies nevertheless resulted in the French withdrawal from U.S.-led NATO in 1966, as well as a period of unprecedented economic growth, state-led industrial expansion, and nationalization of industries. With respect to space development, de Gaullian policies and views undoubtably contributed to the French pursuit of an independent capability in launch vehicles and a presence in the technologically prestigious and symbolically important arena of space.

The desire to eventually lead an independent Europe may also have contributed to the French decision to join the seven-nation European Launcher Development Organization (ELDO) and ten-nation European Space Research Organization (ESRO) in 1964. Regardless, the two organizations provided an opportunity to share research and development costs and thereby circumvent the resource constraints existing in France's rebuilding economy. Although the French program continued the independent development efforts for the Diamant vehicle (and ultimately launched ten French satellites and one German satellite with the vehicle and its derivatives), program funding and resources became increasingly involved with the ELDO's principal project, the Europa launch vehicle. The Europa was intended to provide a launch capability of 200 kilograms to geostationary orbit, and was scheduled to launch two Franco-German Symphonie telecommunications satellites in 1973 and 1974. Despite the significance of the project, however, two separate Europa designs failed on launch in 1970 and 1971, leading to a withdrawal of the United Kingdom from the ELDO in late 1970 and a growing debate within the community regarding the project's viability. In retrospect, a primary weakness of the project was a logistically and technically complicated management scheme entailing the funding and production of individual stages by different countries[3]. Significantly, however, France (and CNES) emerged as the most influential member of the ELDO following the withdrawal of the U.K. By this time, French officials had become outspoken proponents of an independent European launch system. It should be noted that in 1964, CNES relocated its launch facility to Kourou, French Guiana, following the granting of Algerian independence. The ELDO shifted its equipment and personnel to the same site in 1966.

Throughout this time period, however, the ESRO and CNES continued to rely on NASA vehicles and services for the launch of many of their scientific satellites and most of their applications satellites. Even the two Symphonie satellites were ultimately launched on Delta launch vehicles from Cape Canaveral. In early arrangements of this nature, the U.S. would provide technical expertise and the launcher in exchange for the experimental results and data from the mission. In later efforts, the ESRO would design the mission and its hardware independently and simply purchase launch services from NASA.

Despite the general success and mutual benefit of these early projects, events in the 1970s conspired to increase the extant French desire for autonomy in space and eventually convince other European leaders of the value of an independent launch capability for large satellites. The initial catalyst for these events was the ESRO decision to develop a communications satellite network known as the European Communications Satellite System. Following the second failure of the Europa in 1971, representatives from the ESRO initiated high level negotiations with U.S. officials regarding the purcase of launch services for such a system. The final U.S. position in the negotiations, as articulated in a letter from Under Secretary of State Alexis Johnson to the Chairman of the ongoing European Space Conference, was that the U.S. would indeed launch the ECS satellites, but only if their coverage area was permanently limited to the European region[13]. The same policy was implemented in a broader sense by the Nixon administration in a 1972 launch policy (pertaining to all nations and organizations). In summary, the policy stated that the U.S. would only launch satellites that had been approved by Intelsat, in keeping with Intelsat's right by charter to offer non-binding recommendations regarding the necessity and/or impact of new satellite systems. In effect, new systems encroaching "unnecessarily" on Intelsat coverage zones could be denied launch services. For many European leaders, and French officials in particular (who originally favored regional satellite systems over Intelsat anyway), the new policy represented an overt attempt on the part of the U.S. government to restrain European initiatives and autonomy in space[13]. In view of NASA's historical focus on space leadership, this interpretation may have been somewhat valid.

In any event, the effect on European space policies and activities was pronounced.

Six months later, at a December, 1972 ministerial meeting of the European Space Conference, the proposal for an independent European launcher was presented by France and accepted. Not surprisingly, French officials were the most ardent supporters of the plan, while offering to provide both the program management for the project and a majority of the required development funding. Both offers were accepted, as CNES provided the management and 63.4 percent of the funding for what eventually became known as the Ariane launch vehicle (further information about this enormously successful vehicle and its role in current French strategies will be provided in later sections). Approximately one year later, at a similar meeting, the ESRO and ELDO were merged into a single agency, initially comprised of eleven nations (now thirteen) and designated the European Space Agency (ESA). Within a few years, France had emerged as the highest contributor to the ESA on a percentage basis, as well as the primary supporter of many the agency's larger scale applications projects[3].

A Summary of Later Accomplishments In addition to the Ariane program, France supported the development of telecommunications, remote sensing and direct broadcasting satellite technologies throughout the 1970s and 80s. Notable examples of these efforts include 1) the Telecom telecommunications system, which provides both civilian and military services (through the Syracuse network); 2) the TDF system for direct broadcasting, which was developed through a cooperative arrangement with German and based on their earlier collaboration on the Symphonie project; and 3) the commercialized Spot system for remote sensing. In the process, the nation has established a significant manufacturing capability in satellite technologies, primarily through the French companies Aerospatiale and Matra. These companies have also served as prime contractors for the Meteosat weather satellite (the first in Europe) and many scientific payloads. Examples of such projects are the ESA's Infrared Space Observatory and Hipparcos astronomy satellite. In cooperation with NASA, the French program has also been active in ocean circulation studies (Topex/Poseidon) and position location by satellite (Argos data collection/location system, Sarsat search and rescue system). The Argos and Sarsat systems will also be discussed in later sections. On the basis of a series of projects throughout this time period, France has also become the world's foremost collaborator with the Soviet space program. Cooperative projects between the two nations range from high energy astronomy and participation in Soviet Mars-related projects, to the agreement allowing French astronauts to conduct research on board the Soviet space station Mir. More recent French activities have included the ongoing development of a photoreconnaissance satellite (Helios), scheduled for launch in 1993[11].

With regard to funding and program initiatives of the late 1980s and early 1990s, the most significant developments are certainly the Ariane 5 launch vehicle, the French-proposed, manned Hermes spaceplane, and the European participation in the U.S.-led international space station Freedom project. French program officials were prominent in the ESA decision process for these three related projects, and the French program will provide nearly 45 percent of the funding for both the Ariane 5 and Hermes. In a continuation of the now established French specialization in launch vehicles, CNES and French corporations will also be the industrial architects for the two vehicle programs. All three projects represent a significant investment in manned spaceflight activities and a departure from the prior European focus on basic technology development and commercial applications. The implications of these initiatives will be addressed in later sections.

Chapter 3

An Overview of Current Program Structure and Facilities

Whether comparing absolute size, the number and nature of operating centers, or even basic administrative divisions, the administrative framework and structure of the three space programs contain fundamental differences. As might be expected, these differences reflect the contrasting origins and histories of the programs (discussed in the preceding section), as well as the differing expectations and perceptions within each nation regarding the appropriate role for a space program. For example, in terms of overall size the U.S. program is substantially larger than the French and Japanese programs, maintaining a higher number of field centers, launch facilities, and employees. This trend certainly reflects the greater emphasis currently placed on space activities in the U.S., as well as the comparatively high level of U.S. space-related funding and the wide range of U.S. space activities. At the same time, however, it demonstrates the impact of the U.S. program's early orientation to large scale projects involving widespread operations and simultaneous technology development efforts in a variety of field centers, since most of the centers in the current, rather unwieldy array of facilities were established during the program's first decade of existence. Although the nature of the activities at some of the centers has changed since that period, the overall composition of facilities and centers has remained generally the same.

Similarly, the structures of the French and Japanese programs reflect their respective origins and current activities. For example, the number and composition of centers in the Japanese program are indicative of the program's early orientation to university research activities and basic, smaller scale technology development efforts. Although recent Japanese space policy statements call for an enlargement of the sphere and scale of activities, the centers currently in existence remain suited to research and smaller scale development projects rather than extended operations. With regard to the French program, which supports roughly twice the employees of the Japanese program, the nature of existing CNES centers demonstrates the program's initial focus on basic technologies and launch vehicles, rather than manned spaceflight and extended operations. With the addition of the Hermes and Columbus manned programs (and the steady increase of annual Ariane launches since 1986), however, the French program has begun to acquire a significant operational element in its activities and structure. It should also be noted that the French program exhibits administrative and organizational differences resulting from unique governmental philosophies regarding the management of space activities in particular and the support of research and development activities in general. More discussion on these aspects of the program will be provided in this and later sections.

Finally, with regard to the role and organizational impacts of military space activities, the three programs have each followed unique policies and established different identities. For example, in the U.S., space development activities were associated with national security objectives from the onset, and defense-related space initiatives were funded according to the needs and expectations of the U.S. as a military superpower. Consequently, the U.S. DoD was intimately involved with the program from its inception. Although French space activities were also directly associated with national security objectives in the beginning, later French activities have focussed primarily on space launch vehicles, space science, and applications satellites with a commercial focus. Defense considerations have been essential to the funding and governmental approval of some French projects, as will be discussed later. Nevertheless, the role of the French defense ministry in space policy-making has typically been that of an important influence (and customer), rather than a nearly autonomous policy-making body such as the U.S. DoD. In contrast, formal space projects for defense-related applications were expressly forbidden by the Japanese government in the legislation creating NASDA. Such remains the case today, as the Japanese program does not formally support any military activities and contains no DoD equivalent or defense-related element 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, with a particular emphasis on launch infrastructure.

A. 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. 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. Furthermore, DoD technology initiatives have frequently been of benefit to NASA, particularly in the areas of satellite technology and launch vehicle development. Although these examples are more of the exception than the 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[4]. 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 therefore approximately 56,900. For clarification, it should also be noted that the contractor personnel working at production firms most likely divide their time between DoD and NASA projects.

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. At the present time, only the Kennedy Space Center provides active launch services for the STS, while 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.

B. Japan

As briefly discussed in the previous section of this work, 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[14]. 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[15]. 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[7]. 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[16]. 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, Atlas, and Titan IV vehicles of the U.S. each operate on the basis of three pads. As will be shown for the French program, operating with only one pad is not necessarily a problem, particularly if the vehicle's annual launch requirements are low or sufficiently diffused, and/or the facility has an efficient operational scheme for assembling and launching the vehicle. For example, the Ariane IV is currently capable of ten launches per year with one pad. Such is not the case for the Tanegashima facility, however, which is restricted by overlapping safety zones and has never conducted more than two launches per year. Furthermore, 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[17]. 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 offset 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.

C. France

Unlike the frameworks in Japan and the U.S., the management of French space activities is primarily concentrated within a single agency - the Centre National d'Etudes Spatiales (CNES). Within this centralized organizational philosophy, the agency is responsible for the management and support of French efforts in space-related research and development, space science, and commercialization, as well as defense-related space projects for the Ministry of Defense (which is represented in these matters by the Delegation generale a l'Armament, or DGA, and the Direction des Engins, or DEN). The actual form of "management" varies somewhat in each case, however, as will be discussed in more detail below. Although CNES originally operated under the regulating authority of the Ministy of Industry and Research (MIR), it has since been placed under the supervision of the reorganized Ministry of Posts, Telecommunications, and Space. In a related development, the agency has since 1988 acted within the policy guidance and coordination of the Delegation Generale a l'Espace (DGE), which is also formally a part of the Ministry[37]. In terms of function and responsibility, the DGE is similar to the SAC of Japan. It should be noted, however, that in contrast to the strictly hierarchical executive structures of NASA and NASDA, CNES is led by a Director General and an eighteen-member board of administration. The board consists of the representatives from seven ministries, five appointed experts in space activities, and six members elected by CNES personnel[3].

As already noted, various aspects of CNES management merit further consideration, particularly in the areas of science, commercialization, and military projects. For example, in the area of space science, CNES is distinct from the other two programs in that it funds and coordinates space science activities but does not maintain internal space science laboratories. Instead, it procures scientific instruments and payloads from a variety of French quasi-private and public research facilities. These facilities range from the astrophysics section of the CEA atomic energy authority to the Lab of Medical Biophysics at Tours, with approximately thirteen institutions providing services on a regular basis. In another unique management approach, CNES has generally supported space privatization and commercialization efforts through the creation of private subsidiaries and Groupements d'Interet Economique (GIE). Eleven subsidiaries and four GIEs currently exist for the purpose of marketing and exploiting French and international space technologies and activities. CNES is typically the main shareholder in these organizations, although a variety of European companies and banks generally provide capital in exchange for shares as well. This approach is definitely distinct from the U.S. method and differs in form and style from the Japanese approach, which will be discussed in more detail later (as will the French). Finally, with regard to the management scheme for military space procurement activities, CNES in actuality serves as the system and spacecraft architect (providing expertise in space systems development and management), while the DGA/DEN team from the Ministry of Defense (MoD) provides executive program management and project coordination[3]. A recent project example of this management arrangement is the Helios surveillance satellite project. For such projects the MoD contributes a substantial amount of the development funding. Although these arrangements have been effective thus far, they may become less desirable to the MoD as military space funding increases in France and the MoD acquires more technical expertise in space systems. In that event, the French MoD may well develop a more autonomous policy presence and procurement system for space activities (such as that exhibited by the U.S. DoD).

In terms of larger installations, the French program currently maintains four field centers, with a variety of data acquisition and tracking stations providing operational support. As will be seen, this number includes the Ariane launch center in Kourou, French Guiana, which is owned by CNES and made available through governmental agreement to ESA and Arianespace, but does not include ESA facilities located in France. Specifically, these facilities consist of the Centre Spatiale d'Evry, oriented to launch vehicle development and support; the Centre Spatiale de Toulouse, containing CNES' engineering and general technology personnel, the Hermes and Manned Flights

Directorate, and the Multimission Center for satellite positioning and control; the Centre de Lancements de Ballons, providing sites for balloon launching and testing; and the Centre Spatiale Guyanais, utilized for Ariane launches by Arianespace[3]. The number of individuals directly employed at these installations is 2,357 (as of the end of 1989), while the private sector provides the services of approximately 8,850 employees (for both CNES and ESA projects). The total number of French space-related employees is therefore 11,207, or approximately 1/5 the number of U.S. civilian space-related employees[37]. As in the earlier U.S. and Japan comparison, this dramatic difference in staffing reflects a much smaller resource base for experienced technical personnel.

With regard to existing launch infrastructure, the French program has established a flexible and highly efficient launch system with unique advantages. In particular, the Ariane launch complex at Kourou is located closer to the equator than any other existing major launch site, thereby providing distinct payload advantages for launches to geostationary orbit. For example, eastward launches from the CSG allow a seventeen percent increase in payload weight relative to Kennedy Space Center launches. Moreover, the coastline of Guiana offers access to equatorial and polar orbital paths without overland flight. In comparison, the U.S. can only safely attain polar orbits from the Vandenberg facility. Although the center has only one pad for the Ariane 4 and one pad planned for the Ariane 5 (currently under construction), the launch system can nevertheless support ten to twelve Ariane launches per year. This comparatively high launch rate is primarily due to an efficient operational philosophy entailing vehicle assembly and stacking away from the pad, with only payload mating procedures occurring on the pad. In comparison, the Vandenberg Titan IV launch system involves on-pad assembly for the entire vehicle, resulting in a rate of two launches per year. This difference is potentially critical, in that the French approach allows for unforeseeable surges in launch requirements, while the Titan system offers no surge capability whatsoever. Such constraints on launch operations can impact both national security and commercial objectives, as dicussed previously for the Japanese program. Finally, in terms of growth potential, the French program has already reviewed locations near Kourou for an additional pad for the successor to the Ariane 5. Although the pad will probably not be necessary for fifteen or twenty years, the availability of land for expansion should enable flexible planning by program officials. Given that flexibility, the program should be able to maintain its current operational advantages and capabilities in launching[3].

Chapter 4

Space Program Funding: Politics, Practices, and Trends

An evaluation of funding practices and budgetary trends is critical to an understanding of the operating environment and context for the three programs, since these factors directly impact program effectiveness, goal-setting, and management. Perhaps more importantly, the trends in funding are significant in that they reflect the different natures and long term strategies of the programs. For example, the U.S. program has traditionally relied on public sector management and demand, while supporting extensive efforts in both the defense and civilian arenas. Given the scale, range, and nature of these activities, the program has historically required a large government budget for funding support. In contrast, the Japanese government has remained cautious in funding what is essentially a high risk, high investment technology area, while apparently hoping to stimulate private sector demand and support for space technologies. This approach to high technology funding is not necessarily uncommon in Japan, as will be discussed below. In a combined version of these two approaches, the French program has historically relied on a mixture of civilian and military funding for space activities, but in small amounts relative to the U.S. program. Like the Japanese program, however, the French program has generally sought to foster private sector demand, activities, and applications. For the niche-oriented French and Japanese programs, the historically low budget allocations also reflect an emphasis on gradual technology development efforts and unmanned spaceflight.

Further evaluations of these characteristics and their impact on program management are provided in the following paragraphs, along with funding histories for the last decade and an overview of the politics of space funding in each country. Although these issues and characteristics (particularly each nation's more general high technology policies) are intrinsically related to the objectives and strategies for growth for each program, this section will address growth strategies (such as private sector involvement) only to the extent that they directly impact or reflect on current space funding practices in each country and the operating context for the space program. A more thorough assessment of each program's strategies for growth will be provided in succeeding sections. As an additional note, greater emphasis is placed in this section on the evaluation of French and Japanese funding policies, with the U.S. program providing a base of reference only. Nevertheless, U.S. funding and management practices will be addressed in some detail, since they provide a distinct and illuminating contrast to the practices of the other two programs.

A. 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, or environmental projects) 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, although an extreme example is the ambitious Galileo project (involving an interplanetary probe sent to Jupiter), which was canceled four times and revived five times in less than twelve years[18]. 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[19][1].

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, which were discussed briefly in the section regarding program evolution, 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. As well documented in other works on this subject, however, this style of operation also encourages the inefficient utilization of existing resources and often creates long waiting periods between similar or complementary projects[21]. Furthermore, these projects are more prone to design and management complications and related cost overruns[22]. In view of these inherent project-related factors, the potential implications of the recent ESA and Japanese initiatives involving manned spaceflight (at different levels) and larger scale projects merit particular consideration (and will be addressed in later sections).

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[19]. 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

[1]Similar effects of budgetary instability (and congressional "micro management") were observed by Gansler in a study of DoD procurement activities and the U.S. defense industry[20].

FY	Constant 1985 Dollars(millions)		
	NASA	**DoD**	**Others**
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 4.1: U.S. Space Program Funding

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[23]. 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[24].

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 enhanced networks for data transfer and communications[25]. For the same time period, the DoD's space-related funding fluctuated slightly[26]. Both funding histories are presented in tabular form in Table 4.1, 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 4-1). On the basis of the GNP data, one can conclude that the priority attached to the civilian portion of the U.S. space program during that time period did not change relative to the national hierarchy of priorities. In comparison, the priority for defense-related space funding

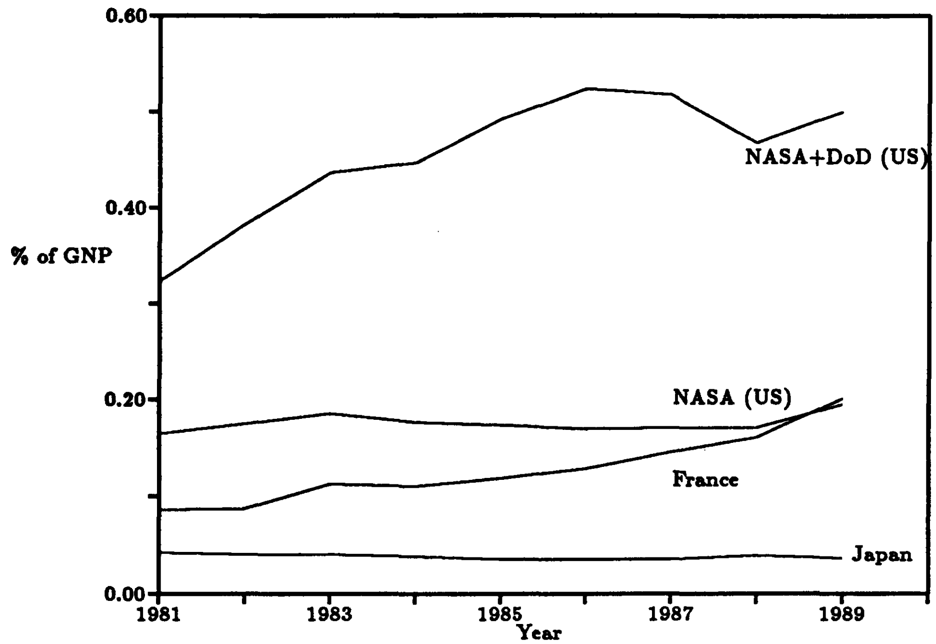

Figure 4-1: Space Program Funding as a Percentage of GNP

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 4.1 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[26]. 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.

B. Japan

In direct contrast to the U.S. program, the funding for the Japanese space program has historically been very steady, though comparatively low (Table 4.2)[7]. These characteristics are primarily due to 1) the nature of the Japanese political process, which relies on consensus and political precedent for decision-making within an enduring and stable political system; and 2) a policy of avoiding a large public sector program, at least for the near term. With regard to the relationship between funding stability and the political 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. Moreover, in a system seemingly designed for the preservation of stability and consistency, such negotiations are almost certainly intensified and perhaps even institutionalized by the intentional distribution of planning authority for a given area among many different organizations[27]. For the specific case of the space program, this approach is reflected not only in the separation of space science and applications efforts into the separate organizations of ISAS and NASDA, but also in the division of supporting ministry authority between the STA, the Ministry of Posts and Telecommunications, the Ministry of Transport, and the Ministry of Education. The Ministry of International Trade and Industry also influences decisions and projects for both organizations.

Furthermore, these negotiations and consensus-building activities take place within a policy framework involving a long dominant political party, the LDP, and an enduring and stable bureaucracy staffed by professional elites. Although membership in the LDP is not a prerequisite for a bureaucratic career, upper level bureaucrats inevitably become associated with (or at least heavily influenced by) the conservative politics and philosophies of the LDP. Consequently, a high degree of commonality often exists between general bureaucratic initiatives and LDP aims and overall philosophies. Moreover, retired bureaucrats often find second careers in private or public corporations related to the area in which they previously worked. This trend leads to commonality and political linkages between the government and significant industrial interest groups as well, and further reinforces a stable political environment allowing for long term planning, budgetary stability, and coherent action[28]. As a result of this stable yet compartmentalized system and the institutional emphasis on consensus, deviations from the budgetary *status quo* are infrequent (or at least gradual), 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 (as will be discussed below with respect to the space program).

With regard to program funding policies, the small operating budget for the Japanese program clearly reflects the government decision 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 hope of increased private sector activity and a plan calling for low, but steady, government investment for basic infrastructure items. The specific methods for stimulating this activity and demand will be discussed in the following section. However, 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 evidently 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 relevant and even important to technological growth in Japan, but space industries overall are not necessarily viewed as primary industries for the future[30]. In such scenarios, the Japanese government has typically relied on the private sector to develop its capabilities in relation to existing (and potential) markets, with the government acting as a "guarantor" and catalyst for investment. As will be seen later, the government also frequently supports the creation of quasi-private research consortia in such areas[31].

Although some groups (represented by such notable spokesmen as Ryuji Kuroda, the General Manager of NEC) have campaigned for a combined public and private sector program supported by higher government investment, the government funding for the program has remained low, while private investment has only begun to

FY	Dollars(millions)($ 1 = 140 Yen)			
	NASDA	ISAS	Others	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	$ 149	$ 195	$ 1,107

Table 4.2: Japanese Space Program Funding

emerge (on a very modest level) in the last five to ten years[2]. The combination of limited funding resources and the technological (rather than industrial) focus mentioned above has fundamentally influenced the niche approach and nature of the program, as will be discussed below and in the technology section.

In terms of space 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 can often result 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 4-1). 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 4.2, 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 (as well as niche) approach to development rather than revolutionary. Indeed, Japanese space projects have typically involved only in-

[2]Recent government reports indicate that private investment in the space program has averaged roughly 100 million dollars annually (or approximately 10 % of total government funding per year) for the last five years[9, 33].

cremental 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 incorporated instruments from the U.S. and U.K. (other examples of this approach will be identified and discussed in the technology section). Furthermore, 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[8]. 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. Such project trends are in sharp contrast to the trends of the larger, megaproject-oriented U.S. program.

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 technologies 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[8]. Moreover, Japanese corporations have been active in funding academic research, 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.

C. France

As in the case of the Japanese program, the funding for the French space program has historically been low in absolute terms relative to the U.S. program. This trend is illustrated by Table 4.3, which shows French funding support for national (CNES), ESA, and military space projects (the MoD funding has been combined with the rather low amounts for other organizations)[37][38]. In contrast to Japanese space funding trends, however, the funding for French space activities has increased regularly as a function of Gross Domestic Product (GDP), particularly throughout the last decade (Figure 4-1). These seemingly incongruous trends are due to certain interrelated factors and characteristics, including 1) the apparent strategy (and partial necessity) of relying on cooperative international efforts and private sector involvement for long term growth, rather than relying exclusively on public sector demand; 2) a fundamental association of national space activities with national security objectives and international prestige; and 3) the increasingly ambitious ESA programs initiated and frequently led by France throughout the 1980s. As will be seen in this and later sections, however, the impact of these factors on the status and form of French space funding and activities is sometimes less than obvious.

With regard to the comparatively low amount of space funding, the French program has long operated within the resource constraints of a nation with less than 1/4 the population and approximately 1/4 the GNP of the United States. As discussed previously, these factors have inevitably limited the amount of French governmental support (relative to the U.S. scale of activities) for what is essentially a high risk

	Dollars(millions)($ 1 = 6.3 FF)			
FY	ESA	CNES	MoD and Others	Total
1985	$ 267	$ 504	$ 110	$ 881
1986	$ 342	$ 561	$ 123	$ 1,026
1987	$ 339	$ 600	$ 283	$ 1,222
1988	$ 418	$ 676	$ 343	$ 1,437
1989	$ 509	$ 774	$ 643	$ 1,926

Table 4.3: French Space Program Funding

investment area with uncertain returns. At the same time, however, space activities in France have long been associated with French military autonomy and prestige. Moreover, this association has in all likelihood been magnified by the highly visible space activities of the U.S. and Soviet Union, particularly given the still prevalent de Gaullian objectives of establishing French independence from the superpowers and leadership in Europe. From a political standpoint, therefore, the result has been a package of seemingly incompatible objectives and constraints.

In one response to this dilemma, the French government has actively supported and indeed been the primary driver of the ESA and its cooperative space activities, as described earlier. Such support has typically come on the basis of nearly forty percent of CNES' annual budget, and even higher levels of participation will be required as major ESA initiatives of recent years come to fruition. In addition to the benefits of distributing the risk and increasing the potential gains of a given amount of funding (for France as well as other ESA members), however, the ESA has provided a European forum for France to display leadership and technological prowess. The success of ESA efforts in the last decade is understandably a source of some pride for France and its government.

In addition to the funding strategy of participating in the ESA, the French program has attempted to both optimize and augment the level of available funding by supporting private sector involvement in space activities (as will be demonstrated in the following section). In this respect the French policies for funding and growth bear at least external resemblance to the privatization strategies of the Japanese program. In contrast to the essentially noninterventionary Japanese strategies of supporting the establishment of consortia for researching and promoting space technologies (without centralized control of consortia activities), however, the French program has provided the initial capital and central coordination for the creation of the previously mentioned GIEs and space-related corporations in return for controlling shares in those organizations. Since such organizations were created for the express purpose of cultivating demand and commercial markets for space technologies, the French program and government are essentially maintaining a centralized, guiding, and more interventionary presence in the commercialization of space activities.

This practice is consistent with more general French policies regarding the state's role in markets and industrial development. Indeed, the industrial policies of the French government have long included such interventionary practices as the creation of national champions in targeted industries, the subsidation of particular industrial projects through lower interest rates and investment credits, protected and/or guaranteed markets, and a strong state role in market negotiations between corporations (and the related reduction of "unnecessary", or destructive, competition)[36]. It should in fairness be noted that government guidance and financial support for the development activities of a non-commercially viable, yet important technology area are a common practice throughout the world. This is certainly true for all international space programs (as well as most military technologies). The difference in the French approach lies in the more interactive and centralized presence of the state in transferring such technologies to the marketplace. This remains true even in comparison to the Japanese system (and its frequently discussed MITI), which certainly incorporates state-level guidance and coordination for certain development activities, but through a mechanism of institutionalized negotiation between industry and the state rather than truly centralized state planning and influence[29].

The entrepreneurial and interventionary tradition of the French government has certainly been facilitated by the existence of a stable bureaucracy - composed of elites - that maintains extensive ties with both the national parliament and French industry[34]. Indeed, the French system for civil service recruitment and selection involves training in elite schools for administration and engineering, known as the Grandes Ecoles, followed by acceptance into one of the Grands Corps (which divide the government into what are essentially guilds). Members of the Corps can occupy both administrative and legislative positions in the government simultaneously (a particularly unusual practice), and they frequently assume upper level industrial positions upon retirement. The result is a particularly cohesive, powerful network of individuals in the administrative, legislative, and business sectors of the society, with similar backgrounds and often similar views about the role and needs of the state. As stated in a pamphlet produced for the Conference des Grandes Ecoles (and recorded by Suleiman[35]):

"Among the one hundred largest French firms, two-thirds are headed by graduates of the grandes ecoles. An even larger proportion are found at the highest levels of government administration. Finally, the grandes ecoles provide France with most of its engineers, managers, researchers in industry, and administrators. This means that whoever has occasion to come into contact with the decision-makers in the private or public sectors in France inevitably finds himself face to face with men whose mind and manners and attitudes have been profoundly marked by a training which, despite any differences in specialization, manifests a number of common traits."

This characteristic of the French state and society certainly reinforces the tendency toward centralization and intervention, as well as the intimate ties between bank and credit institutions, industry, and government in France. It also lends itself to a more uniform, concerted set of policies with regard to a given area. The effectiveness and impact of this approach and system with respect to space technologies and activities will be evaluated in the program strategies sections, along with a more detailed assessment of the specific activities, status, and character of the GIEs and space-related corporations.

With regard to the increase in French space funding as a percentage of GDP, various factors have contributed to an apparent increase in priority for space activities in France. In particular, upon review of the French space-related budget and project trends for the last decade, one observes a significant increase in the proportion of French expenditures for national civilian activities, and a corresponding increase in proportional expenditures for defense-related activities(Table 4-3). Although French support for ESA projects doubled during this time period, the expenditures for national civilian and military activities increased at an even higher rate. These trends reflect an increased French orientation to independent projects, bilateral projects with the Soviet Union and U.S., and military applications. Specific examples of projects in these areas will be provided in the following section of this work. At the same time, however, France is a key player in the extremely ambitious manned ESA programs initiated in 1987, which include the Ariane 5 launch vehicle, the Hermes manned spaceplane, and the Columbus portion of the international space station Freedom. Such projects have contributed to the increase in ESA contributions from France. The overall result has been a marked increase in French space funding as a percentage of GDP. Indeed, the 1989 value of .20 % is second only to the U.S. (and possibly the Soviet Union, though its GNP is unknown and virtually uncalculable) among the world's space programs. In comparison, the other European nations involved in the ESA allocate an average of approximately .05 % of GNP to space activities. At a minimum, this level of relative funding signals the commitment of the French government to space activities, and its continued emergence as a space power, both within and outside of the ESA.

Finally, in terms of program management, the seeming commonality of purpose in the French government regarding space, the membership in the ESA, and the increased priority for space funding have all had a stabilizing impact on the management of space-related funds and projects. For example, though the French program does not have a record of project stability comparable to the Japanese program, project cancellations and restructurings are nevertheless rare compared to the instability existing in the U.S. program. This is at least partially due to the French preference for multiyear funding plans that include both project development and production (as compared to the annual budgetary battles related to the U.S. program). As with Japan, this characteristic is evidently related to the relative stability of the political environment and the commonality of purpose that can result from the networks of bureaucrats, politicians, and industrial leaders involved in government policy decisions. The funding and project stability is also related to France's membership in the ESA, since project agreements in the ESA framework generally have the legal status of an international treaty for participating nations, therefore superceding national laws and regulations[13]. For example, this is the case for the European signatories in the space station intergovernmental agreement, whereas the U.S. agreement for the same project is in essence only an executive agreement. Moreover, the Columbus program declaration stipulates that participating nations must provide funding through project completion (although the program does exist in two stages, with possible refusal following the first stage). This type of budgetary commitment for space projects simply does not exist in the U.S. and exists only in a more indirect form in Japan. As with the Japanese program, this stability on the project level (combined with an increasing level of governmental support) has enabled patience and long term commitment in the development of basic space technologies.

Chapter 5

Program Objectives and Strategies

An assessment of general program objectives and strategies for growth is essential to the analysis of the nature, orientation, and longer term direction of the French and Japanese space programs. Indeed, these factors directly reflect national priorities and philosophies regarding space development, and often define (either directly or indirectly) the institutional mechanisms for supporting space activities and pursuing space goals. Along with the funding practices and national policy trends defined in the previous section, such characteristics basically compose the policy framework from which specific space-related capabilities and technology development strategies emerge.

Although some of the goals and strategies that will be discussed in this section relate directly to potential market niches for the programs, others are associated with more fundamental national objectives such as autonomy in space or the privatization of space efforts. Nevertheless, such policy characteristics will be considered in detail, since they impact the allocation of available space-related resources and therefore often determine (or at least influence) the niche sectors that can be realistically pursued. For example, the French goals of military autonomy and (eventually) launch autonomy led to the development of the Ariane, which has in turn led to a French specialization in launch vehicles within both the ESA and the overall arena. Similarly, in the case of the Japanese program, the less interventionary privatization policies described earlier (combined with the low level of public sector demand) have certainly contributed to the current private sector focus on value-added niche markets, which the private sector can effectively enter. These relationships will be addressed in more detail both below and in later sections. In any event, given the obvious relationship between some general objectives (such as autonomy) and certain niche capabilities, a thorough review of formally stated and observed program goals and strategies is warranted for increased understanding of the nature of the programs. Particular attention will be given to the areas of 1) non-technical strategies for growth; 2) the related strategies for stimulating markets and demand for space products; and 3) the space-related private sector organizations in both nations. These issues and factors are particularly relevant given the low government budgets of the programs.

However, specific niche capabilities will be addressed herein only when appropriate or necessary for clarity, since more detailed analyses will be provided in later sections. Similarly, specific technology development strategies will only be considered in this section when applicable to overall objectives. As in the prior section, a brief summary of U.S. objectives and strategies will first be provided for comparison.

A. United States

As described in the program evolution section, the initial goals and activities of the U.S. space program were fundamentally influenced by the evolving superpower conflict with the Soviet Union, as well as national pride and prestige. In particular, an orientation to national security objectives, manned spaceflight, and revolutionary projects overall was established during the program's early years. Although much has transpired since the successful Apollo project and the public enthusiasm existing at that time, 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 and goals. 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 increased 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 (as discussed earlier). 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, serving 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. Indeed, one of the few current examples of a U.S. private sector initiative is the Earth Observation Satellite Corporation (Eosat), created to manage the U.S. Landsat system and market Landsat data to commercial users. Originally intended to be self-sustaining, Eosat has instead required continuous financial support from the government and often faced termination due to low political support and interest. With the exception of Eosat, corporate 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.

B. 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. As mentioned previously, such objectives in a potentially strategic growth area are easily fathomed for Japan, particularly in view of its dependence on high technology resources and trade. As also established previously, however, true consensus has not yet been established among space-related interest groups with regard to the appropriate process or framework for the planned development. Moreover, debate continues in Japan (as in all nations) regarding the ultimate commercial potential of space activities, or the specific markets that will eventually emerge. In response to such uncertainties, the Japanese government has thus far provided low, yet stable funding for the attainment of fundamental capabilities, while encouraging private sector investment and involvement for the sustainment of long term growth. Conservative in nature, this philosophy could perhaps best be characterized as one of positioning Japanese industry for long term possibilities, without "undue" short term investment, commitment, or risk. At the same time, Japan has been able to maintain a presence in a highly visible technology arena. Within the resulting budgetary limitations, however, Japanese program planners have been compelled to rely on a combination of evolutionary development philosophies and the importation of technologies through licensing agreements.

Nevertheless, in the mid-1980s an evolving combination of factors served to enhance the commercial appeal and visibility of space technologies and ultimately increase the emphasis on space development activities within Japan (as signalled by the release of two SAC policy statements in 1987 and 1989). Firstly, certain industries and markets for space technologies, such as those for communications satellites and satellite systems, matured to levels sufficient for self-support and profitable entry. Furthermore, other arenas, such as the areas of materials research and remote sensing, began 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 further visibility and prestige in the space 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[39].

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 significant increase in related government funding. That is to say, the underlying goals for the program are self-sufficiency and privatization, with an associated reduction of government responsibility[40]. From this perspective, the rationale for the stated policy objectives can be demonstrated in various ways. To begin with, the capacity for autonomous development and action 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 indigenous capabilities necessary for autonomy 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. Secondly, indigenous capabilities should increase the appeal and credibility of the Japanese space program as a partner in international space ventures. Participation in such projects would enable Japanese engineers and scientists to acquire further knowledge and experience in advanced space technologies for a fraction of the cost of truly autonomous development[1]. Finally, indigenous technologies and capabilities in "critical" technology areas should allow greater access to the value-added industries and niche markets for space subsystems in those areas (the specific technological niches and strategies of the Japanese program will be addressed in the following section). 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 overall strategic objective mentioned above - 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

[1] Such possibilities played a direct role in the Japanese decision to participate in the international space station Freedom project[39, 40].

organizations to develop and market commercially-relevant space technologies and capabilities, and 2) the encouragement of markets and demand for these products and services[41].

In terms of creating private organizations for managing space technologies, the program has already made some notable progress, as will be discussed below. In 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.

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 niche markets in the Pacific Rim. Although further detail will again be provided below, 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 other space 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)[43]. 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 per functional area relative to comparable organizations such as the World Bank. Moreover, many of the experts in the agency are not fluent in other languages[42]. Consequently, the effectiveness of the agency in facilitating space program growth in other countries may be limited for the near future.

Status of Japanese Initiatives

In terms of the objective of improving 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 demonstrated below and in the following section, subsystem technologies represent a market "niche" that Japanese firms have proven well suited for. Finally, the program is supporting the ongoing development of the "state-of-the-art" H-II launch vehicle.

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 (as discussed earlier). 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 low.

In terms of subsystems and value-added industries, however, 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[32]. Although the ground station exports are currently the only 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. Further analysis of these specific market strengths, technical niches (both existing and potential), and technological strategies will be provided in the following two sections of this work.

With regard to the cultivation of markets in the Pacific Rim, Japanese efforts have thus far involved more preparation and advance diplomacy than actual business or planning. Government and private sector study groups have evaluated the prospects for a regional satellite system and/or a Pacific mobile communications network and presented such studies at Pacific telecommunications conferences[44]. Certain Japanese telecommunications development efforts have also involved technologies that may prove particularly suitable for the needs of the region, as will be discussed in detail in the following section. Beyond such exploratory efforts, however, little action has been taken by either sector. 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. Such 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 minimal at the present time. This fact would seem to indicate a lack of private sector confidence in the near term viability of the market for Japanese space-related products.

These issues are relevant to what is seemingly the critical overall objective for the future of the program (particularly given the low level of government funding) - the goal of stimulating private sector investment and involvement in space activities, with the intent of eventual privatization and self-sustainment. Despite some of the market and competitiveness issues discussed above, the Japanese program has made notable progress 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 110 million dollars[50]). 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 again the Pacific Rim, where the RSC would be forced to compete with another local supplier - the highly subsidized Chinese space program - as well as U.S. launch firms and Arianespace. Similar subsidies would be politically unfeasible for the Japanese program in the current international trade environment. As an added drawback, the Japanese operational experience base of forty launches (including the science missions of ISAS) 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 may also explain the decision to invest in a sophisticated, modern launch vehicle such as the H-II rather than a "dumb booster" based on older technology (as will be discussed in detail in the following section).

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)[30]. 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. Specific attention will be given to the processing of semiconducter materials such as gallium arsenide. Six companies contributed approximately 12.1 million dollars to the consortium, while the Key Technology Center (a government organization supervised by MITI and responsible for supporting consortia research and development projects) has provided 28.5 million dollars[30]. 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 the microgravity experimentation and space-based materials processing niches. 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 necessary long term 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[45]. 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.

C. France

With national aspirations often surpassing available state resources, France has long sought a balance between the twin goals of independence from the superpowers and leadership in Europe and the constraints of a comparatively low GNP and population. In this regard it has on different occasions both benefitted and suffered from (depending on the circumstances) a political economy involving a relatively centralized power structure and state intervention in the market[36]. Nevertheless, given the system's capacity for commonality and concerted action, the state has often been successful in crafting strategies capable of achieving a balance between national objectives and available resources. With respect to the specific case of the space program, the result of such efforts has thus far been a truly unique blend of 1) an ongoing drive for national autonomy (within certain boundaries, as will be discussed below); 2) a strong national funding commitment, in the form of high proportional funding levels; 3) consistent support for cooperative ventures (both bilateral and within the ESA); 4) a prioritization of commercial objectives and activities; and 5) a simultaneous (and often mutually reinforcing) emphasis on defense-related objectives and activities. In contrast to other small and medium sized space programs, including that of Japan, the commercial policies of the French program have also evidently benefitted from a strong governmental belief in the future marketability and strategic value of space activities and technologies.

As might be expected, the continuation and expansion of these activities and initiatives constitute the core of current French program objectives and strategies. In particular, the pursuit of autonomy in space, which provided the impetus (indirectly) for the early French launch vehicle efforts in the 1950s and the Ariane launch vehicle in the 1970s, continues to be a primary focal point for the program's current efforts.

In a departure from prior French and European policies, however, the goal of autonomous capability has now expanded to include manned spaceflight, as exhibited by the French-led Hermes project and the Columbus segment of the space station Freedom. The implications of this policy change will be considered in a later section, though it should be noted herein that the Hermes and Columbus projects have already had a dramatic impact on ESA (and French) funding requirements and resource allocations. As in the case of the Japanese program, the objective of autonomy also includes the establishment of indigenous capabilities in satellite technologies and space science. Unlike the Japanese program, however, the French program is generally not constrained by licensing agreements from other nations in critical technology areas. Using the multinational framework of the ESA and its predecessors for funding assistance and risk dilution, France has instead been able to develop a technology base through a mixture of shared and independent resources and institutions. Such methods are in many ways a natural extension of the decisions and philosophies implemented in 1973 following the launch vehicle dispute with the U.S. and the creation of the ESA. Further details and analyses of the current levels of French capability in space technologies will be provided below and in the technology section.

With regard to the current and future role of the ESA in French space efforts, French program objectives and policies continue to demonstrate significant support for ESA projects and goals, as illustrated by the funding trends of the preceding section. In this respect, France has truly chosen an intriguing and perhaps more pragmatic definition of national autonomy. As discussed previously and stated in other works on this subject, however, this strategy may indeed be the only way France *can* support projects of the scale and complexity of the Hermes spaceplane. Furthermore, the ESA framework has proven critical in the development of basic French capabilities, many of which are now supporting independent French civilian and military space projects. This process has not been a direct one for the defense-related technologies, since the ESA constitution limits its activities to strictly civilian projects and institutional incompatibilities still exist between European nations with respect to military missions and needs. Nevertheless, as noted by Paolini in a study of French national space policies, European civil cooperation in space has "paved the way" for military space activities in France, both in terms of launch vehicles and satellite technologies[46]. For example, early funding and technical assistance from European partners were essential to the eventual success of the French-led Ariane project. Similarly, the Syracuse 1 military communications satellite network (which will be discussed in more detail below) was based on the French Telecom civilian network, which in turn was derived from the early platforms and systems for the European Communications Satellite (ECS) discussed earlier. Moreover, West German industry contributed 15 percent of the necessary development funding for the Telecom system in return for equivalent French support of the German version, the DFS. On the basis of such interactions, the national infrastructure and industrial capacity necessary for the sustainment of military and civilian space technologies in France can be viewed as fundamentally linked to civilian projects involving European cooperation. Given the necessarily limited nature of French space autonomy, the policy of simultaneously supporting both ESA objectives and independent military initiatives will surely continue.

In terms of specific (or direct) military space objectives, the French government has recently increased the funding and priority for military satellite systems in the areas of telecommunications, photoreconnaissance, and general surveillance. The catalysts for this surge in military interest and demand have included 1) the logistical difficulties encountered in gathering reliable reconnaissance with jet aircraft during the Chad crisis of 1985-1987; 2) an increase in Soviet research of antiballistic missile defense systems, which prompted concern regarding future French penetrative capacity and the reconnaissance methods for evaluating that capacity; and 3) the announcement of the U.S. Strategic Defense Initiative (SDI) in 1983, which enhanced the global visibility of space-based military systems and in effect raised the ante for aspiring nuclear powers. More recently, the success of U.S. military satellite systems in the 1990-91 Persian Gulf conflict greatly increased French interest in an autonomous (or at least European) surveillance satellite network, as evidenced by the strongly worded comments of Pierre Joxe - the French Prime Minister - following the conflict[47]. Significantly, this objective once again involves the longstanding French pursuit of military independence from the superpowers, since the U.S. does not release unprocessed satellite data from its surveillance systems to any European nation except the U.K. To the consternation of France, other nations must currently rely on information selectively packaged for release by the U.S. DoD. The progress of French efforts in these areas will be evaluated below.

With respect to space science activities, current French policies continue to emphasize French initiatives in basic science. As with the Japanese program, space science projects are considered good investments in view of their high public visibility and low associated costs. At the same time, such "non-sensitive" projects often provide excellent opportunities to combine efforts with other programs without technology transfer restrictions. In this manner, the program can dilute the costs associated with space science efforts, while profiting from the technological expertise and resources of other nations. The French program has given particular emphasis to joint efforts with the Soviet Union, as will be discussed below. However, bilateral efforts with other European nations, the U.S., and Canada have also occurred.

Finally, with regard to the commercialization of space activities, the French program has employed the institutional mechanisms of the French system and a significant level of resources in a concerted effort to establish markets and demand for space technologies and activities. Like the Japanese program, these efforts seemingly incorporate strategies for 1) the creation of organizations to develop and market space technologies, and 2) the stimulation of demand for these products and services. Moreover, French commercialization strategies have also seemingly aimed at the penetration of areas combining legitimate commercial promise with a low or dormant superpower presence. Unlike the Japanese efforts, however, French initiatives have also included a level of government ownership and control (through CNES) of GIEs and public and private space-related corporations, as discussed previously. The actual functions and structures of these organizations and corporations will be discussed below.

Status of French Initiatives

In terms of autonomy and the related development of indigenous capabilities, the French program has made considerable progress, at least partially by adapting the desired level of autonomy to existing resource constraints. Particularly notable success has been achieved in the area of launch vehicles, as the cost-effective and widely used Ariane 4 has emerged as the dominant launch vehicle in the current market, and the Arianespace corporation has recently attained profitable status in the provision of launch services (further details regarding vehicle capability, market position, and services will be provided in later sections). Moreover, the ongoing, French-led Ariane 5 development project is essentially on schedule and only slightly over projected cost. The Ariane 5 vehicle is expected to provide heavy class capability for up to three satellites per launch and will comprise the basic launch stage for the Hermes spaceplane. Although the success in the arena of satellite technologies and systems has been somewhat less noteworthy, the French program has nevertheless established indigenous capabilities in technologies for civilian and military communications, optical remote sensing, direct broadcasting, meteorology, and data collection and position location. The corresponding industrial base for these capabilities primarily consists of the Matra Marconi, Alcatel Espace, and state-owned Aerospatiale corporations. These capabilities vary widely relative to the "state-of-the-art" (often defined by U.S. technologies) and will be the subject of detailed analysis and comparison in the following section of this work.

With regard to the Hermes and Columbus manned ESA projects, however, the situation is less clear. In particular, their projected costs have increased by nearly 33 percent, while the schedules for both have already slipped one year (after a 1987 start). The Hermes is now scheduled for a 2000 first flight, while the Columbus is projected for a readiness date of 1998. Furthermore, both projects have become a source of concern for ESA members, particularly the less ambitious and/or enthusiastic nations. Even the German government, which is responsible for leading the Columbus development efforts, has expressed serious reservations about the required funding increases (partly due to the German capital constraints resulting from the recent union of East and West Germany)[49]. Although the German government has expressed continued support for the Columbus station module, it has specifically mentioned the French-led Hermes as a potential problem area for funding. Such statements have instigated a certain level of political turmoil within the ESA, since the two nations initially agreed to support each other's preferred project in return for equivalent support. This situation serves to illustrate the political complexities inherent in the coordination of strong states with individual national priorities. Further implications of this situation and these project difficulties will be considered in the last section of this work.

As stated above, French military space projects have also received increased funding priority in recent years, with particular emphasis on satellite technologies. Specifically, a 1987-1991 funding package of FF9100m ($ 144.4 million at 6.3 FF/$) was allocated to the Helios optical reconnaissance satellite system, the Syracuse telecommunications system, and a study of potential space surveillance networks. By 1991 the annual funding for these efforts will consist of FF3000m, a four fold increase from the 1987 level of FF760m. After including the potential development funding for a surveillance satellite system and the projected operational costs for the Helios and

Syracuse systems, the annual funding may further increase to FF5000m by the year 1995, representing a larger budget allocation than the projected contributions to ESA projects[46].

In terms of specific military objectives, the Helios system will represent the first independent French capability for reconnaissance and is expected to be operational by 1993. As will be discussed in the technology section, the platform and other technologies for the system have been based on the SPOT remote sensing system in order to reduce development costs[3]. This approach reflects a greater willingness on the part of the French program and government to combine civilian and military missions and technologies, as suggested earlier. In another intriguing development, the French government has accepted funding assistance from Italy and Spain for 14.5 and 6.5 percent of the Helios development costs, respectively, in return for satellite data from the system and a share of development contracts proportional to their individual levels of contribution. This arrangement again represents an effective balance of French control and leadership in a space project with European participation. Given the ESA constitutional restrictions regarding military projects, the arrangement may also serve as an example for cooperative projects of the future. In comparison, the Syracuse 1 network (established in 1986) is a purely national system devoted to military and government communications. The space segment for the system consists of the French civilian Telecom satellites (each satellite contains transponders devoted to the military network), while the ground segment consists of fixed and mobile stations[3]. Future derivatives of the system (scheduled for initial operation in 1993) will also be capable of connecting with small mobile receivers, U.S. AWACS aircraft, and French nuclear submarines. This system approach again reflects the cost-effective method of combining military and civilian missions and technologies.

Finally, with regard to the proposed surveillance and radar reconnaissance satellite networks, study and advisory groups have been formed within France, the Western European Union (WEU - a European support group for NATO), and NATO to evaluate potential measures for verifying Soviet compliance with the Conventional Forces in Europe Treaty. Thus far, a WEU technical committee has focussed its efforts on derivatives of the Helios system, while other possibilities involve military applications of the synthetic aperture radar technologies in the ERS-1 satellite. At this time the ultimate configuration and management scheme for a European surveillance system remain undetermined and could involve an independent French effort, a WEU-based effort, or a model similar to the Helios cooperative development scheme. In any event, serious technical challenges remain for such a system, as no European nation has yet achieved the level of radar resolution capability necessary for effective military applications. Indeed, some European observers estimate that the technologies for military radar surveillance systems are still ten years from successful development in Europe. Moreover, satellite radar systems generate data at a faster rate than it can be transmitted to the ground or stored. Consequently, data storage and relay satellite networks are required for the effective operation of such systems. Since Europe has no system comparable to the U.S. Tracking and Data Relay System (TDRS), this requirement may further limit surveillance system development in France and Europe for some time[47].

In the realm of space science, the French program (both alone and in conjunction with partners) has also made considerable progress, as stated above. Although a complete technical and management summary would be beyond the scope and intent of this section, a brief overview of the current, larger French projects is nevertheless instructive. In terms of ESA science projects, France is currently participating in the Hipparcos astronomy satellite project (with Matra as prime contractor), the Infrared Space Observatory project (ISO, with Aerospatiale as prime), the 2-tonne Solar Heliospheric Observatory (SOHO), and the Cluster magnetospheric project. The support of these projects has involved the contribution of roughly twenty percent of the ESA science budget (which is less than the proportional amount provided for the Ariane and manned projects but still considerable). With regard to cooperative ventures with the Soviet Union, an area in which France is more active than any other nation, the French program is currently participating in the Granat project, involving a gamma/X-ray astronomy satellite (with a French-built gamma-ray telescope); the Gamma 1 astronomy satellite, also entailing gamma-ray observations; and projects involving the inclusion of French instrumentation on Soviet biosatellites and weather satellites. In perhaps the most significant Soviet cooperative project, France is also involved in the Phobos mission to Mars, with CNES providing experiments and instrumentation and managing a related asteroid (or small body) flyby mission scheduled for launch on a Soviet Proton rocket in 1994. Finally, in terms of joint projects with the U.S., France is participating in the Cassini mission to Saturn, the Quasat optical interferometer project, the Lyman ultraviolet astronomy project, and the Topex/Poseidon oceanographic satellite project (with CNES providing the

GIE	Purpose	Ownership
GDTA	Promote applications and demand for remote sensing data (formed in 1973)	CNES 1/4; French Public Corp. 3/4
Prospace	Promote French space activities and companies (1974)	CNES; 51 Comp.; 3 French Banks
Satel Conseil	Provide info. and consulting regarding telecommunications services(1978)	CNES; TDF; French Cable
Sat Control	Production and marketing of satellite control centers(1985)	CNES 1/3; Matra 1/3; Aerospatiale 1/3

Table 5.1: French Space-related GIEs

Poseidon radar altimeter and developing the Doris precision-locating system). The Topex/Poseidon satellite will be launched on an Ariane 4 in 1991, representing the first European launch of a NASA satellite and perhaps signifying the dawn of a truly cooperative era in space science[11].

Finally, with regard to commercialization efforts, the French program has perhaps demonstrated a more coherent set of policies and initiatives than any other program, in addition to achieving more legitimate commercial success in certain space systems. Indeed, only the privatization policies of the Japanese program compare in terms of either coherence or potential effectiveness. Within the channels of the French political and economic system, the policies for creating organizations to develop and market space technologies and stimulate demand have resulted in the four GIEs and eight companies listed in Table 5.1 and Table 5.2, respectively[37, 11][2]. The background and operating context of these organizations have also been addressed in previous sections of this work where appropriate.

A review of the organizational functions of the GIEs indicates a strong orientation to the stimulation of markets and demand for French space activities, while the organizational emphases of the companies range from manufacturing to marketing and consulting. Significantly, the market orientations of both types of organization concentrate almost exclusively on launch-related services and various aspects and products of applications satellites (the more robust of near term space-related markets). As might be expected, these market orientations correspond roughly to the niche sectors previously targeted by the French program (which will be discussed in more detail in the following section). With regard to organizational character and

[2] Arianespace, SPOT Image, and Service Argos (in Table 5.2) also have North American subsidiaries that are not listed

Company	Purpose	Ownership
Arianespace	Manufacturing, financing, marketing, and launching of Ariane vehicles (formed 1980)	CNES 1/3; Eur. Industry and Banks 2/3
S3R	Subsidiary for providing launch insurance (1986)	Arianespace 100 %
SPOT Image	Processing and distribution of SPOT remote sensing data (1982)	CNES 1/3; French Ind. and Banks 9/16; For.1/10
Intespace	Conduct spacecraft environmental testing and design relevant facilities (1983)	CNES 2/5; Industry 3/5
Scot Conseil	Provide consulting services regarding Earth Observation systems (1986)	CNES; Industry
Service Argos (CLS)	Promotion and marketing of Argos data and services (1986)	CNES 1/2; Banks 1/3; Industry remainder
Novespace	Promote innovative ventures and spin-off uses for French space technologies (1980)	CNES; Banks; Anvar
Locstar	Develop and market satellite-based mobile locating service (1987)	CNES; Eur. Banks and Indus.; U.S. Geostar 1/7

Table 5.2: French Companies Operating on CNES Capital

status, the GIEs are legally distinct from an actual company in that their formation covenants allow full access to the personnel and technical facilities of supporting or contributing organizations[37]. For example, the personnel of Sat Conseil can utilize the resources of CNES, TDF, and France Telecom when appropriate for a given issue or contract. This arrangement seemingly represents a truly effective and efficient use of specialized national resources, with an emphasis on avoiding redundancy. From a more general perspective, all of these organizations reflect the now established French governmental method of associating an industry-related agency (in this case, CNES) with French and European manufacturers, customers, and banks. As discussed previously, the relative success of this methodology owes much to the level of authority maintained by the state in economic matters and the interwoven nature of the French power structure. It should also be noted that the French experience with such organizations may have influenced the formation of the externally similar Japanese organizations for managing and promoting space services, particularly given the existing Japanese tradition for such organizations and networks.

Although the relationship of these organizations to the specific technical strategies and market niches of the French program will be addressed in the following two sections of this work, certain aspects of their practices and intended functions merit consideration here (and will clarify the strategies discussed in the later sections). In particular, the French practice of providing a self-contained package of launch services should be noted, as indicated by the related functions of Arianespace and S3R. Through these companies the program can effectively offer a prospective customer manufactured vehicles, marketing services, launch insurance, and launch financing. This capability is significant given the often unstable nature of the world launch insurance market, and the S3R policy of offering substantially lower rates than otherwise available. Indeed, such incentives are potentially critical in the competitive launch market of today. As mentioned earlier, the proven success of such techniques may have influenced the Japanese program's decision regarding the range of services offered by the RSC. In another innovative technique, the demand stimulation organizations (such as the GDTA, Sat Conseil, or Scot Conseil) offer training and consulting regarding the use and/or application of their respective technologies, services, and systems. This again represents a potentially powerful market cultivation technique and bears a resemblance to the potential space-related activities of Japan's JICA. However, JICA's employees are often not technical specialists (and are generally overextended), while the French organizations described above are staffed by engineers trained in space-related technologies. These techniques will be referenced in the following strategy and market analysis sections where applicable.

Chapter 6

Technological Capabilities: Niches and Strategies

Prior sections of this work have been concerned primarily with the historical and operational context for both space programs, and the policy environment in which national space-related capabilities are targeted and developed. The overall objectives and growth strategies of the two programs have also been assessed in order to determine general program orientation and longer term direction. Such contextual and goal-related considerations are essential for a comprehensive analysis of the nature, style, and orientation of the French and Japanese programs relative to the overall space arena.

Perhaps more fundamental to the determination of program orientation, however, is an evaluation of the specific technological capabilities and sectors currently supported and/or pursued by the two programs. Such is the case because space technologies are typically cost-intensive in nature and often require long lead times for research, development, and production (particularly on the system level). For the smaller programs, therefore, the selection of specific technologies and systems for development involves a high level of proportional commitment and some risk. This is particularly true in view of the predominance and available resources of the U.S. and Soviet space programs. From that perspective, an analysis of the capabilities already established by the two programs (relative to the overall arena) should both illuminate prior technology strategies and clarify the programmatic factors that are influencing current development strategies. At the same time, such an analysis will aid in the basic identification of the niche capabilities of the French and Japanese programs (one objective of this research). In combination with a review of ongoing development projects, conclusions can also be drawn regarding the niche sectors that have been targeted for further development (a second objective of this research). Therefore, this portion of the research will address the current and targeted niche capabilities of the French and Japanese space programs relative to a range of space technology areas and markets. The capabilities of the U.S. program (which has until now been used extensively for programmatic comparison) will be referenced only as a standard of measurement or when appropriate for the clarification of a particular French or Japanese strategy.

In terms of the analytical structure for this section, assessments are provided for both programs in the areas of 1) launch vehicles; 2) communications, direct broadcasting, and remote sensing satellite technologies; 3) mobile communications systems technologies; and 4) space-related subsystems. These categories have been chosen because they either represent a current (or rapidly emerging) space-related market, or have been explicitly targeted by one or both of the programs for development. Since the relative level of program emphasis varies from category to category, the degree of nation-specific evaluation will also vary according to each category. Such distinctions will be addressed relative to each program's strategies when appropriate. Furthermore, in reviewing these arenas, attention is necessarily given to the relationship of the respective niche sectors to the overall arena and market. When necessary for clarity or niche identification, therefore, a brief overview of the overall arena (or recent market or technology changes therein) will also be provided. Finally, early development strategies will first be summarized for a given category when relevant, followed by a more explicit evaluation of the current program capabilities and strategies in that area.

With regard to the niche concept itself, a technological niche as discussed in this research refers to a specific application of a particular technology relative to a range of possible applications. For example, in terms of integrated satellite systems, the decision to focus on optical remote sensing technologies would constitute a niche strategy with respect to both remote sensing systems and applications satellite systems overall (a niche within a niche). Similarly, a niche in the area of satellite technologies could consist of satellite subsystems such as antennae or power units rather than integrated systems themselves. These concepts are essential to an understanding of the orientations and direction of the two programs and will be used throughout the analysis.

In another area of conceptual importance, the term "strategy" is meant to describe a predetermined, conscious plan for either 1) attaining a technological capability, or 2) using an existing or expected capability in a particular manner. For example, the programmatic decision to develop a certain technology through licensing agreements would constitute a strategy, as would the decision to employ an existing technology resource base in a particular endeavor or commercial effort. However, fortunate timing does not necessarily constitute a strategy (though strategies could evolve from such catalytic factors or events), nor is an assumption made that only good or advisable strategies qualify. Care will be exercised in the following analyses to distinguish between a "fortunate" application of existing technologies in a serendipitous manner, and an actual strategy. When such a distinction is impossible or impractical, the decision and/or project path leading to the observed result will nevertheless be traced and evaluated.

With regard to the occasionally indistinct boundary between French and ESA technological resources and plans, the ESA projects relying primarily on French leadership and industrial capability will be treated as French technologies in the analysis. For example, the Ariane launch vehicle family is essentially the result of a French development strategy, while much of the vehicle design and production work is also located in France. Consequently, the Ariane will be assessed as a French project. At the same time, ESA projects involving only limited French participation but resulting in some technological returns will be considered only to the extent that France will actually benefit from the project. These issues will be discussed further in each technological category.

A. Launch Vehicles

In view of the obvious relationship between launch capabilities and national autonomy in space, a study of launch vehicle technologies is essential to the overall analysis of program capabilities and direction. Moreover, this arena has long been a focus for French and Japanese development efforts, with France serving as the launch vehicle specialist within the ESA and Japan pursuing advanced launch technologies (as will be seen below). Although various forms of this technology exist or are under research, the most cost-effective type for current payload delivery operations - the chemical fuel Expendable Launch Vehicle (ELV) - will be the focus for this assessment. The larger classes of such vehicles provide all of the commercial launch services for the current market (though the reusable STS did provide commercial launches at one time). At the same time, these vehicles still represent a significant development challenge, with high up-front costs and long project lead times. Although both solid and liquid propellant versions of the ELV class exist, the liquid propellant-based launch technologies for each program will be emphasized, since solid propellant vehicles are generally less complex in nature and typically used for smaller vehicles (or as boosters for the larger vehicles).

In general, certain launch subsystems present the greatest challenge for development and are therefore the natural focus of this study. These technologies primarily consist of the main propulsion system for the vehicle, the vehicular control system (generally based on some form of inertial guidance), and the upper stage, on-station delivery system. Of these, the main propulsion system generally requires the longest lead time and often represents the critical design variable. Since the strategies of the programs are partially reflected in the design choices for this system, a brief summary of propulsion system alternatives and design trade-offs is provided below for clarification and later reference. Vehicular guidance technologies are also reviewed below, since these systems have been the focus for innovative work in both the Japanese and French programs. Finally, again for later reference, two mission-related terms are commonly used in measuring vehicle payload capabilities - the geostationary orbit (GEO) and the geostationary transfer orbit (GTO). A geostationary orbit, which is utilized for communications satellites, consists of an orbit located 22,300 miles over the equator (with zero degrees of inclination) that allows the satellite to stay positioned over the same spot on the Earth. In comparison, a geostationary transfer orbit is an elongated, elliptical orbit path designed to transfer a satellite from a lower-altitude parking orbit to GEO itself. Depending on the mission philosophy, vehicles can be designed to deliver a payload to either orbit through different means. When comparing on-station payload capability in terms of these orbits, however, it should noted that the mass of a payload at GTO (before the transfer) is typically 2 to 2.5 times higher than the actual on-station GEO mass for that payload.

Critical System Technologies

With regard to liquid propellant propulsion systems, two general classes are in common use today - the long developed storable propellant system, and the cryogenic propellant system, first developed by the U.S. in 1966. As their name suggests, storable propellants can be kept in sealed storage tanks for long periods of time (without evaporation) and are therefore easier to manage logistically. In comparison, cryogenic propellants consist of liquified gases (generally liquid hydrogen for the fuel and liquid oxygen for the oxidizer) that must be maintained at extremely low temperatures (-150 to -253 degrees Celsius). These propellants are prone to evaporation and more difficult to handle in terms of operational logistics. However, a cryogenic system based on liquid hydrogren and liquid oxygen is far more efficient in terms of thrust generated per unit of propellant consumed (the specific impulse), and therefore enables significantly lower vehicle liftoff weights for a given thrust capability. Since a tradeoff exists between base vehicle weight and allowable payload mass (for a given thrust), the lower vehicle weight essentially allows heavier payloads. This characteristic of cryogenic systems can prove advantageous for commercial applications, especially given the commercial importance of launch cost per pound of payload. Nevertheless, depending on the vehicle design and operational approach of a cryogenic launch system, the total launch cost can also increase due to the higher operational expenses related to cryogenic propellant storage and handling. This potential tradeoff must be considered in evaluating potential launch systems for development. In terms of technology sophistication, cryogenic systems are also considered the most advanced and generally represent the "state-of-the-art."

In addition to the two classes of propellant system described above, various approaches can be taken to the design of the rocket engine itself. This design choice can also have a fundamental impact on the performance of the system, as well as the difficulty and related cost of development (as will be seen throughout the following analysis). Although a complete description of these different approaches is beyond the intent of this work, a brief review of the performance and cost tradeoffs for the two common approaches (or cycles) is essential for an evaluation of the development choices of the two programs. Toward that end, the two general types of cycle in common usage today are the open loop and closed loop cycles. These classes correspond to the different treatment of the propellants following their pressurization in the system turbopumps, which are part of the "feed system" that transfers the propellants from the vehicle fuel tanks to the combustion chamber (turbopumps are a common feature of high-thrust propulsion system designs and are critical to overall system performance). In general terms, the open loop cycle is less complex than the closed loop but also less efficient, since it involves the wasteful discharge of the turbine working fluid after expansion. In contrast, a closed cycle system injects the used turbine fluid into the combustion chamber, along with higher quantities of unused propellants, providing greater efficiency and higher performance for an otherwise similar design. Specifically, a one to five percent increase in specific impulse can be expected from this design technique relative to the open cycle approach. The percentage increase in actual thrust capability can be even more dramatic[51].

Further specialization can occur within these two classes of engine cycle, including such alternatives as the gas generator and hydrogen bleed techniques for the open cycle, and the staged combustion technique for the closed cycle. These techniques simply represent different ways to drive the turbopumps mentioned above and provide different levels of engine efficiency. The staged combustion/closed cycle approach, which was first utilized in the design of the U.S. Space Shuttle Main Engines (SSMEs), is the most efficient and advanced of these alternatives and represents the true state-of-the-art. In a notable tradeoff for the closed cycle/staged combustion technique, however, the operating pressures for such a system tend to be much higher than in an open cycle system, necessitating much sturdier (and more complex) turbines, pumps, and system piping. As a result, the development of the closed cycle system can be far more challenging and costly. Project evidence of this effect will be provided below.

With regard to vehicle guidance, techniques in the early 1960s for guidance and course control relied on radio transmission and control from the ground. This was a relatively ineffective means of maintaining vehicle attitude and course. By the mid-1960s, however, the U.S. had successfully established the technology for inertial guidance, which involves an attitude-sensing package located on the vehicle. Course correction is provided in this system through a navigational computer and some type of thrust-vectoring or reaction control system. Given its importance to mission reliability, this technology was also targeted for development by both the French and Japanese programs and has since been an area of some innovation for both. In particular, both programs have utilized a ring laser gyroscope in recent development efforts rather than the normal mechanical gyroscope. The advantages of this technology include favorable dynamic characteristics, since the system has no acceleration sensitivity, and high linearity. Nevertheless, ring laser gyros have to date been used primarily in U.S. commercial and military aircraft and military space systems rather than launch vehicles[57].

Prior Development Efforts

As described in earlier sections, both the Japanese and French programs have emphasized the development of autonomous launch capabilities from the onset, albeit with different strategies. For the Japanese program, early launch vehicle development strategies (following the initial ISAS and NASDA difficulties described earlier) were characterized by 1) the incorporation of licensed U.S. Delta technologies, and 2) evolutionary improvements to those technologies. Both of these strategies were aimed at the ultimate objective of attaining an indigenous capability in advanced launch technologies, as well as an autonomous launch capability for satellites. The specific performance targets for this desired capability were revealed to U.S. officials in the exhaustive 1971 negotiations regarding the Delta licensing agreements. In particular, program officials hoped for a 130 kg GEO payload capability in the early 1970s, a 300 kg capability in the late 1970s, and a 500 kg capability by the mid-1980s, all (hopefully) incorporating U.S. technologies[52]. After some internal debate, the U.S. government granted licenses for an early Delta first stage engine (the storable propellant Delta MB-3), an obsolete vehicle guidance system based on radio control, and the Delta payload fairing. Along with an indigenous second stage engine (the LE-3), these older technologies formed the basis for the development of the N-1 and slightly modified N-2 vehicles mentioned previously. In keeping with the above strategy, these successful vehicles, introduced for full operations in 1975 and 1982, were capable of launching 130 kg and 350 kg to GEO, respectively. The more notable additions to the N-2 design consisted of two additional licensed U.S. systems - an inertial guidance system and small strap-on boosters[9]. Although these launch vehicles were far below U.S. and French standards at that time, the Japanese program nevertheless seemed to be on its intended path for launch system development.

In order to simultaneously obtain higher payload capability and gain access to more advanced launch technologies, however, Japanese program officials sought an additional license in the mid-1970s for the more critical and politically sensitive cryogenic technologies. U.S. officials refused, presumably on the basis of the advanced nature of the technology and its potential suitability for cost-effective commercial activities. Subsequent negotiations with the French government in 1974 also failed, apparently for similar reasons[52]. The combination of these rejections and the motivations mentioned above evidently led to the landmark government decision to develop the currently operating H-1 launch vehicle, capable of launching 550 kg to GEO (again in step with the earlier milestones) and involving cryogenic technologies. Indeed, in an illuminating glimpse of longer term objectives, the H-1 design includes an indigenous cryogenic engine in the second stage (the LE-5), an indigenous solid motor for the third (payload delivery) stage, and an indigenous inertial guidance system - the three critical systems technologies mentioned above.

The choice of the crogenic LE-5 for development rather than a less complex and expensive storable propellant engine is particularly relevant to the analysis of longer term strategies. Indeed, the LE-5 seemingly represents a departure from the more evolutionary philosophies of previous years. Although the LE-5 cryogenic engine is based on the somewhat less complex open loop/gas generator cycle described earlier, it also contains efficiency-enhancing features such as a restart capability and regenerative cooling. In general it represents an advanced level of launch technology. As can be seen from Table 6.1, this efficiency is not necessarily reflected in the overall capability of the vehicle, since it still employs the older Delta first stage engine. Nevertheless, this development choice signifies a clear program commitment to advanced launch capabilities and technologies, as will be seen in the H-II analysis below. At the same time, the decision to focus existing resources on the LE-5 implies that such considerations were prioritized over near term commercial applications (which may have been considered unlikely anyway given the market strength of French and U.S. vehicles). These issues will also be considered further in the analysis of H-II development decisions.

In contrast to the technology importation strategies of the Japanese program, the French program initially supported indepedent vehicle development projects (such as the Diamant program) and eventually shifted its focus to joint development efforts through the auspices of the ESA. The primary goal of these joint efforts was the development of an independent, cost-effective delivery system for European satellites, inspired at least partly by disagreements with the U.S. (as discussed in the program evolution section). Given the prior experiences with the Europa project, however, the Ariane project was approved with some reservation by many nations in the ESA and ultimately required a heavy funding and management commitment from France. Moreover, the project was evidently under close scrutiny for complications and was therefore faced with a need to demonstrate near term operational success. As a result of such political and financial considerations, the development philosophies for the Ariane emphasized low up-front costs and potential cost-effective operations, as well as mission flexibility[3].

These philosophies are reflected in the design choices for the Ariane 1, which incorporated storable propellant technologies for the first and second stages. Moreover, the engine utilized in the engine clusters for these stages consisted of the less complex open cycle/gas generator design, which was already established in France. Even the third stage system, which consisted of a small cryogenic engine, was based on a French engine established earlier after seven years of testing. Finally, in an attempt to reduce equivalent launch costs and increase mission efficieny, the vehicle was designed with the capability to launch two payloads into GTO in one mission when capacity constraints so allowed. This technique essentially involved a different third stage delivery method and did not increase system complexity in a significant manner. Together, these design features and development concepts produced a highly cost-effective launch vehicle in comparatively little time. The Ariane 1 program reached initial fruition with a successful test launch in December of 1979, and the vehicle was declared fully operational in January of 1982, with a GTO capability of 1850 kg. By that time, Arianespace had already been established to manage production and launch operations and conduct potential marketing activities. Although the creation of Arianespace signified at least some interest in commercialization, the available evidence does not indicate that the Ariane was envisioned as a major provider of commercial services at that time. Rather, the vehicle was still seemingly oriented to flexible and low-cost launch services for Europe.

The following two models of the Ariane family were developed according to the same philosophies, involving only incremental changes to propellant capacity and the addition of strap-on boosters. Approved in 1981 and ready for launch in 1984, the Ariane 2 and 3 were capable of launching payloads weighing 2175 kg and 2580 kg to GTO, respectively. In a testament to the long range planning and intentions of the French program (and ESA), however, the development project for their planned successor, the currently operating Ariane 4, was already approved by 1982 (two years before the first launch of the Ariane 2). This vehicle was also derivative in nature, involving a higher propellant capacity and a longer burn time for the first stage. In addition, the base vehicle was modified to allow six possible strap-on booster configurations, ranging from no strap-ons (the Ariane 40) to different combinations of solid and liquid rocket boosters. The most commonly used configuration thus far has been the Ariane 44LP, with two solid and two liquid boosters and a single GTO payload capability of 3700 kg. This approach clearly allows Arianespace to tailor the vehicle for individual missions and thereby use its resources more efficiently. Moreover, in the dual-launch mode, two satellites of approximately 1500 kg can be

Rocket	Gross Wt.	Payload Capability	Launch	Cost (1989)
	(Tonnes)	to GEO (kg)	Success Rate(%)	(Mil $; 140 Y/$)
H-I	139.3	550	100	87
Delta 3920/PAM-D	192.3	730	98.3	50
Ariane 44LP	418.5	3700/2x1500 (GTO)	88.7	84
Atlas I	163.9	2340 (GTO)	85	60

Table 6.1: Comparison of the H-I, Delta 3920, Atlas I, and Ariane 44LP

launched into GTO with the Ariane 44LP[3]. Significantly, this capacity is roughly equivalent to two Delta 3920-class satellites in one launch (as shown in Table 6.1[3]). Once again, mission- and cost-effectiveness were seemingly the underlying drivers behind the Ariane 4 design. As will be seen below, these system characteristics, which were based as much on political and funding constraints as a long term strategy, proved to be critical in the eventual positioning of the vehicle for the launch market of the late 1980s.

A Niche Opportunity for France

Although the Ariane family of launch vehicles was clearly developed according to a philosophy of mission flexibility and low up-front costs, there is no indication that the vehicles were developed explicitly for the commercial market. Arianespace officials did publicly express doubt about the cost-effectiveness of the reusable STS in the early 1980s and may have considered a market opening for ELVs to be a possibility[55]. However, the Ariane vehicle development programs were implemented far too early in the 1980s to have been in response to the market changes that will be described below. Regardless of this question, various events conspired in the mid- to late 1980s to create tremendous opportunities for the commercialization of this efficient launch system. The precursor to these events was the U.S. governmental decision to focus U.S. launch capabilities and requirements on the STS (and away from ELVs). This policy naturally resulted in the virtual elimination of ELV production capabilities and resources in the U.S. As the STS soon proved incapable of its projected launch rates, a significant backlog of U.S. commercial and military missions began to emerge. Moreover, since the global demand for satellite launches was continuously increasing and the U.S. was at that time the world's primary commercial launch provider, the low STS launch rate also resulted in a substantial backlog of world commercial launches. With the commercial launch market thus defined, the STS Challenger accident of 1986 (and the subsequent three-year grounding of the system) created a tremendous void in the world market for launch services[56].

With the elimination of Soviet and Chinese vehicles from consideration due to security and political concerns, the Ariane emerged as the only active vehicle capable of providing efficient commercial launch services. This window of opportunity was recognized and soon taken advantage of by the ESA, France, and Arianespace (although the backlog was temporarily increased even further by a subsequent Ariane failure and eighteen month downtime). Indeed, for the next two years, Arianespace conducted the only commercial launches in the world. Although the U.S. ELV industry has since revived somewhat and the Soviet Union, China, and Japan are attempting to enter the market, the Ariane has nevertheless emerged as the world's most prominent and successful commercial launch vehicle (a fact that will be further substantiated in the niche market section).

Since the dramatic penetration of the commercial launch arena, France and the ESA have demonstrated far more conscious and explicit strategies for the further commercialization of the Ariane and the protection of its market share. Some of these strategies are reflected in the design choices for the Ariane 5 and will be discussed below. Others reflect directly on current operational practices and merit consideration here. In particular, Arianespace (with ESA support) completed the technical and scheduling negotiations in 1988 for a single package purchase of fifty Ariane 4 vehicles, with the intent of streamlining production, increasing quality control, and reducing unit cost. These vehicles are expected to provide launch services until the late 1990s, when the Ariane 5 is scheduled to become operational[3]. Other methods, such as the provision of packaged launch, financing, and insurance services, have been described in previous sections. In view of the technical, market, and more recent strategy-related issues addressed in this section, the Ariane launch vehicle can indeed be considered a current technological and market niche for the French program.

Current Development Programs and Strategies

As discussed in prior sections, both France and Japan are in the process of developing heavier class launch vehicles. These vehicles entail significant advancements in indigenous capabilities and relate directly to general program objectives. For example, the Japanese program is focusing its current vehicle development efforts on the fully indigenous H-II launch vehicle, which is scheduled for first launch in 1993. The H-II is projected to have a GEO payload capability of two tonnes - the payload weight class of many of the larger communications satellites in use today. Far more

Rocket	Gross Wt.	Payload Capability	Launch	Cost (1989)
	(Tonnes)	to GEO (kg)	Success Rate(%)	(Mil $; 140 Y/$)
H-II	260	2000	96 (est)	110 (est)
Ariane 5 (Base)	725	6800/2x2800 (GTO)	99 (est)	Undet.
Titan IV/Centaur	862	5670	95 (est)	180 (est)

Table 6.2: Comparison of the H-II, Ariane 5, and Titan IV

significant in terms of long term strategies, however, is the incorporation of a new, indigenous cryogenic engine (the LE-7) for the first stage and a more efficient LE-5 design (the LE-5A) for the second stage.

Based only partly on the indigenous cryogenic experience with the LE-5, the LE-7 instead utilizes the complex, highly efficient staged-combustion approach discussed earlier. The LE-7 design is less complex than the other example of this approach in current operation - the state-of-the-art U.S. Space Shuttle Main Engine (SSME) - and provides less thrust. Nevertheless, the usage of the staged-combustion technique represents a significant increase in system complexity and sophistication, as well as potential efficiency and performance. Moreover, this development choice clearly highlights the previously discussed Japanese orientation to advanced launch technologies (rather than near term commercial possibilities), as will be discussed further below. However, this rather dramatic departure from a more evolutionary approach has also resulted in the unprecedented scheduling delays for the H-II project discussed earlier, as the program has suffered repeated failures in the design and testing of the LE-7 turbopumps and blades[58]. Similar problems were also encountered by U.S. engineers during the design of the SSMEs in the mid-1970s. For such reasons, the closed cycle propulsion system design is still not in common use in the world today. The expected performance characteristics of the H-II are provided in in Table 6.2, along with the characteristics of the Ariane 5 (described below) and the heavy class U.S. Titan IV/Centaur[3].

With regard to current French and ESA efforts, the Ariane 5 launch vehicle currently under development by the ESA (with the leadership of CNES and Aerospatiale) is a two stage design expected to provide a single payload capability of 6800 kg to GTO and a dual GTO payload capability of 2800 kg. With first launch scheduled for 1996, the vehicle is expected to assume full operational status for Arianespace in 1998, replacing the Ariane 4. Significantly, the Ariane 5 is also intended to comprise the lower (or base) launch stages for the Hermes spaceplane. Certain vehicle performance and configuration design criteria have resulted from this decision, including a mission-dependent second stage and severe "man-rated" reliability targets (98 percent for the launch vehicle). These targets are an order of magnitude greater than the 90 percent reliability value established and nearly attained for the Ariane 2-4 vehicles. Due to changes in launch operations methodologies, the Ariane 5 should be capable of ten launches per year, with two of these annual launches allocated for Hermes missions[59].

In terms of the crucial area of propulsion technologies, the design and program choices for the Ariane 5 reflect different philosophies and priorities from those influencing the H-II design. For example, the first stage will consist of the newly developed cryogenic HM60 Vulcain engine, which (like the LE-7) utilizes liquid hydrogen and liquid oxygen as propellants. However, in contrast to the LE-7 and SSMEs, the HM60 employs an open cycle and gas generator system rather than the more complex and efficient closed cycle approach. According to available information, the closed cycle approach was seriously considered by ESA officials but ultimately rejected due to concerns about cost and potential scheduling delays[53]. In addition, the second stage consists of an open cycle, storable propellant engine (built by a German contractor), rather than a more advanced cryogenic engine. Other noteworthy Ariane 5 design characteristics include the modification of the payload assembly to allow for the launch and delivery of a third, smaller payload in an under-capacity, dual payload mission. Finally, the diameter of the payload bay has been increased to 4.55 meters from the 3.65 meter bay of the Ariane 4. This feature was incorporated on the basis of a perceived market transition to larger volume satellites (the U.S. STS and Titan vehicles already provide this payload volume capacity)[59].

In terms of development strategies, the design philosophies and apparent missions for the H-1 and Ariane 5 vehicles directly illustrate the launch vehicle development objectives for the two programs. For example, the Ariane 5 is the product of two converging goals of the French program. The first goal relates to the longstanding French pursuit of autonomy, with the particular form of autonomy in this case consisting of manned spaceflight and the capability to deliver the Hermes to orbit. At the same time, the Ariane 5 has clearly been designed to sustain and perhaps even expand the market share established with earlier Ariane models. Indeed, ESA officials have stated that all other uses for the vehicle are of secondary priority[60]. Numerous design choices reflect this priority, including 1) the increase of the dual payload capability to 2800 kg, which is in the payload weight range projected for most common usage by 1995 (based on Arianespace customer surveys); 2) the flexible and potentially cost-saving mission option for a three payload-launch; and 3) the emphasis given to maintaining a rate of ten launches per year (even with the larger vehicle), which is the number of Ariane commercial launches projected for the next few years. By comparison, the U.S Titan IV is capable of six launches per year, while the H-II will at most be capable of four (as discussed in previous sections). The less complex propulsion system design chosen for the HM60 cryogenic engine also reflects the desire to increase performance to targeted levels without incurring the high development costs and potential scheduling delays associated with more advanced technologies. Such costs would be reflected in unit costs and vehicle launch costs, potentially reducing the Ariane 5's competitiveness in the current launch market. At the same time, however, the development of the high thrust HM60 engine should still position French industry for the more complex engine technology projects of the future (in a more evolutionary approach), if such projects become advisable or necessary. Together these choices signal a clear orientation to the sustainment of both the capability and the market share for what has become a definite French niche.

In contrast, the H-II development choices indicate a lower emphasis on commercial viability in the near term, particularly given the lack of a current Japanese commercial launch foothold. Rather, the H-II seemingly represents 1) the fulfillment of the goal of autonomy for two tonne-class launches, and 2) an attempt to position Japanese launch industries for launch technology applications and requirements of the future. These conclusions are primarily based on the analyses of program objectives provided earlier, and the development and unit cost implications of the decision to develop the LE-7 crogenic engine rather than a high thrust storable propellant engine, or a less complex cryogenic system. In particular, the decision to develop a staged-combustion/closed cycle engine reflects the goal of attaining that level of technology rather than penetrating the near term commercial market in a significant manner. As discussed in the program objectives and status section, the projected price of the H-II relative to vehicles of comparable performance (such as the Ariane 4 or Atlas) supports this inference. Given the competitiveness of the current launch market, these development strategies may have indeed been the most pragmatic, particularly for the long term. They certainly represent an effort to establish a technological niche. Regardless of that possibility, however, the Japanese program will not have truly attained a commercial niche for the near future, even if the LE-7 (and H-II) development efforts are ultimately successful.

B. Communications Satellite Technologies

As in the case of launch vehicles, the communications satellite arena merits review in that both the French and Japanese space programs have clearly targeted the sector for development. This category of space technologies is also significant for its level of maturity as a market - both systems level and secondary product markets have existed since the early 1960s. With regard to general system characteristics, a communications satellite system can be thought of as containing two general segments - the ground segment and the space segment. The space segment naturally consists of the orbiting satellite itself, while the ground segment consists of stations for tracking and orbital control, signal transmission to the satellite, and/or receiving and processing of signals from the satellite (different transmission and receiving functions can be combined). The ground stations also interface with networks for the provision of telecommunications services, which can involve telephony, simple data transmission, television broadcast, or faxes[1]. The operational capacity of a satellite is typically allotted to some combination of these services.

Certain system and subsystem technologies of the satellite itself are critical to the overall performance of the system and also warrant some explanation for later reference. Firstly, the signal receiving and transmission functions of the satellite are handled by devices known as transponders, which must shift the frequency of a received signal (the "uplink") and amplify it before transmission (the "downlink"). The number of available circuits for voice, video, or data transmission is a direct function of the number (and quality) of transponders that can be carried in the satellite. Furthermore, since most service carriers have opted for larger satellites and more transponders per craft, the platform (or "bus") technologies for larger satellites have also become increasingly important in satellite production. Indeed, the attainment of larger scale bus technologies is an explicit objective of both French and Japanese satellite development efforts (as discussed in the previous section). One critical element of such technologies is that for craft stabilization in orbit, which is important for maintaining the correct position and orientation of the satellite relative to the Earth's surface. Two techniques for stabilization (both established by the U.S.

[1]As mentioned previously, the ground segment equipment represents an important component of the value-added approach of Japanese space-related industries.

in the 1960s) are in common use today - the spin and the more complex three-axis-stabilization techniques. These technologies are also referenced below.

Other critical bus technologies consist of the method for power generation and the technique for orbital station-keeping (or maintaining orbital position, as opposed to the orientation function described above). All represent important "minimum capability" requirements for indigenous satellite development. Finally, in reference to an important system characteristic, various frequency ranges exist for satellite operations. The most commonly used for communications satellites are the C-band (4 to 6 GHz) and the higher Ku-band (12 to 14 GHz). As will be seen, however, the development of technologies for operation in higher ranges has become one area of innovation in the arena. Recent market and technology developments of particular relevance to this analysis will also be summarized below.

Market and Technology Developments

In recent years certain market and technology developments have fundamentally altered the nature of and market for satellite services. The first of these developments has been the emergence of fiber optics networks for telecommunications services. Fiber optics systems are capable of more rapid data transfer rates and exhibit a lower time delay than satellite-based services. Moreover, such systems are more cost effective for densely populated regions (a 400 mile service range is considered the cost-effectiveness boundary between satellite and fiber optics-based services). Given such considerations, many analysts have predicted a gradual shift of voice and data services to terrestrial networks, with video services remaining on satellite-based systems[62]. Despite such trends in competitive technologies, various technology improvements have also occurred in the satellite realm, with the most significant including the increased capacity trend mentioned above, and a notable shift toward higher-powered satellites. For example, a comparison of two Ford Aerospace satellites (the Intelsat 5 and the Superbird) built in 1980 and 1989 shows a doubling of the satellite power-to-weight ratio (resulting in a Superbird power level of 4000 watts and an on-station weight of 1500 kg). In combination with improved receiver electronics for ground terminals, this trend has enabled a corresponding reduction in the size of ground station antennae (from 100 feet to 4 feet)[61].

This decrease in allowable ground terminal size has led to one of the most revolutionary changes in the recent satellite market - the tremendous growth in the number of small, easily deployable ground terminals known as VSATs (Very Small

Aperture Terminals). VSATs have proven particularly useful in business networks, which incorporate a private central hub to transmit satellite data, telephony, and video signals to outlying office sites and plants. A notable aspect of these systems from a regulatory standpoint is that they bypass national hubs and essentially undercut rate averaging schemes instituted by state-owned carriers. As a result, the VSAT technology and market developments have been most pronounced in the U.S., which first established the technology and currently represents the largest VSAT market. Indeed, nearly 95 percent of the world's insalled VSAT networks are in the U.S.[63]. Finally, in a potential development that may reinforce the VSAT market, some space programs (most notably Japan and Italy) have begun the operational evaluation of higher satellite frequency ranges (above the Ku- and C-bands mentioned earlier). In particular, the Ka-band (20 to 30 GHz) is under evaluation for certain applications. This frequency range has attracted interest within the satellite communications arena because it requires less orbital space for operation and provides more resistance to microwave interference. Moreover, it provides wider available bandwidths and potentially higher data transfer raters. These characteristics may make the band suitable for integrated services combining fiber optics networks and VSATs. On the negative side, the Ka-band suffers from signal obscurement due to rain attenuation. Other characteristics of the Ka-band will be considered as they relate to particular efforts on the part of the two programs.

Current Capabilities and Projects

The Japanese development efforts for communications satellite technologies have thus far consisted of 1) an evolutionary series of technology demonstration projects known as the Engineering Test Satellite (ETS) series, and 2) a concurrent series of operations-oriented satellites known as the Communication Satellite (CS) series. As their names may suggest, the ETS series has concentrated on the establishment of fully indigenous, system-level satellite technologies, while the CS series has been oriented to both operational services and technology demonstration. Both series are directly related to the previously discussed objective of attaining system-level capabilities in satellite technologies. Procurement of the systems has been supervised by NASDA, while the operational oversight of the CS system is provided by the public Telecommunications Satellite Corporation of Japan (TSCJ).

With regard to the ongoing ETS series, the first four spacecraft concentrated on the demonstration of basic satellite tracking and control techniques, GEO insertion methods, attitude control, and space equipment operation. The 1987 ETS-V project went considerably further, since it involved the verification of three-axis-stabilization techniques for large geostationary satellites and mobile communications experiments (the mobile experiments will be discussed in a separate category). Continuing that trend, the ETS-VI satellite project, which will be launched on the H-II in 1993, is oriented to the demonstration of two tonne-class bus technologies and higher power capabilities, with lesser mission objectives including intersatellite communications, additional mobile communications experiments, and advanced power system experiments[7, 3]. The focus on bus technologies is particularly significant given the Japanese program's previous reliance on U.S. platform and integration technologies for the CS series (as will be discussed below). Similarly, the choice of weight class and the focus on power capacity (4200 watts) clearly reflect a desire to stay in step with the market trends described above. The strategic significance of other ETS-V and VI technologies and experiments will be discussed in later technology sections when appropriate.

As with the earlier example of Japanese launch vehicles, the service-oriented CS series have relied on a combination of U.S. technologies (particularly for the bus) and evolutionary development philosophies. Three operational CS systems have thus far been developed (including the ECS, CS-2a and b, and CS-3a and b spacecraft), with the late 1980s CS-3 satellites demonstrating slight improvements in capacity and operational life relative to the rather modest ECS and CS-2 satellites. The characteristics of the currently functioning CS-3 spacecraft are provided in Table 6.3, along with the capabilities of two U.S.-manufactured satellites (the Comstar and Intelsat 6) and the current French Telecom 1 satellites[3]. As can be seen from the table, the CS-3 satellites are far below industry standards in terms of overall capacity, the number of transponders per craft, and on-board power capability (even in comparison to the 1976 Comstar). Moreover, the disparity in available circuits between the CS-3 and Intelsat 6 is actually larger than that indicated, since the recorded Intelsat 6 value does not reflect the equivalent circuit capacity (approximately 120,000) resulting from the usage of digital modulation and compression techniques. Such evidence strongly indicates that Japanese manufacturers have simply not attained the levels of integrated system technology or efficiency in production demonstrated by state-of-the-art satellite manufacturers (particularly those in the U.S.). However, the Japanese have achieved impressive levels of capability in the production of compo-

Satellite	Launch date	Mass (kg)	Transponders	Voice Circuits	Power (W)	Life (yrs)
US Comstar	1976	811	24 (C/Ku)	18000	760	7
Intelsat 6	1989	1700	48 (C/Ku)	33000	2600	14
CS-3	1988	550	12 (C/Ka)	6000	833	7
Telecom 1	1984	690	12 (C/Ku/X)	?	1200	7

Table 6.3: Comparison of US, Japanese, and French Satellites

nents (such as transponders) and the design and implementation of subsystems, as will be discussed below and in a later technology section.

In a noteworthy departure from established industry trends, however, the three CS systems have concentrated almost exclusively on Ka-band operations and system technologies. Some of the benefits of this frequency range were summarized above. Other advantages include a particular suitability for HDTV transmission by satellite, the potential to allow further reductions in antenna and receiver size (which may link the Ka-band to future VSAT developments and direct broadcasting), and a related applicability to mobile communications[65]. As will be considered in detail below, this expertise in the Ka-band is seemingly a primary element of Japanese strategies for further development and growth. Despite such potential advantages, the normally standard-setting U.S. program has just begun the experimental development and application of Ka-band technologies in NASA's Advanced Communications Technology Satellite (ACTS), scheduled for launch on the STS in 1992, and the DoD's Milstar program[65]. Other notable characteristics of the CS-3 include a xenon-fueled ion propulsion system for station-keeping and the use of efficient gallium arsenide solar cells in the craft solar arrays. Both are considered potential weight-savings technologies.

With regard to the French program, early development efforts involved Franco-German cooperation through the Symphonie project and were reinforced by the previously described ECS project. This approach was similar to that utilized for launch vehicle development, and again reflects the trends in development strategy noted earlier in this work. In terms of technology, the Symphonie satellites were noteworthy for their focus on multiple access techniques and three-axis-stabilization (which France developed after the U.S. but before Japan)[3]. By comparison, the ECS system provided the bus technologies and system integration experience for larger satellites. These system-level technologies subsequently served as the basis for the currently functioning Telecom 1 system and the ongoing Telecom 2 development project, both of which will be described below. Together these projects illustrate the derivative nature of early French development efforts (a tendency noted in earlier sections).

In terms of system characteristics, the Telecom system was designed to provide a full range of telecommunications services to domestic and overseas customers (under the management of state-owned Telecom France). Toward this end, three satellites - the Telecom 1a, 1b, and 1c - were launched on Ariane launch vehicles in 1984, 1985, and 1988, respectively. As shown in Table 5, each spacecraft weighs 690 kg on station and contains twelve transponders (with five back-ups) - four C-band and six Ku-band transponders for civilian services, and two X-band (seven to eight GHz) transponders for the Syracuse military network described earlier[3]. These capabilities are again far below the industry standards set by the U.S. Furthermore, the system has been plagued by operational problems, including the failure of the attitude control system on the Telecom 1b and recurring power outages on the Telecom 1a due to electrostatic charging (a common environmental design challenge). Such difficulties demonstrate the complexities inherent in the design and operation of satellite systems. Nevertheless, the Telecom system has successfully demonstrated operational technologies for time-division multiple access (a form of multiple access entailing the processing of signals in time segments without overlap) and real-time demand assignment. Such technologies are relatively sophisticated by world standards but certainly not innovative (the U.S. has offered such capabilities for many years).

Although still below the industry standards described above, the Telecom 2 system currently under development should demonstrate marked improvements in capability relative to the Telecom 1 system. The system will again consist of three satellites, scheduled for launch in 1991, 1992, and 1994. However, each of the satellites will provide 27 primary transponders (over twice the number on the Telecom 1) and ten years of expected life, while displaying an on-station mass of 1100 kg. Other notable characteristics include the capacity to interact with small mobile receivers for military purposes and the "hardening" of on-board circuits and equipment for protection from electromagnetic pulses[3, 46]. On the basis of such evidence, it would seem that the French satellite industry has made some progress in catching up to the U.S. standards for integrated system performance (and may now lead Japan in this area). At the same time, however, it must be reiterated that the Telecom 2 satellites will provide substantially less operational life and power and lower capacity than the satellites designed by Ford Aerospace (now Loral Space Systems) and Hughes in the mid-1980s.

Strategic Implications

The strategic implications of these development efforts for the two programs can only be understood in the light of the current world market, and the domestic markets in France and Japan. In addition to the fiber optics and VSAT considerations mentioned above, the world market is essentially characterized by the predominance of U.S. satellite manufacturers. Indeed, the Hughes Corporation alone supplies nearly half of the world's satellites and satellite systems[3]. Loral Space Systems supplies a considerable portion of the remainder (roughly 25 percent). This market strength provides economies of scale to U.S. firms that are difficult for French and Japanese firms to match on a competitive basis, even in their home markets. An illuminating illustration of this fact is provided by the actions of the two private Japanese telecommunications companies formed in 1985. Both the Space Communications Corp. and the Japan Communications Satellite Corp. (JCSAT) selected U.S. satellite systems for implementation rather than domestically produced satellites.

Furthermore, both French and Japanese firms are faced with relatively small domestic markets. In the case of Japan, this situation is certainly exacerbated by its suitability for fiber optics networks. For example, an estimated 80 percent of Japanese "long distance" communications traffic travels between Osaka and Tokyo - a distance of approximately 400 miles (the cost-effectiveness boundary mentioned earlier)[68]. Moreover, Japanese firms are particularly competitive in fiber optics technologies, lending further impetus to the switch to terrestrial networks[70]. With regard to the French market, French systems must share the available market not only with Intelsat, but also with regional systems such as Eutelsat. Furthermore, many densely populated regions in France are also more suited to terrestrial networks. Finally, the French telecommunications market is heavily regulated, a fact that has limited the growth of secondary markets for products (such as VSATs) that bypass national carriers.

In response to this playing field, Japan has seemingly chosen to combine its basic satellite technology development efforts with a concurrent focus on Ka-band operations - a potential leading edge sector that has not yet been taken over by U.S. firms. This appeal is surely reinforced by the frequency's theoretical suitability for HDTV transmission (another leading sector for Japan), mobile communications, and integrated network services with fiber optics systems (through VSATs). According to NASA publications, such possibilities contributed to the decision to initiate the ACTS project, which will investigate the usage of advanced on-board processing, circuit switching, and on-demand access in addition to Ka-band technologies. The combination of Ka-band bandwidths and these technologies could potentially allow rural or remote users to access international fiber optics networks without terrestrial switching hubs. Furthermore, such applications are considered particularly suitable for many Third World countries and the island nations of the Pacific Rim (a potential niche market discussed earlier)[65]. Most of these applications will be the focus of a new Japanese development project known as the Communications Broadcasting Technology Satellite (CBTS, slated for launch in 1997). The CBTS spacecraft will carry Ka-band transponders for data relay, HDTV programming, and mobile communications demonstrations[71]. On the basis of such evidence, the Japanese program has clearly selected the Ka-band as a potential niche technology and capability. At the same time, the evidence suggests that the Japanese program and Japanese firms may still be pursuing potential markets in the Pacific region for satellite systems, with these applications in mind. As established earlier, however, sales in this region would probably require hardware packages involving ground and space segment equipment.

As an additional note, analysts disagree somewhat as to the actual necessity or ultimate usefulness of the Ka-band for HDTV applications, mobile communications, or even orbital spectrum relief. In addition, the technical and operational problems of rain attenuation are not fully resolved. Finally, the existing ground segment infrastructure is primarily geared to the Ku- and C-band frequencies and may prove resistant to wholesale change (even the existing VSAT networks operate in the Ku-band)[61]. Despite such considerations, the clear relationship between potential Ka-band applications, related secondary markets (such as VSATs and smaller receivers), and existing Japanese production strengths have seemingly encouraged a general strategy of positioning Japanese firms for the development of these markets. Relative to the overall satellite telecommunications market, these strategies certainly constitute a niche market approach that relies on areas of proven technical capability. Further analyses of the space-related subsystem and value-added market strategies of the Japanese program and Japanese firms will be evaluated in the following section.

With regard to French development strategies, the implications are somewhat less clear. The French program has thus far generally focused on "normal" integrated satellite systems and operations in the domestic market (along with the overseas territories). Although the government efforts to build an indigenous satellite production base have been aided by ESA and regional carrier contracts, the French program has nevertheless essentially focused on the same arena in which the U.S. is strong. These efforts have not been fruitless, as evidenced by the performance improvements expected for the Telecom 2. Nonetheless, the performance of French systems is still below the standards set by U.S. firms, a fact that will make future competitions in the Third World, Eastern Europe, or the Pacific Rim that much more difficult to win.

In seeming recognition of this situation, however, the French government and leading French space firms have recently initiated a series of attempted mergers, both within France and between French firms and international firms. The apparent motivation for this initiative was the collective perception that too many European satellite firms existed for them to be competitive with the U.S. This perception may in fact be realistic in light of the predominance of U.S. firms. Regardless, one such merger attempt, involving Alcatel Espace (which is private) and state-owned Aerospatiale, has already failed due to perceived incompatibilities. Another attempt, involving Matra and the Marconi company from the U.K., has thus far proceeded successfully. In a different approach, Aerospatiale, Alcatel Espace, Alenia (from Italy), Deutsche Aerospace, and Loral Space Systems of the U.S. have recently signed a non-competition agreement, which essentially divides the world market into zones for each company (and also involves contract sharing)[72]. The potential of these efforts remains to be seen, since mergers often reduce efficiency in the short term rather than increase it. From a strategic standpoint, however, they certainly represent a retreat from the effort to build a wholly indigenous (or purely autonomous) production capacity for communications satellites.

C. Direct Broadcasting Satellites

Although direct broadcasting satellite (DBS) technologies are in many ways comparable to those for satellite communications, certain differences in operation and subsystem technology make them worthy of separate consideration. Firstly, as their name suggests, DBS systems entail the transmission of television signals "directly" to small receiving dishes located at private buildings, rather than to a central ground receiving station for rebroadcast over cable networks or television airwaves. Due to this operational characteristic, DBS transmission at one time required substantially more power (and transponder amplification) in order for the smaller antennae to be effective receivers. For example, the Traveling Wave Tube Amplifiers (TWTAs) utilized for DBS signal amplification in a transponder were originally required to generate 100 to 200 watts of amplification power, while the TWTAs on a communications satellite typically operate in the 15 to 30 watt range. This characteristic obviously necessitated a substantial upgrade in the level of amplifier technology and imposed power-related constraints on the number of transonders (and thus channels) that could be supported on a given craft.

Such limitations have generally made DBS systems economically inefficient, expensive to develop, and difficult to establish a market and range of suitable programming for[73]. Indeed, for such reasons a structured DBS market has not truly developed in the U.S., despite the fact that the U.S. established the technology in 1974 as part of NASA's ATS-6 (Advanced Technology Satellite) experimental broadcast project (U.S. firms have also produced DBS satellites for the domestic systems of other countries). Nevertheless, various nations (including Japan and France) have supported national DBS projects for some time. These projects were naturally influenced by the transmission requirements described above, as were the international agreements designating orbital space for DBS operations. Over time these agreements even produced a formal definition of a DBS craft - a high powered satellite capable of transmitting directly to an 18-inch dish.

In more recent years, however, higher-gain antennae, more efficient receiving equipment, and improved on-board power systems (as discussed earlier) have enabled the evolution of "medium-powered" DBS systems requiring only slightly larger receiving dishes (24 to 36 inches). As a result of the lower amplification and power requirement, these systems are capable of offering 3 or 4 times more channels than the older systems and are therefore more cost-effective. Furthermore, such systems may be allowed to operate under the broadcasting regulations for normal telecommunications satellites rather than the more restrictive DBS regulations. As might be expected, these developments have caused a great deal of political turmoil in the international telecommunications arena. An additional subject of dispute within Europe has involved the actual technical standards for broadcasting, and the related bandwidth and receiver requirements[74]. This issue has risen in importance because DBS systems are considered very suitable for HDTV transmission (for distributional reasons), and government officials believe that the broadcasting standards should be compatible with that application. Given their potential impact on further development, these issues will be considered in the analysis when appropriate.

Current Capabilities and Projects

As mentioned above, both the French and Japanese space programs supported the development of domestic DBS systems in the early 1980s. The two programs were evidently pursuing what was perceived to be an unoccupied growth market, as well as (particularly in the case of Japan) the societal benefits of such a system. With regard to the Japanese program, early DBS efforts again relied on imported technologies, including a U.S. General Electric bus design and TWTAs from Thomson Tubes Electroniques of France (a subsidiary of Thomson-CSF). In a pattern similar to that for the CS series described earlier, these technologies formed the basis for the experimental BSE project and a follow-on operational series known as the BS-2 (including the 2a and 2b spacecraft, scheduled for launch in 1984 and 1986, respectively). All three spacecraft were of the high-powered type, employing 100 watt TWTAs for signal amplification in the Ku-band. Involving only incremental improvements, the BS-2 spacecraft were each designed to provide two primary channels (with one back-up) for television services, and were intended to produce the operational experience for a later, improved system known as the BS-3. The BS-2 also constituted the first operational DBS system in the world[3, 7]. Despite the prior success with the BSE satellite and the ostensibly proven technologies, the BS-2 series was plagued by recurring technical problems almost from the time of launch. Two of the three transponders on the BS-2a failed within three months, as did the primary three-axis-stabilization system provided by GE. The planned operational services of the system were subsequently shifted to the still functioning BS-2b.

In an unprecedented formal acknowledgment of these difficulties, the prime contractor role for the current BS-3 (a and b) series was given to NEC instead of the previous contractor, Toshiba. This event provides an interesting illustration of the general trends regarding contractor loyalty and associated responsibility in NASDA procurement relationships (as discussed in a prior section). Presumably in response to the failures of the imported technologies (as well as the desire for autonomy), the initial BS-3 project goals also included the greater usage of indigenous equipment and components, including the critical TWTAs[75]. These two actions also seem to signal a serious program commitment to the indigenous development of operational DBS systems. In terms of capability, the high-powered BS-3 spacecraft carry three 120 watt transponders (with three back-ups) and one wideband television relay transponder. Other system equipment packages and capacities are generally similar to the

CS-3 series described earlier[3]. From a strategic perspective, however, a particularly notable aspect of the BS-3 project has been the decision to utilize one channel of the BS-3b (scheduled for launch in August of 1991) for eight hours of daily HDTV programming through Nippon Hoso Kyodai (NHK). The 1990 BS-3a has also been utilized for HDTV demonstrations, providing one hour of experimental programming per day[79]. These decisions clearly indicate an interest in linking HDTV technologies with DBS transmission. Further analysis of this association and its market implications will be provided below.

Despite the programmatic changes mentioned above and the obvious significance of the project, the BS-3 system has also been troubled by a series of technical malfunctions and disasters. Firstly, a short circuit in the GE-built solar panel on the BS-3a has reduced the available power supply by roughly 25 percent. This power reduction is expected to reduce the satellite's operational life and force intermittent shutdowns of at least one transponder[76]. Secondly, the program has undergone a disastrous pair of launch failures involving DBS spacecraft within the last eighteen months. The first failure occurred on an Ariane 44LP in late 1989 and involved a replacement satellite for the disabled BS-2a (purchased from GE-Astrospace). The second failure occurred on a U.S. Atlas vehicle in April of 1991 and involved the BS-3H payload - another replacement satellite purchased from GE-Astrospace. Following these failures, only the aging BS-2b and the troubled BS-3a remain in service[77]. The implications of this situation will also be addressed below.

Although the resulting project decisions have ultimately been different, the French development efforts for DBS systems have demonstrated remarkably similar motivations and operational difficulties to those described above. As discussed previously, these early French efforts involved cooperation with Germany through the Franco-German Eurosatellite consortium and were based on technologies established as part of the Symphonie project. The result was the currently operating, high-powered TDF-1 satellite (and the equivalent TV-Sat for Germany), launched in 1988 on an Ariane. The TDF-1 contains five 230 watt Ku-band transponders (with one reserve) and is expected to provide eight years of design life. The TDF spacecraft also provided 4300 watts of power at the beginning of operation, a necessary feature given the high power rating of the five transponders. In an indication of similar Japanese and French objectives, the TDF-1 was specifically designed for HDTV demonstrations as well as basic DBS services, incorporating the D2-MAC HDTV transmission standard[3]. Also like the Japanese efforts, however, the TDF-1 system has been plagued by a series of technical malfunctions. The first failure involved an exhaust leak in the attitude control system, which in turn led to a short circuit of one TWTA in 1989. Following the upgrade of the reserve transponder to active status, a second TWTA failure occurred in 1990, leaving the satellite with four operational channels. The TWTAs were again supplied by Thomson Tubes Electroniques of France and a German firm[78].

Midway through the development program for the TDF-1, the French program faced a decision regarding a planned follow-on craft, the TDF-2, intended for launch in 1990. Program officials naturally had no way of predicting the later difficulties of the TDF-1 at this time. Nevertheless, out of concern regarding the economic viability of a domestic DBS system and the emergence of the more cost-effective medium-powered systems, officials at the Ministry of Posts, Telecommunications, and Space considered the cancellation of the TDF-2 project (which involved only minor changes). On the basis of sunk development costs and the objective of promoting the D2-MAC standard for European HDTV, however, the Prime Minister ruled that the TDF-2 would be completed as scheduled[3]. This decision perhaps proved somewhat regrettable, as two of the five TWTAs on the TDF-2 failed within weeks of delivery into orbit. These failures collectively reduced the two satellites in the TDF system to eight operational transponders out of the original twelve. Consequently, out of concern for the integrity of the services, the state-owned organization managing the system, TDF, announced in February of 1991 that the two satellites would only provide four DBS service channels, with four transponders serving as back-ups. In response to these disheartening events and the earlier concern about the economics of high-power systems, the French government soon announced that it would not develop another TDF spacecraft.

Strategic Implications

Due to a combination of technology and associated market changes, the two programs face a much different landscape for DBS systems and services than they did in the early 1980s. Moreover, the two programs have encountered substantial difficulties in the development and sustainment of their respective systems. Therefore, it is reasonable to assume that the French and Japanese programs may have modified the earlier objective of establishing an indigenous, or autonomous, niche capability in DBS technologies.

Based on the intended applications of the forthcoming Japanese CBTS demonstration project described earlier, however, the Japanese government has every intention of pursuing further DBS development, albeit with some different approaches. In particular, the 1997 CBTS spacecraft will carry three Ka-band transponders (with one spare) for direct broadcasts of radio and television signals to both buildings and moving vehicles. The suitability of the Ka-band for smaller receivers and, hence, for direct broadcasting and mobile communications, was discussed earlier. An additional feature of the project, however, is the demonstration of HDTV programming as part of the Ka-band direct broadcast demonstrations. Together these efforts signify a continuing Japanese interest in the possible linkage of HDTV programming and DBS systems, with the additional niche feature of operations in the Ka-band. This implied commitment is certainly not refuted by the government commitment shown to the preservation of the endangered BS-2 and BS-3 systems. Although the two satellites purchased for replacement were destroyed on launch, they were nevertheless indicative of a willingness to provide funds for the continuation of the system. This overall commitment to DBS technology can be partially explained by the significance of Japanese DBS systems from a social and domestic market standpoint. In contrast to the market situation for communications satellites, Japan does currently provide a relatively strong domestic market for DBS services, since cable television networks have not established a strong foothold in Japan (only 13 percent of the total number of suscribers for cable or DBS services are cable suscribers). The government also seemingly believes that DBS systems provide a social benefit in that they allow effective television services for outlying islands in the archipelago[79]. Both of these benefits almost certainly augment the acknowledged appeal of this technology area as a potential Japanese niche.

Although the full ramifications of the global market shift to medium-powered DBS systems are not yet apparent, the Japanese program has seemingly chosen to focus on the continued development of new DBS applications, particularly those relevant to other strategic niches. The government conclusion in this regard may have been that the medium-powered technologies are less complex, easier to master if necessary or beneficial, and subject to greater near term competition. By comparison, the Ka-band approach again allows the program to establish a position in a potential growth area. Furthermore, these efforts will be supported by the domestic market, as described earlier. The strength of this market (and its capacity as a base for growth) will be considered further in the niche market section.

With regard to French DBS development strategies, the lack of a sufficiently strong domestic market and the recurrent technical difficulties of the TDF series have apparently convinced the government to withdraw from further pursuit of a national, high powered DBS system. The TDF project will be abandoned at the end of the satellites' useful lives. Instead, the French government has seemingly opted to fall back on the proven method of European cooperation for further DBS development efforts. Indeed, along with Germany, the government is currently working through the Eutelsat organization for the development of a nine nation, multi-satellite DBS system known as Europesat, scheduled for operation in 1995. For the near term, Germany and France (together with Sweden and Italy) have also announced that they will purchase channels on a pre-Europesat, medium-powered direct broadcasting satellite nearing completion by Eutelsat and tentatively scheduled for a 1993 launch. This joint effort, as well as the Europesat consortium to follow, will attempt to establish an HDTV DBS transmission standard for Europe. From this perspective, France has not abandoned the pursuit of DBS technologies (and the related application for HDTV) altogether. However, the French program has apparently retreated from the pursuit of an indigenous niche capability in this arena (once again illuminating the limitations of French autonomy in space). In this sense, the recent policy decisions regarding DBS bear some resemblance to the decisions for future communications satellite development described earlier.

D. Mobile Communications Technologies

As with DBS systems, mobile communications technologies bear many similarities to general communications satellite technologies, and sometimes utilize the same space segment hardware. However, satellite-based mobile communications transmissions are intended for small receivers on moving vehicles and therefore display different operational characteristics. It should also be noted that "mobile" communications services have of course been provided for many years with ground equipment on radio frequencies. Nevertheless, such systems have not proven suitable for certain uses, with one longstanding example being maritime applications. Indeed, as late as the 1950s, maritime applications such as distress systems, position determination, and ship-to-shore communications were still based on the inefficient "brass key" radio telegraph method. With the steady growth of the maritime industry following the end of World War II, an effective form of position location and communication for ships became a necessity.

Inmarsat and GPS

In response to this situation, an international satellite organization similar in form to Intelsat but tailored to maritime applications was proposed to the United Nations in the early 1970s. The eventual result was the International Maritime Satellite Organization (Inmarsat), comprised of fourteen nations (including the U.S. and Japan) in 1975 and now claiming 64 signatories. The organization initially relied on three U.S. Marisats and ultimately incorporated two Marecs leased from the ESA and four leased Intelsat 5 craft. At the present time, 6000 ships and "marine users" (such as ocean-based oil platforms) are serviced by Inmarsat, which provides search and rescue, navigation, and communications services in UHF, L-band (1 to 2 GHz), and C-band channels. These users are required to purchase their own mobile terminals, a fact that has effectively instituted a form of cost threshold for prospective customers and fueled a drive to develop smaller, less expensive terminals. In recognition of potential aeronautical and land mobile service markets, Inmarsat has also obtained an L-band frequency assignment for aeronautical applications and begun an aggressive development plan for land mobile services. However, the land applications are generally considered to be in competition with cellular radio systems and have thus far fared poorly by comparison (as will be seen below)[62].

A separate (but related) system has recently been implemented by the U.S. Navy, with the intent of providing navigational information and position location services for naval ships. Known as the Navstar Global Positioning System (GPS), the system currently consists of 16 satellites and will contain 24 satellites by 1993. In a rather unique decision for the DoD, however, the continuously broadcasting system has been cleared for public "access," meaning simply that potential users can purchase GPS receivers on the market and utilize the system. This development has resulted in the emergence of a secondary (and highly competitive) market for GPS receivers, with both Japanese and U.S. firms currently vying for market position. The targeted user communities primarily consist of outdoor sportsmen such as backpackers and recreational boat owners.

On the basis of the success of Inmarsat and the GPS system, other firms and organizations have recently implemented mobile communications systems in various forms, with examples including Qualcomm, Geostar, and Comsat of the U.S., Eutelsat, Telesat Mobile of Canada, and potential firms in France and Australia. Indeed, some of the U.S. firms have already begun limited, two-way services for land mobile applications[80]. Such market activity strongly indicates that the mobile communications market has (or at least had) been targeted by various nations and firms as a satellite communications growth market with realizable commercial potential. This has certainly been true of the French and Japanese space programs, which have also supported commercial and experimental efforts in this promising yet uncertain arena. Further evaluation of these national efforts and strategies will be provided below.

Current Development Efforts

With regard to the Japanese program, early development efforts have consisted primarily of an experimental package on the ETS-V spacecraft, as well as planned packages on the ETS-VI and CBTS craft. Specifically, the ETS-V package involved two L-band coverage beams for the Northern Pacific and Pacific Rim region, capable of providing position location data and voice communications services to ships, aircraft, and automobiles. Involving far more complex technologies, the ETS-VI project will entail the use of spot and multibeam antenna technologies, on-board switching, and the Ka-band and C-band frequencies in an evaluation of more sophisticated mobile services for maritime, land, or aeronautical applications[14]. As discussed previously, the Ka-band (a now familiar niche target for the Japanese program) is considered particularly suitable for mobile applications due to its potential for very narrow beams and the capacity for operating with much smaller receivers. Similar experiments will be conducted with the 1997 CBTS spacecraft, which will carry two Ka-band transponders designated specifically for voice, data, and video communications with mobile receivers. According to NASDA officials, a related objective for these experiments will be the development of light, omnidirectional antennae and compact receiver terminals[71]. Indeed, both NASDA and NASA (as part of the ACTS project) are hoping to develop handheld receivers that can be produced at low cost. This technology may soon be available, as Inmarsat has already produced a suitcase-sized, two-way unit for interactive use with the Inmarsat system, as has Magnavox[81]. The strategic implications of these secondary markets will be considered below.

In comparison, the French program has to date concentrated its efforts on 1) position location and data collection through the U.S./French Argos system, and 2) the creation of the Locstar company for L-band position location and message services for mobile land users. As discussed previously, both of these systems represent major elements of the overall commercialization efforts of the French program. With regard to the Argos system, the position location and data collection services are based on remote beacons and satellite links, with the space segment consisting of one-way transmission packages installed on U.S. NOAA weather satellites. Operational since 1978, the Argos system is capable of transmitting environmental and location data (gathered with the beacons) in near real time. Approximately 80 percent of the Argos beacons are utilized for scientific purposes, while the remaining 20 percent are used for industrial applications[11]. A similar system for search and rescue purposes, known as the Sarsat-Cospus system, was developed in 1982 with the cooperation of the U.S., Soviet Union, and Canada. The Sarsat system involves similar technologies and methodologies, except the beacons relay distress signals at a different frequency and allow identification of the user. Significantly, French companies have produced most of the Argos and Sarsat beacons in use today. Although these systems involve basic position location technologies rather than those for voice or video mobile communications, they nevertheless serve a legitimate market and seem to constitute a program foothold in one type of satellite-based mobile information services.

With regard to the CNES-supported Locstar company and project, cooperative agreements were signed in 1986 with the Geostar Corporation of the U.S. for a space-based mobile location and message transmission system. The original target market for these services consisted of trucking companies, railroads, and private aircraft (Geostar had already begun limited operations for such customers in early 1990). In terms of technology, the space segment of the system was to consist of "piggyback" digital location/transmission payloads installed on GTE and Inmarsat satellites and utilizing the L-band for operations[11]. Both companies also planned to procure small satellites in the mid-1990s following a projected market growth. Despite the early promise of and government interest in these projects, however, both companies have recently declared bankruptcy and begun the liquidation of company assets[83]. The reasons for this decline vary, ranging from a lack of confidence in the financial communities of both countries to the onslaught of cellular radio services in the target markets. Nevertheless, other companies and organizations are continuing mobile services with some success, including Qualcomm and Comsat of the U.S. and Eutelsat (which is implementing a modest system based on the technologies and receiver terminals of the Qualcomm system). Further consideration of these developments will be provided below.

Market and Strategy Implications

Despite the success of Inmarsat for maritime applications and the apparent market for position location systems, the aeronautical and land mobile communications markets remain highly uncertain and unproven. The emergence of the cellular radio technologies has certainly contributed to this situation, since such technologies are simply more cost-effective for urban areas and provide a higher fidelity voice circuit than satellite-based mobile transmissions. The uncertainties of the land mobile market are illustrated by the demise of the highly visible Locstar and Geostar companies, which originally had major government (in the case of Locstar) and corporate backing. Nevertheless, some type of land mobile service for trucking companies and railroads will probably remain necessary and continue to evolve on a modest level.

Although both the French and Japanese space programs had clearly targeted this arena (or niche) for development at one time, the recent market and technology developments have undoubtably influenced previous strategies and induced modifications. With regard to the Japanese program, project efforts thus far have focused primarily on the experimental development and application of new technologies for mobile communications. This trend, which certainly resembles the technology orientation of the program in other areas, may have been the result of a perception that the market was not yet ready for full scale commercialization. Regardless, in the wake of recent events, the program will almost certainly maintain (at least for the near future) its concentration on niche technology development rather than immediate commercialization of a government-supported system. As in the technology areas described earlier, this approach essentially constitutes one of positioning Japanese firms for potential leading edge applications of mobile systems technologies (particularly in the Ka-band). At the same time, the growing secondary market for receivers and terminals represents a clear commercial opportunity for Japanese firms, particularly given their strength in miniaturized electronics. Indeed, despite the earlier presence of various U.S. firms in this market, Sony Corporation has already begun marketing a 1.25 pound GPS unit at less than half the price of corresponding U.S. units[82]. With the exception of the handheld Ka-band receivers mentioned earlier, however, such efforts will be purely private sector in nature.

In contrast to early Japanese strategies, the French program emphasized the near term development of a commercial system. This strategy was presumably due to a perception that early market entry would yield competitive advantages. As stated above and in the program objectives section, the level of importance ascribed to this potential niche market was partially reflected in the amount of initial CNES backing, as well as the fact that construction had already begun on the ground segment for the system. Despite the initial interest, however, the demise of Locstar clearly indicates that CNES, as well as the French financial community, eventually lost confidence in the potential of the market and withdrew support from the project. In a now familiar development, more recent government statements have indicated that the French program will instead shift its efforts to cooperation with the more modest Eutelsat effort[83]. As in the case of DBS, this policy shift does not represent a complete withdrawal from the arena. Indeed, French firms will surely receive some of the implementation contracts for the Eutelsat system (known as Euteltracs), as in many other satellite-related European efforts. Nevertheless, the new policy indicates that the French program will not pursue an autonomous niche capability (or even niche technologies) in the mobile communications arena. Given the low cost of the Argos system, however, French support for basic position location services of this nature will probably continue.

E. Remote Sensing Technologies

Another rapidly growing field of satellite applications is that of remote sensing, or satellite-based imaging, of the Earth's surface. As with many of the satellite technologies described previously, the general technology for this application was established by the U.S. in the early 1970s, primarily through the Nimbus weather satellite project and the Landsat land sensing program. Since that time, however, the level of U.S. support for civilian remote sensing activities has wavered, while other nations (including France and Japan) have increased their efforts substantially and recently established new civilian applications for this technology. Indeed, the remote sensing arena provides one of the clearest examples of niche sector targeting by the French and Japanese space programs.

In terms of different uses, the applications for remote sensing can be divided into four general categories: sensing of the land, oceans, and clouds (for weather prediction), and military surveillance. Specific uses within these categories vary, ranging from forestry and natural resource studies to oceanography or urban planning. This assessment shall concentrate on the civilian technologies for land and ocean sensing, since the current meteorological systems are generally less complex and the more complex surveillance systems actually involve different technologies (such as on-board photography and digital photo scanning and transmission). Within the usage categories described above, various differences exist in system technology and operation, including the detail of the images (or resolution) and the areas of the spectrum utilized for operations. Resolutions of 10 to 30 meters are commonly used by land sensing platforms, while lower resolutions are frequently used in oceanographic platforms. Higher resolutions of course allow greater detail, but also limit the size of the possible viewing area. In terms of spectrum characteristics, the visible areas of the spectrum are utilized for optical sensing of subjects requiring visual study, while the infrared portion of the spectrum (longer wavelengths) is employed for natural resource studies and cloud or ocean temperature measurements. Microwave sensing technologies by comparison provide the advantage of all-weather viewing and the capacity to more accurately determine surface contours. However, microwave sensors can only produce black-and-white images. Consequently, they are considered more useful for applications such as wave studies or surface contour measurements than color-dependent activities (such as vegetation studies).

Finally, certain distinctions between current sensor technologies warrant further explanation. Such technologies vary widely in form and complexity, ranging from mechanical mirror assemblies to radar antennae, depending on the system and wavelength of operation. Of these technologies, two of the more recent and advanced are 1) an optical system employing lenses and photoelectric cells (in devices known as Charge Coupled Devices, or CCDs) for electronic imaging in the visible and infrared wavelengths, and 2) a system known as a synthetic aperture radar (SAR), for operations in the microwave wavelengths. The SAR technologies are the most recent for civilian applications and involve large antenna panels that detect microwaves reflected off the Earth's surface after transmission by the craft. An additional feature on more advanced craft is that of stereoscopic imaging, or imaging from different viewing angles (off-nadir). Different combinations of these features can be provided on one platform, depending on size or power constraints and the objectives for the system.

Overview of U.S. Capabilities

As stated earlier, the U.S. established civilian remote sensing technologies in the 1970s, but then gradually reduced the level of program emphasis on such activities. In fact, the once revolutionary Landsat system has faced funding battles and near termination on an almost annual basis since the early 1980s. Such problems ultimately led to the privatization of the system in 1984, under the supervision of the Eosat consortium. However, Eosat has only been marginally successful as a private entity, requiring annual subsidies for survival. Nevertheless, given the early entry of the U.S. into both the arena and the market, a review of U.S. sensing technologies and capabilities is necessary for an understanding of later French and Japanese development choices and strategies.

With regard to land remote sensing, U.S. activities remain reliant on the Landsat platform, which has steadily evolved since its 1972 introduction. Five versions of the craft have been developed and launched, while a sixth and more modern seventh version are currently under development. The earlier versions utilized mechanical mirror assemblies and a multispectral scanner for visible wavelength imaging (with a resolution of 80 m), while the transitional Landsat 3 also included the capability for thermal imaging (120 m resolution). Far more advanced in nature, the Landsat 4 and 5 spacecraft are notable for the addition of the advanced Thematic Mapper (TM) device, an imaging system providing higher resolutions (30 m) and capability in more spectral bands. This device was developed for applications such as vegetation studies, near infrared measurements, and thermal mapping. Significantly, however, none of the operational Landsats provide the capability for stereoscopic imaging. The Landsat 6, scheduled for launch in 1992, will add a panchromatic resolution capability of 15 meters and an ocean measurement device. Finally, the expensive Landsat 7 (the completion of which is in doubt) will provide stereoscopic imaging and an additional wide field ocean sensor, with launch currently scheduled for 1996[3].

In terms of ocean sensing, the U.S. conducted the world's first ocean sensing studies with the short-lived Seasat craft in 1978, which also involved the first microwave sensor systems. Two later STS-based ocean sensing projects also investigated microwave applications. Since those early projects and demonstrations, however, the U.S. has relied on the less appropriate Landsat system for ocean studies.

Current Capabilities and Projects

As already stated, both the French and Japanese space programs have dramatically increased their remote sensing activities in recent years, while developing both innovative and (in the case of France) marketable systems. With regard to the Japanese program, development efforts have thus far focused on ocean sensing technologies in general and microwave technologies in particular. The first project of this nature consisted of the Marine Observation Satellite (MOS) system, involving two spacecraft launched in 1987 and 1990, respectively. The MOS design provides low resolution multispectral capabilities in the visible and near infrared ranges for ocean and cloud imaging, a thermal/infrared sensor for ocean temperature measurements, and a microwave sensor based on a dish antenna. The visible sensors utilize the advanced CCD technology described earlier rather than mechanical mirrors. The other sensors are roughly comparable to early Seasat capabilities. Although the MOS system has not been utilized for true commercial activities, the Japanese government has signed agreements with nations throughout the Pacific Region allowing the construction of ground receiving stations for MOS data. In addition to providing operational experience and useful resource data, the MOS has proven its usefulness by allowing a 10 to 20 percent reduction in fuel use by the nation's fishing fleet[3].

In a more dramatic illustration of the Japanese program's orientation to advanced sensing technologies and ocean studies, the ongoing Earth Resources Satellite (ERS-1) project, scheduled for launch in early 1992, has entailed the development of both advanced optical sensors (again based on CCDs) and the sophisticated synthetic aperture radar (SAR) technology mentioned earlier. Intended for two years of operation, the three-axis-stabilized craft will provide images with 18x24 meters of resolution in the visible and infrared wavelengths (for land use and resource studies), and 18 meter resolution in the microwave range. The optical resolution capabilities are equivalent to those of current French satellites and superior to those of Landsat, while the SAR technologies will be the most advanced in civilian use at time of launch. Both systems allow off-nadir viewing and stereoscopic imaging, allowing greater sensing versatility[86]. Given these capabilities, the ERS craft represents a truly advanced level of remote sensing capability. At the same time, the project reinforces the growing Japanese niche capability in ocean sensing technologies. A follow-on project known as the Advanced Earth Observation Satellite program (ADEOS) is still in the planning stages, but is expected to further extend the ocean niche. However, it should be noted that both the ERS and ADEOS projects are considered demonstration projects and are not intended for commercial applications.

With regard to the French program, autonomous development efforts have thus far concentrated on optical remote sensing technologies for land-based applications, although the program is also participating in an ESA project involving ocean studies and SAR technologies (also known as the ERS-1). The land remote sensing efforts have resulted in the highly successful SPOT series, which has been referenced frequently in earlier sections of this work. As described in a previous section, the SPOT platform has been utilized in the ongoing Helios development project, providing a clear example of the overlap often existing between French military and civilian projects. The SPOT project is also interesting in that it was first proposed to the ESA, becoming a French project (with participation from Sweden and Belgium) only after its rejection. In terms of capabilities, the current SPOT 2 satellite, launched in 1989 (following the 1986 SPOT 1 craft), provides resolutions of 20 meters for multispectral images and 10 meters for panchromatic images. Both resolution capabilities are superior to those demonstrated by Landsat. The system also provides stereoscopic capabilities upon customer request - the first civilian example of this technology. Moreover, the SPOT 1 craft was the first remote sensing platform to successfully demonstrate CCD photoelectric technologies, as opposed to the mechanical mirror assemblies used on early Landsats. Although this technology was initially provided to France by Fairchild of the U.S., later SPOT platforms have used CCDs built by Thomson-CSF. Next generation SPOT craft, "scheduled" for launch upon need throughout the 1990s, will add infrared capabilities as part of a sophisticated vegetation monitoring instrument[3].

Although current and forthcoming SPOT craft provide fewer spectral capabilities and instruments than current Landsat craft (and are more concentrated on land sensing), they nevertheless provide certain capabilities that the Landsat satellites are incapable of, as well as more advanced technologies in certain subsystem areas[84]. The apparent competitive theme in these development choices is underscored by the fact that the SPOT Image Corporation was created for marketing system data in 1982 - the same time period in which Landsat support was waning. On the basis of such evidence, it is reasonable to assume that the remote sensing arena was targeted by the early 1980s as a potential niche market for the French space program.

Market and Strategy Implications

With regard to the Japanese program, the technologies selected for development in the MOS and ERS projects demonstrate a clear program interest in the attainment of advanced remote sensing capabilities, particularly for ocean applications. This development strategy once again involves the positioning of Japanese firms for future applications of niche technologies, while providing near term benefits for resource planning and the nation's fishing fleets. In combination with the visible presence of MITI as an agency supporter, these projects also signify the level of emphasis seemingly placed on the remote sensing arena as a potential growth market. This inference is supported by recent corporate discussions of a Japanese-led international remote sensing organization, similar in form to Intelsat or Inmarsat. Although the government has not pledged any funding support for such efforts (apparently due to a belief that it should be a private sector initiative, consistent with SAC policy)[87], these proposals indicate the growing interest in the arena. Nevertheless, for the near term, Japanese efforts will remain oriented to niche technology development rather than system commercialization.

In terms of French efforts, the SPOT system seemingly represents the result of both a niche market strategy and the simultaneous goal of developing remote sensing technologies for later military applications. The development choices described above also indicate that the satellite was intended to provide certain niche capabilities that Landsat could not. As a partial indication of the success of that strategy, the revenues for SPOT Image have grown steadily since the initation of operations in 1986 and now roughly equal those of Landsat. Together the two systems provide the basis for the current world market in remote sensing data and images, as will be demonstrated in the following section. Although this market is still rather small, it nevertheless represents a legitimate niche (albeit a shared one) for the French program.

Current CNES plans call for the replacement of the SPOT 2 with three additional craft on need, although SPOT and Eosat officials have both stated that the growth of the market will be more reliant on new data formats, greater public awareness, and the value-added sector than further improvements to the space segment hardware. On that basis, SPOT has been particularly active in the value-added sector, both internally and with smaller outside firms. Given the available evidence, it would seem that SPOT and CNES have every intention of capitalizing on their current market presence and sustaining this niche[85].

F. Subsystems and Component Technologies

Various space-related subsystems and component technologies have been referenced in prior sections when applicable to those technology areas. Nevertheless, a separate and more thorough analysis of this broad category is warranted, particularly since such technologies seemingly represent a genuine strategic focus of Japanese electronics firms in space-related industries. More generally, these technologies are also representative of the value-added approach often demonstrated by Japanese firms in established high technology arenas. In this usage the term "value-added product" refers to a segment or layer of a larger system, service, or market for which value (or cost) can be measured and added to the value of the overall system. A value-added approach would therefore involve a concentration on the production of such products rather than the integrated system or service itself. Various factors in a national market or production framework might make this approach appear more reasonable, including poor economies of scale in integrated system production, the lack of an easily accessible market, or insufficient production experience on the system level.

In the case of Japanese space-related industries, numerous examples of this scenario seem to exist, with the most readily apparent being the Japanese difficulties in establishing a competitive production base for system-level satellite technologies. At the same time, however, Japanese firms have been successful in penetrating the markets for components and subsystems such as ground stations and transponders. Furthermore, the technological development strategies described in this work have frequently involved a value-added or secondary market component, indicating that Japanese policy-makers actively pursue this niche as well as the more obvious basic infrastructure items. The reasons for this philosophy are surely varied and difficult to quantify, although the more plausible possibilities include the lack of a strong civilian market for many space-related systems, the lack of military demand, and the current existence of a strong, indigenous production base for miniaturized electronics and components. In addition, the aforementioned government policy of encouraging industry to tailor its capabilities to the market (with government guidance and more limited budgetary support) would predictably lead to an industrial response involving the targeting of markets and technologies that are extensions of existing technological strengths. In that sense, Japanese firms are essentially "doing what they can justifiably do" from a business standpoint. These relationships and general concepts will be established relative to specific products and capabilities below. When possible, the Japanese market position in these areas, as measured by revenue and sales data, will also be assessed in the niche market section of this work.

In contrast to Japanese tendencies in this regard, French space-related firms exhibit far less of an orientation to the value-added space markets. Moreover, French program planners seem to emphasize such markets less in overall program strategies, preferring to focus on system-level capabilities for the domestic, military, and European markets (with one example being the case of communications satellites discussed earlier). One reason for this curious attitude may be the reassuring existence of the

European market, and the obvious commitment of organizations such as Eutelsat and Meteosat to European system-level products. This commitment frequently favors the three large satellite manufacturers in France, who also lead European firms in terms of space revenues. Perhaps more fundamentally, however, institutional characteristics such as the centralization of authority in French industry and society, the interventionary nature of the French state, and the related protection of the domestic market do not naturally lend themselves to production areas involving a high degree of process (as well as product) evolution in a shortened time frame. This conclusion was established by Zysman in earlier research pertaining to the French electronics and computer industries[36]. Similar conditions certainly exist in the subsystem, component, and secondary product areas (and markets) for many space industries, which are process-oriented and innovation-intensive. Nevertheless, some French firms have pursued a limited range of subsystems markets. These firms and products will also be discussed below.

Targeted Subsystem Industries and Markets

With regard to Japanese activities in this area, various subsystem niches have seemingly been targeted by Japanese space-related firms, with some genuine success and notable potential for growth. The industrial leaders in these activities have primarily been NEC, Mitsubishi Electric (MELCO), Toshiba, Hitachi, and Fujitsu. Significantly, these firms all normally specialize in various aspects of the consumer and miniaturized elecronics industries, while sustaining wide and diverse product and technology bases from which to operate. Indeed, space-related sales comprise on the average only 1 to 2 percent of the total revenues for these firms[30]. This characteristic most likely encourages the tendency to specialize in space products based on existing strengths, since the firms are in no way restricted to space markets or forced to stimulate demand for those markets. It may also influence the tendency to pursue niche space technologies and markets overall.

In terms of specific Japanese technologies and products, the most successful examples thus far include satellite ground stations, satellite transponders, antennae, and to a lesser degree, VSATs. Other promising areas include such products as DBS receivers, GPS units, and handheld mobile communications units. As discussed previously, the ground stations (which have been the province of NEC and MELCO) are one of the clearest examples of a Japanese niche space technology. Significantly, the expertise in these technologies was acquired during the design and development of microwave communications networks in Japan in the 1950s. Microwave projects have also aided the indigenous development of transponders, since the critical TWTAs that are typically utilized in transponders (as described earlier) are also used in line-of-sight microwave networks and over-the-horizon networks (as well as satellite ground stations)[68]. NEC has also been the industry leader in transponder development, providing many of the transponders for U.S. and Intelsat satellites. Both the transponder and ground station examples clearly illustrate the expected linkage to existing production strengths. In the case of satellite antennae, which must be both lightweight and resistant to severe thermal gradients, Japanese firms have focused on composite materials and advanced production processes in developing fixed beam and horn antennae for Intelsat satellites. Moreover, as part of the ETS-VI and CBTS projects, these firms are also pursuing the development of advanced multibeam and spot beam antennae, which should come into increased use with ACTS-type satellites. It should be noted, however, that U.S. satellite manufacturers are also pursuing such technologies. Finally, although Hughes of the U.S. is the acknowledged world leader in VSAT production, NEC and Hitachi have also been active in this area and have publicly stated their interest in pursuing both a domestic market and the world market for VSATs. Each of these areas represents a legitimate, existing niche capability for Japanese firms in the overall space arena.

In addition to these product niches, certain advanced satellite technologies have apparently been targeted by the Japanese program and Japanese firms for development and application. Of these technologies, the most noteworthy are gallium arsenide solar cells for solar array panels, xenon-fueled ion thrusters for attitude control, and nickel-hydrogen batteries. Although these technologies are not yet in common use, each has been identified as potentially critical for the reduction of future spacecraft weight[61, 88]. Significantly, the gallium arsenide cells have already been successfully implemented on the CS-3 satellite series, while the ion thruster and nickel-hydrogen battery technologies will be evaluated as part of the ETS-VI project[3]. These technologies vary in terms of market readiness, as the solar cells are substantially more expensive than silicon solar cells and ion thrusters are still considered an experimental technology. However, efficient nickel-hydrogen batteries have already been used on certain U.S.-built satellites. Although U.S. satellite manufacturers are certainly pursuing these technologies as well, the emphasis on such technologies in Japanese projects clearly signifies an interest in establishing an early position in technologies perceived to have high growth potential. These efforts are also representative of niche strategies (for advanced satellite subsystems) for the Japanese space program.

In terms of French components, the only possible examples in the current world market for space-related products are those of high-powered TWTAs for satellite transponders (built by Thomson Tubes Electroniques), advanced CCDs for optical sensors (such as those in SPOT), and (to a lesser degree) satellite ground stations. However, the market appeal of the TWTAs has almost certainly been reduced by their poor performance on the French TDF and Japanese BS-2 satellites, while the advanced CCDs are not yet in wide use on remote sensing satellites. The component market for remote sensing satellites is also rather small, since only a few nations currently build such systems. Moreover, U.S. and Japanese manufacturers also have the capability for both of these products. Finally, the limited success with satellite ground stations has primarily been within Europe and its protected market, rather than in open competitions for organizations such as Intelsat. On the basis of such evidence, French space-related industries simply do not maintain a large presence in this sector of the overall space market.

Chapter 7

Niche Markets

Throughout the course of this work, the term "niche" has been used in reference to particular segments (or layers) within general technology areas, classes of system-level capabilities, and space-related markets. Each of these connotations has proven suitable for describing various aspects of current French and Japanese activities in space. For example, launch vehicles have proven to be a successful niche for France relative to both the capabilities of other programs and the general range of space systems technologies. Similarly, Japan has demonstrated a niche approach in pursuing Ka-band technologies within the telecommunications arena and advanced microwave sensor technologies (for ocean sensing) within the remote sensing arena. Numerous variations on this theme were identified and evaluated for both programs in the previous section.

For many of these examples, however, the term "niche market" is not yet fully applicable, as the technologies or systems are still in the development stage, or a market has not yet truly evolved for the particular application. Indeed, such is the case for most of the advanced niche technologies currently under development by the Japanese program. This status does not lessen the value or importance of such technologies and systems as potential niche capabilities, not does it refute the basic argument of this work. Indeed, in many of these cases, the specific niche capability has been pursued (not always successfully) in order to gain access to a perceived niche market of the future. Nevertheless, the lack of reliable market data makes the comparative assessment of such activities on a market basis (as opposed to a technology basis) somewhat impractical in the near term. This difficulty is a common obstacle in market studies of space technologies.

Despite this general limitation for market analyses, certain of the program capabilities assessed in the previous section have reached the commercialization stage and resulted in legitimate niche markets for the two programs. The clearest examples of such capabilities are 1) the cases of the Ariane launch vehicle and the SPOT remote sensing system for France; and 2) the examples of telecommunications subsystems and value-added components and (to a lesser degree) DBS systems for Japan. Although "market" data for space activities are inherently uncertain in nature, a review of these areas from a market perspective provides further substantiation of the niches occupied by the two programs, as well as additional clarification regarding the basic niche concept. Toward that end, the following analysis will first define the general market for the four areas described above, and then provide data as to the French or Japanese position in that market.

Commercial Launch Vehicles

Representing one of the more mature space-related markets, the commercial launch market is primarily comprised of launches for geostationary satellites, with roughly 90 percent of these launches consisting of telecommunications satellites and the remainder of meteorology satellites. This market does not include U.S. government payloads, which are restricted to U.S. launchers, or remote sensing payloads, which operate at lower orbits and therefore do not require the larger commercial vehicles. Soviet payloads are also not included in the market projections.

Prior to the 1986 Challenger disaster and the subsequent market disruption, the annual number of commercial launches varied between six and fifteen launches per year, with peaks corresponding to the replacement cycles for Intelsat and U.S. domestic satellites. After 1986 and the rash of launch failures, a backlog naturally developed (as discussed previously), resulting in an abnormally high rate of twenty launches per year from 1988 through 1990. This annual rate is expected to further increase to roughly 23 launches per year through 1994. Due to the projected elimination of the 1986-87 backlog and the end of an expected replacement cycle, however, the annual demand for commercial launches will decrease to roughly sixteen through the early 21st century (with some analysts predicting a decrease to ten annual launches by the year 2000)[90].

Based on such projections and market information, the dominant market status of the Ariane launch vehicle becomes readily apparent. For example, both of the commercial launches of 1987 occurred on Arianes, while 13 of the available 16 payloads of 1988 were launched on seven Ariane vehicles (due to the dual payload capability)[3].

Moreover, the Ariane was projected to provide launch services for over half of the 18 payloads available for launch in 1989. Although actual scheduling information was not available at the time of this research, Arianespace has also projected that it will safely preserve this 50 percent market share through the mid-1990s[91]. Significantly, this market position has been maintained despite the revival of the Atlas, Delta, and Titan vehicles for the U.S. and the attempted entry of Chinese and Soviet vehicles. Such evidence indicates that the Ariane truly provides both a legitimate niche capability and access to a niche market for France (relative to the overall space arena), regardless of how that opportunity initially emerged. However, it should in fairness be noted that, like the case of U.S. government payloads, the ESA and France limit all commercial payload launches to the Ariane vehicle. Some of these payloads were included in the market projections.

Remote Sensing Markets

In comparison to the relatively mature markets for launch vehicles and many telecommunications technologies, the market for remote sensing data and applications is still small and in an early stage of evolution. Indeed, the total 1990 revenues related to the sale or transfer of remote sensing data have been approximated at 70 million dollars (less than the price of one Ariane launch). These revenues are the result of actual sales to private and government customers and the annual system user fees charged to nations operating a ground receiving station for raw satellite data. Furthermore, all of the remote sensing systems currently in operation rely on government subsidies on some level for survival (as indicated earlier). Despite the modest size of the present market, however, over 250 small companies and organizations now exist worldwide for the value-added enhancement and packaging of raw satellite data. Based on such activity (as well as some optimism), various analysts have predicted a potential market of 400 to 600 million dollars within ten years, perhaps explaining the appeal of these activities to the smaller programs[85, 92].

At the current time, however, the two primary distributors of satellite data are the Eosat and SPOT Image corporations, utilizing the U.S. Landsat and French SPOT systems, respectively. Despite the different capabilities and features of the two systems, these two organizations have basically divided the world market into halves since 1988, when Eosat generated revenues of approximately 20 million dollars and SPOT Image generated 16 million in sales. Given its more recent start-up, SPOT Image has naturally seen a more rapid growth in sales. Both companies have since targeted the value-added data market (both internally and externally) as the critical growth area, apparently in the belief that further hardware improvements will not substantially alter market size or their respective share[85]. Significantly, SPOT Image has been particularly effective with marketing outreach programs and demand stimulation efforts, with a focus on public awareness, quick turnaround time, ready data availability, and user-friendly formats.

Although the SPOT system clearly does not represent a niche or market force comparable in size, degree, or potential to that of the Ariane launch vehicle, the French program has nevertheless established a legitimate niche capability and market in the remote sensing arena - one that CNES and SPOT Image are actively trying to improve, in some contrast to the more troubled Eosat consortium. Through such efforts, the program should be well positioned for the expected growth of the market when it occurs.

Satellite Ground Stations

Various examples of current Japanese niches in satellite subsystems and components have been provided in earlier sections, with the prime examples including satellite ground stations, transponders, and antennae. Given the nature of the component markets, reliable revenue data have been difficult to obtain, particularly for the transponder and antennae cases. The evidence for Japanese positions in these areas has instead been based on reports and articles containing system descriptions and subcontractor information. Nevertheless, viable analyses of the ground station market have been conducted by the Japanese Association of Aerospace Industries, with the most recent study emphasizing the Intelsat system in the mid-1980s. At the time of this study, 350 satellite ground stations had been manufactured and installed worldwide for the Intelsat system since its inception. Of this number, 215 stations had been manufactured by Japanese firms (without foreign subcontractors), resulting in an approximate production ratio of 61 percent for Japan. Based on estimates of the proportion of Japanese subsystems in the remaining stations, the total percentage of Japanese technologies utilized in the Intelsat network of ground stations was calculated to be roughly 70 percent[32]. Although these numbers are hardly absolute in nature, they nevertheless illustrate the extent of the Japanese dominance of this particular niche. The ground station market also provides one of the clearest illustrations of the Japanese value-added approach to space-related markets.

DBS Systems

The case of Japanese DBS systems is perhaps less applicable than the other examples described in this section, since these systems serve only the domestic market in Japan and represent a social as well as commercial objective (as described earlier). In contrast, the examples discussed above all involved international commercial markets. Moreover, the potential (or even desire) to expand these efforts beyond the domestic market, whether on a system, subsystem, or secondary product level, remains unclear and untested. In that sense the DBS case does not truly represent a "niche market" occupied by Japan within the overall telecommunications market . Rather, it is more clearly an example of a niche capability with overall market potential (as also discussed earlier). Nevertheless, since the growth potential of Japanese DBS activities will probably rely on the strength of the domestic market, it is instructive to evaluate the size of this market relative to other nations.

Based on statistics maintained by NHK (the Japanese public broadcasting corp.), 3.8 million Japanese households had subscribed for DBS services by 1991, while current data indicate that 5.7 million will have subscribed by early 1992[79]. As discussed earlier, these numbers far exceed the number of domestic cable subscribers in 1991 (roughly 500,000). Perhaps more significantly, these numbers surpass the projected number of DBS subscribers in all of Europe. Recent analyses of European DBS households have resulted in estimates of 1.5 million subscribing households (including the U.K.). Although these numbers are certainly in a state of flux and involve uncertainties, the difference indicates that the Japanese DBS market is considerably stronger than the European market, while not facing much competition from other broadcasting technologies. It is too early to reliably assess the implications of such trends, particularly given the recent emergence of the medium-powered, more cost effective systems. Nevertheless, it would seem that the domestic DBS market in Japan has the potential to sustain growth efforts - at least in the form of products for secondary markets, and possibly for overall systems. In that sense, Japanese DBS capabilities have legitimate niche market potential.

Chapter 8

Conclusions

Based on the evidence and analyses provided in the preceding sections of this work, it is indeed reasonable to assert that the French and Japanese space programs have evolved into niche market players, particularly in comparison to the larger, more all-encompassing U.S. program. This has been found to be true with respect to specific technological capabilities and objectives as well as certain underlying program goals. As suggested earlier in this work, however, the paths and means used to achieve that end status have differed in both form and substance for the two programs. For example, the French program has relied on a military component of demand, the multinational framework of the ESA, and interventionary commercialization policies for growth. In contrast, the Japanese program has used technology importation agreements, evolutionary development philosophies in concentrated areas, and less interventionary privatization policies to attain its current level of activity. Perhaps more importantly, the term "niche player" has also been found to have different connotations in relation to the two programs and their respective approaches to development. These differences may have significant implications for the longer term growth prospects of the two programs (which are already somewhat constrained by the usage of the niche approach) and will therefore be considered further below.

With regard to the Japanese program, the niche approach has been characterized by a curious paradox between the development objectives for overall systems and the objectives regarding subsystem technologies or potential applications. In virtually every case reviewed in the preceding sections, the program has emphasized rather modest capabilities and characteristics on the system level, while simultaneously concentrating on advanced technologies and innovative applications on the subsystem level. This paradox was observed in the cases of communications satellites (and the corresponding emphasis on Ka-band applications), remote sensing satellites (with the focus on expensive SAR technologies and a small number of instruments per craft, rather than a more standard but also more versatile craft), and to a lesser degree, launch vehicles (with the LE-7 engine and the capable but expensive H-II). In this sense, the development efforts for the Japanese program have emphasized potential niche technologies, and unique applications for those technologies, rather than the near term development of more capable but also less unique systems. Only the efforts regarding DBS systems provide an exception to this general rule, although this technology area has also been unique for the overall lack of a U.S. market presence. The rather inescapable conclusion is that these development activities have been oriented to the positioning of Japanese firms (and the program) for future applications and markets for those technologies, rather than to near term commercialization or system-level markets. This conclusion is consistent with the technological (rather than commercial or industrial) focus of Japanese space policies identified in the earlier space funding section of this work (as well as other works on this subject).

Combined with the low government funding for the program, this version of the niche approach has predictably had a significant impact on the capabilities of Japanese firms in these areas, as well as on private sector development strategies for space-related technologies. Faced with low public sector demand and well established competition from both other nations and alternative technologies, Japanese space-related firms have seemingly been unable to establish suitable economies of scale for cost-effective production on the integrated system level or, in many cases, to even acquire sufficient design and production experience for larger scale spacecraft or systems (without substantial corporate investment). As demonstrated in earlier sections, the impact of these factors is particularly evident in the highly competitive communications satellite arena. Given such factors, moreover, Japanese firms have little incentive to invest corporate funds in the production or further development of most types of operational space systems. Rather, the firms have an incentive to do precisely what they have been doing - pursue component and secondary product markets related to existing areas of competitive production strength. Without question, the capabilities in advanced subsystems will facilitate that pursuit, and may provide the access to (or competitive position for) potential subsystem markets of the future. Nevertheless, without greater governmental support for system development, the firms have little justification for pursuing the high risk, cost-intensive markets for integrated space systems.

These apparent private sector trends are particularly meaningful relative to the longer term goals of the Japanese space program - an increase in private sector investment and involvement, and general autonomy in space activities (including manned spaceflight). As stated above, such investment from the private sector will remain unlikely without a more assured or accessible market to justify it. In that sense, the Pacific Rim market will remain an important testing ground for the growth strategies of the program. If acceptable hardware/financing packages can be developed for Pacific Rim customers, the region may yet provide the level of demand necessary for meaningful increases in private sector activity beyond the value-added activities described above and earlier. The program has certainly focused its development efforts (with the exception of the H-II) on technologies that may prove particularly suitable for the specific needs and operational constraints of the region. Similarly, the development of a legitimate market for Ka-band telecommunications technologies could provide Japanese firms with a niche market capable of supporting further growth and activity without increased government investment. However, neither of these examples is an assured proposition. The Pacific Rim will also be the target of U.S. and European manufacturers, as discussed earlier, while the Ka-band applications market appears very promising but has not yet truly developed. In the meantime, increased private sector "involvement" will probably entail the continued pursuit of value-added markets for components, subsystems, and secondary products (as it has up to this time), and corporate participation in quasi-private consortia such as those described in earlier sections (again for positioning).

With regard to the objective of "full" autonomy, the niche technology approach summarized above has clearly provided the Japanese program with experience in small, concentrated projects rather than larger scale development programs or extended operations. Moreover, these projects have primarily entailed unmanned space technologies and operations, with the ongoing Japanese portion of the space station Freedom constituting the first significant manned development effort. As a result, the program essentially remains unprepared for the technical and management complications associated with full scale development efforts and manned spaceflight technologies and operations. Indeed, the ambitious H-II project has already provided some internal evidence of the difficulties associated with the development of advanced, larger scale space systems, while the U.S. program regularly displays a variety of external illustrations of the cost and scheduling dangers of the megaproject approach. Given the emphasis on accurate scheduling in the Japanese system and the conservative nature of Japanese space development, the H-II may in fact represent a cost and complexity boundary (or limit) for Japanese development efforts within the current funding environment. Such is the case because continued support for more expensive and larger scale projects within that environment could very conceivably jeopardize the mode of operation that has proven successful thus far - the cost-effective completion of smaller scale, focused projects on a steady basis. This prospect seems both unlikely and politically unacceptable given the characteristics of the Japanese system described in the funding section. Therefore, a more achievable form of program autonomy will probably involve the continued support of indigenous capabilities in unmanned launch vehicles and satellites (on a level similar to that existing now), combined with limited participation in projects such as the space station Freedom. More aggressive activities seem unlikely given the current Japanese space funding environment and the lack of sufficient private sector investment in space activities.

With regard to the French program, the term "niche player" has been determined to have an entirely different meaning than that outlined above, both in terms of development philosophies and outcomes. Though the French program has also searched for potential niche opportunities in space activities (such as in the cases of mobile communications, DBS, and remote sensing), it has by contrast oriented its associated development efforts to the establishment of operational systems in the near term and the rapid commercialization of those systems. In keeping with this shorter term philosophy, French technology development efforts have often emphasized low up-front costs and a *sufficient* level of technology for meeting operational requirements and instituting reasonably cost-effective operations. As demonstrated in previous sections, this objective has often resulted in superior performance on the system level relative to Japanese efforts, but fewer advanced or unique subsystem technologies. This statement is not meant to imply that the French program has avoided advanced technology development efforts entirely - the TDF satellites and the SPOT system both involved advanced components at their respective times of development. Moreover, as in the case of the efficient Ariane vehicle, a system can be "advanced" in the operational sense without containing the most sophisticated subsystem technologies. Nevertheless, French efforts have generally not involved the indigenous development of unique technologies or applications, emphasizing instead the attempted development of cost-effective, integrated technology packages.

In view of the available evidence, the French government has seemingly adhered to a philosophy of early market entry in the less mature markets, while relying on the protected European market for the more mature applications markets. From that perspective, the French program has sought niche "markets" within the overall range of applications (such as the remote sensing, DBS, and mobile communications markets), and otherwise relied on the "niche market" of Europe. This far more aggressive approach to technology development and commercialization is in marked contrast to the conservative Japanese approach of pursuing an upstream presence, or capability, for niche technologies or applications. This particular difference may be partially due to the greater French emphasis on the international prestige associated with independent space development and exploration. It may also be related to the more interventionary nature of the French state in market-related activities.

In terms of meeting program objectives, the outcomes of this approach have been rather varied, as well as quite different from the Japanese program. For the cases of launch vehicles and remote sensing satellites, the French program has successfully developed a legitimate niche capability *later* in the development cycle for the technology, and eventually established a strong position in the market on the basis of timing and/or system attributes. The program did not have the advantage of first entry into the market in either case, although the existing U.S. position in both markets was rather weak at the time of entry and European competition was essentially non-existent. As a result, the marketing efforts for both cases were ultimately reinforced (either directly or indirectly) by support from other European nations and a relative lack of international competition. In the DBS and mobile communications arenas, however, the program aggressively initiated a fully autonomous system (primarily for domestic customers) early in the evolving market, but was ultimately forced to fall back on cooperative European ventures. Similarly, in the communications satellite arena, the French program and French firms have begun to rely far more explicitly on European regional satellite systems and global market sharing agreements, as opposed to truly autonomous system-level activities or independent bids for contracts. This case is somewhat different in that the program is still supporting the Telecom system (partially for military reasons) and had never sought full independence from European ventures. Nevertheless, the nature of the previous policies and efforts regarding satellite production imply that France once desired a more independent competitive presence in the realm of satellite manufacturing. Given the recent surge in government supported market sharing agreements and mergers of French and European firms, this policy has also been modified, at least for the near term.

Various conclusions can be drawn about French space-related activities and policies on the basis of these outcomes. The first such conclusion is that, for many system applications, France does not provide a large enough domestic market for an independent French system. Despite the apparent desire to function more independently in many space-related activities, France essentially requires European support and market guarantees for successful development and cost-effective operations. Secondly (and somewhat ironically), the French program has seemingly maintained development aspirations that would be more appropriate for a larger program and nation, despite its resource constraints and the conclusion established above. This tendency, which was discussed on a qualitative level in the earlier funding and program objectives sections, is reflected in the observed desire to establish some type of French system-level presence in the full range of emerging market areas discussed earlier. These development efforts still represented a type of niche approach, since they generally entailed a specific technology specialization within each application area. Nevertheless, the program has generally pursued (though often failing) a wider range of independent, system-level "specializations" than other European programs or the niche technology-driven Japanese program. From that perspective, the French program has evolved into a niche market player, in both the technology and market sense of the word, out of a frustrated necessity rather than a strategic choice. This incongruity exists for Japan on a more superficial level and may have even influenced recent Japanese policy statements and initiatives. Nevertheless, such paradoxes have had a less profound impact on Japanese development philosophies.

An understanding of this characteristic is critical to the analysis of French objectives and potential in space, since it clearly influenced the French-led, prestige-driven ESA decision to develop the Hermes manned spaceplane and (along with Germany) the Columbus space station module. As in the case of the Japanese H-II and space station efforts, these programs signify a dramatic departure from the previous unmanned focus of ESA activities, while representing a substantial increase in technical and managerial complexity relative to prior efforts. Also like the two Japanese projects, however, the Hermes and Columbus projects have already suffered the cost increases and scheduling delays so often associated with megaprojects (a label these projects certainly qualify for). Furthermore, they have introduced an almost unprecedented level of potential discord and political turmoil within the ESA regarding the appropriate completion schedules and resource allocation plans for the efforts. From that standpoint, these projects may actually represent a type of cost and complexity boundary for the ESA (as the H-II does for Japan), in that the level of innovation required for the projects is beyond that which ESA nations have previously encountered (at least on that scale), while the costs may be beyond what many are willing to collectively pay. Indeed, the ESA can be more clearly thought of as a group of niche players, all with different specialties and primary areas of interest, sharing resources and development costs in pursuit of a common goal. Within that framework, the Hermes and Columbus projects have collectively increased the financial risk associated with space development for most ESA nations and very possibly surpassed the level of commitment that many of those nations think such development is worth. Although the final outcome of such political complexities is far from certain, these two projects nonetheless illustrate the difficulties of forcing larger scale efforts into a funding environment and framework more accustomed to the niche approach.

In view of the evidence presented earlier in this work and above, certain general conclusions can be drawn with regard to the longer term growth prospects of both the French and Japanese programs. Firstly, additional projects of the scale and nature of the Japanese H-II or French-led Hermes will be difficult to support in the near term without substantial funding increases from some source. Both of these projects have strained their respective budgets at current program funding levels and dramatically affected the allocation of scarce program resources (as such projects are prone to do). Moreover, they have introduced the political and scheduling ramifications so often witnessed in the U.S. in relation to such projects - ramifications that have thus far been generally avoided by the two programs (at least at this level). In effect, continuous (or numerous) projects of this nature would necessitate a transition to the funding and resource levels of a larger space program (such as that in the U.S.).

As established previously, however, such funding increases for the two programs are unlikely given the overall resource constraints in both nations, the historically low levels of public sector funding for space activities, and the reluctance of the respective private sectors to invest at the necessary level. Even the ESA nations have collectively balked at the combined costs of the Hermes and Columbus programs. Moreover, the current privatization and commercialization efforts of the two programs will not be capable of generating sufficient revenues for the sustainment of general program activities, at least not for the near term. Rather, these efforts have been significant with respect to certain niche markets and for long term positioning, as established earlier. Such evidence indicates that both programs will continue to operate on the basis of limited government funding and resources, while remaining constrained in terms of larger scale activities.

Given these factors and constraints, the two programs - which evolved into niche market players as a result of limited resources and necessity - will most likely continue in this mode of development for the foreseeable future, with full autonomy being improbable. Despite this "constraint" on space development activities relative to the larger programs, however, the French and Japanese space programs represent legitimate and increasingly significant players in the overall space arena, with niche capabilities that compare favorably with those of other programs. Moreover, the evidence presented in earlier sections indicates that the programs are well positioned to maintain their current niches, as well as pursue certain niche markets that are still evolving. For example, the value-added industrial sector of Japan should remain an important asset for the Japanese program, particularly if the miniaturization trend in many telecommunications products continues and Japanese firms continue to penetrate component and secondary product markets. In addition, the DBS arena demonstates clear promise for growth in terms of both secondary product markets and potential systems-level applications. Similarly, the French program occupies a very strong position in the commercial launch market (through Arianespace) and has taken active measures to preserve this position in coming years. As discussed in earlier sections, these measures involve design choices (relative to specific vehicle characteristics) as well as preparations for upgrading the launch facilities of the program. Existing French capabilities in remote sensing technologies and applications should also provide the program full access (through SPOT Image) to the emerging markets for remote sensing products.

Finally, both the French and Japanese programs have established the basic infrastructure necessary for pursuing the space-related markets and applications of the future. For both programs this growing infrastructure includes consortia and state-supported ventures for managing space activities, as well as the space-related systems, technologies, and production capabilities necessary for independent action. Such infrastructure and privatization efforts are significant from the perspective of positioning for future activities, if not always for near term growth or commercialization. Thus, the French and Japanese space programs can be viewed not only as niche market players at the present time, but also as players poised for future applications that may arise. In that respect, the two programs truly represent niche players with evolving assets and roles.

Appendix A

List of Acronyms

ACTS	Advanced Communications Technology Satellite - U.S.
BS	Broadcasting Satellite - Japan
CBTS	Communications Broadcasting Technology Satellite - Japan
CCD	Charge Coupled Device.
CNES	Centre National d'Etudes Spatiales
CS	Communications Satellite - Japan
DBS	Direct Broadcasting Satellite
DoD	Department of Defense - U.S.
ELDO	European Launcher Development Organization
ELV	Expendable Launch Vehicle
Eosat	Earth Observation Satellite Corporation - U.S.
ERS	Earth Resources Satellite - Japan, ESA
ESA	European Space Agency
ESRO	European Space Research Organization
ETS	Engineering Test Satellite - Japan
GEO	Geostationary Orbit
GIE	Groupement d'Interet Economique - France
GPS	Global Positioning System
GTO	Geostationary Transfer Orbit
HDTV	High Definition Television
Inmarsat	International Maritime Satellite Organization
Intelsat	International Telecommunications Satellite Organization
ISAS	Institute of Space and Astronautical Science - Japan

JICA	Japan International Cooperation Agency
JSUP	Japanese Space Utilization Promotion Center
LDP	Liberal-Democratic Party
MITI	Ministry of International Trade and Industry - Japan
MoD	Ministry of Defense - France
MSSC	Japan Manned Space Systems Corporation
NASA	National Aeronautics and Space Administration - U.S.
NASDA	National Space Development Agency - Japan
NATO	North Atlantic Treaty Organization
NHK	Nippon Hoso Kyodai
RSC	Rocket Systems Corporation - Japan
SAC	Space Activities Commission - Japan
SAR	Synthetic Aperture Radar
SSME	U.S. Space Shuttle Main Engine
STA	Science and Technology Agency - Japan
STC	Space Technology Center - Japan
STS	Space Transportation System - U.S.
TWTA	Traveling Wave Tube Amplifier
USEF	Institute for Unmanned Space Experiments with free Fliers
VSAT	Very Small Aperture Terminal

Appendix B

Chronology of Events

1954	ICBM technologies established by the U.S.
1955	Launch of the Pencil Rocket by Japan
1957	Launch of the Sputnik 1 by the Soviet Union
1958	Launch of the Explorer 1 by the U.S.
1958	Formation of NASA in the U.S.
1959	Formation of French committee to study uses of space
1960	Formation of NSAC in Japan
1961	Launch of first human into orbit (by the Soviet Union)
1962	First successful U.S. manned flight
1962	CNES established in France
1963	Signing of interim agreements for Intelsat
1964	Creation of NSDC in Japan
1964	Formation of the ELDO and ESRO
1965	Launch of the Asterix by France (on the Diamant vehicle)
1966	U.S. developed Centaur cryogenic engine
1968	Creation of SAC in Japan, replacing NSAC
1969	Formation of NASDA in Japan, replacing NSDC
1969	Apollo manned landing on the Moon
1970	Launch of the Osumi by Japan
1973	Formation of the ESA
1975	NASDA's first satellite launch (on the N-1 vehicle)
1975	Signing of interim agreements for Inmarsat
1979	First launch of the Ariane vehicle

1980	Formation of Arianespace
1981	Univ. of Tokyo Institute group reorganized into ISAS
1981	First flight of the U.S. Space Shuttle
1985	Japan agrees to participate in the space station Freedom project
1986	Fatal launch of the U.S. Space Shuttle Challenger
1987	ESA approves Ariane 5, Hermes, and Columbus programs
1993	Projected first launch of the H-II vehicle
1996	Projected first launch of the Ariane 5 vehicle

Bibliography

[1] R.C. Hall, "NASA: Thirty Years of Space Flight," Aerospace America, pp.6-9, December, 1988

[2] J. Logsdon, "Evaluating Apollo," Space Policy, pp.188-192, August, 1989

[3] *Interavia Space Directory*, Jane's Information Group,Inc., 1989

[4] *NASA Historical Data Book*, Vol.1, NASA Historical Series, 1988

[5] B. Yenne, *The Encyclopedia of US Spacecraft*, Exeter Books, New York, 1985

[6] T. Pirard, "The Rising Sun," Spaceflight, pp.99-108, vol. 18, March, 1976

[7] *Space in Japan, 1988-1989*, Keidanren Publishing, Tokyo, Japan, 1988

[8] "Space Scientists Gain New Freedom," Science and Technology in Japan, Vol.8, no.32, pp.28-34, Oct./Dec., 1989

[9] "20 Years of Space Applications," Science and Technology in Japan, Vol.8, no.32, pp.20-23, Oct./Dec., 1989

[10] B. Gire, J. Schibler, "The French National Space Programme 1950-1975," Journal of the British Interplanetary Society, pp.51-66, vol. 40, February, 1987

[11] P. Langereux, "France's Silver Anniversary in Space," Aerospace America, p.50-62, vol.25, April, 1987

[12] B. Crozier, *De Gaulle*, Charles Scribner's Sons, New York, NY, 1973

[13] P. Creola, "European-U.S. Space Cooperation at the Crossroads," Space Policy, pp.97-106, May, 1990

[14] *NASDA Information Booklet*, Japan Advance Plan Co., Ltd., Tokyo, 1988

[15] *ISAS Information Booklet*, Tokyo, 1987

[16] Interview with NASDA official, January 15, 1991

[17] D. Okimoto, "The Liberal-Democratic Party's Grand Coalition," paper in collection, *Inside the Japanese System*, ed. by D. Okimoto and T. Rohlen, Stanford University Press, Stanford, Ca, 1988

[18] E.J. Lerner, "Galileo's Tortuous Journey to Jupiter," Aerospace America, pp.19-28,51, August 1989

[19] *Report of the Advisory Committee On the Future of the U.S. Space Program*, known as the Augustine Report, December, 1990

[20] J. Gansler, *The Defense Industry*, esp. pp.72-96, The MIT Press, Cambridge, MA, 1981

[21] J. Bennett, P. Salin, "The Private Solution to the Space Transportation Crisis," Space Policy, pp.181-205, August, 1987

[22] A. Wheelon, "Struggling to Make Space Policy," MIT Lecture Paper, May 2, 1989

[23] *Space Technology to Meet Future Needs*, National Research Council, Aeronautics and Space Engineering Board, National Academy Press, Washington, D.C., December, 1987

[24] *Launch Options for the Future: A Buyer's Guide*, U.S. Office of Technology Assessment, Washington, D.C., July, 1988

[25] "Background Material: NASA Budgets (FY 1988-90)," NASA News, Washington, D.C., 20546

[26] Aerospace Daily, vol.0150, Issue 0026, May 8, 1989

[27] D. Okimoto, "Japan, the Societal State," paper in collection, *Inside the Japanese System*, ed. by D. Okimoto and T. Rohlen, Stanford University Press, Stanford, Ca, 1988

[28] T.J. Pempel, "Organizing for Efficiency: The Higher Civil Service in Japan," paper in collection, *Bureaucrats and Policy Making: A Comparative Overview*, ed. by E. Suleiman, Holmes and Meier, New York, NY, 1984

[29] R. Samuels, *The Business of the Japanese State*, Cornell University Press, Ithaca, NY, 1987

[30] Y. Morino and F. Kodama,"An Analysis on Space Commercialization in Japan," Science and Technology Agency, Tokyo; submitted to the 41st Congress of the International Astronautical Federation as IAF-90-614, October 6-12, 1990

[31] R. Nelson, *High-Technology Policies: A Five Nation Comparison*, American Enterprise Institute for Public Policy Research, Washington, D.C., 1984

[32] R. Kuroda, "The Future Prospects for Japanese Industries: The Role of Private Companies in Space Development," 1988

[33] A. Lawler, "Japan Ups its Space Investment Despite Uncertain Strategy," Space News, p.14, Sept. 24-30, 1990

[34] E. Suleiman, *Politics, Power, and Bureaucracy in France: The Administrative Elite*, Princeton University Press, Princeton, NJ, 1974

[35] E. Suleiman, "From Right to Left: Bureaucracy and Politics in France," paper in collection, *Bureaucrats and Policy Making: A Comparative Overview*, ed. by E. Suleiman, Holmes and Meier, New York, NY, 1984

[36] J. Zysman, *Political Strategies for Industrial Order: State, Market, and Industry in France*, University of California Press, Berkely, Ca, 1977

[37] *European Space Directory*, Sevig Press Publications (sponsored by Eurospace), Paris, France, 1989

[38] P. de Selding, "France Maintains Lead in European Space Industry," Space News, p.6, May 27-June 2, 1991

[39] "Outline of Japan's Space Policy," Space Activities Commission, Japan, June 28, 1989

[40] "Japan Sizes Up an Opportunity," Aerospace America, pp.38-41, February 1987

[41] G. Eberstadt,"History and Management of Japan's Space Program," October 25, 1990

[42] "Japan and the Third World: Co-Prosperity by Peaceful Means," The Economist, pp.25-28, June 17, 1989

[43] "International Cooperation in Space Communications in Asia-Pacific Region," Science and Technology in Japan, Vol.8, no.32, pp.18-19, Oct./Dec., 1989

[44] F. Smith, "Pacific Cooperation," Satellite Communications, pp.34-35, March, 1990

[45] "Japanese Foresee Dim Prospects for Commercial Microgravity Work," Space News, p.14, Feb. 25-March 3, 1991

[46] J. Paolini, "French Military Space Policy and European Cooperation," Space Policy, pp.201-210, August, 1988

[47] M. Mecham, "Gulf War Rekindles European Interest in Developing Military Satellites," Aviation Week and Space Technology, p.59, April 8, 1991

[48] R. Gibson, "Europe's Next Move," Space Policy, pp.186-187, August, 1989

[49] J. Lenorovitz, "Europeans Facing Major Hurdles in Implementing Long-Term Space Plan," Aviation Week and Space Technology, pp.96-102, June 17, 1991

[50] Interview with NASDA official, September, 1990

[51] G. Sutton, *Rocket Propulsion Elements*, John Wiley and Sons, New York, NY, 1986

[52] Internal NASA Memorandum, March 27, 1974

[53] C. Bulloch, "NASDA's New Launchers: Japan Outbids Europe on Technology," Interavia, pp.299-302, March 1986

[54] J.F. Meyers, L.C. Raburn, "The Delta Expendable Launch Vehicle," 24th Space Congress, Cocoa Beach, Florida, 1987

[55] K. Iserland, "Ten Years of Arianespace," Space Policy, pp.341-342, November, 1990

[56] J. Logsdon, "The Space Shuttle Program: A Policy Failure?," Science, pp.1099-1105, May 30, 1986

[57] M. Miyazawa, "Homegrown Technology for Japan's Heavy-Lift Launcher," IEEE Spectrum, pp.51-55, March 1989

[58] "Initial Flight of H-II Launcher Delayed by First-Stage Engine Problems," Aviation Week and Space Technology, p.39, Sept.20, 1989

[59] M. Vedrenne, M. Van Gaver, "Ariane 5 Program," submitted to the 38th Congress of the International Astronautical Federation as IAF-87-185, Oct. 10-17, 1987

[60] P. de Selding, "Advanced Rocket Engine Work Driven by Varying Agendas," Space News, p.1, March 11-17, 1991

[61] M. Dornheim, "Advances to Boost Power, Capability of Commercial Communications Satellites," Aviation Week and Space Technology, pp.124-126, March 20, 1989

[62] A. Wheelon, "Is There a Future for Communications Satellites?," MIT Lecture Series, March 6, 1989

[63] "The Basics Behind VSATs," Satellite Communications, p.4a, February, 1990

[64] L. Keesey, "Strong VSAT Growth Seen in the Non-U.S. Markets," Space News, p.9, Oct.22-28, 1990

[65] R. Stoddard, "ACTS: Implications for the '90s," Satellite Communications, p.16-19, Jan 1990

[66] W.L. Morgan, "CS(Sakura) and CS-2a and -2b," Satellite Communications, January, 1982

[67] "Satellites to Demonstrate Autonomous Capabilities," Aviation Week and Space Technology, July 28, 1986

[68] T. Kuroda, "Competition through Partnership," Aerospace America, pp.68-70, March, 1985

[69] N. Davis, "Japan Advances its Aerospace Timetable," Aerospace America, pp.18-25, March, 1987

[70] N. Davis, "Japan Nurtures Telecommunications on Classic Formula," Aerospace America, pp.32-34, March, 1987

[71] D.J. Marcus, "Japan Takes Next Step in Communications Technology," Space News, p.18, March 25-31, 1991

[72] P. de Selding, "European Space Leaders Call for Industry Restructuring," Space News, p.10, Oct. 1-7, 1990

[73] R. Stoddard, A. Grimes, "U.S. DBS on the Comeback Trail," Satellite Communications, pp.15-19, July, 1988

[74] G. de Vries, "Satellite Broadcasting in Europe: The Politics of Standardization," Space Policy, pp.288-292, November, 1987

[75] S. Smith, "Japan Lofts TV Satellite Loaded with Domestic Technology," Space News, p.13, Sept. 3-9, 1990

[76] D.J. Marcus, "Japanese Pinpoint Reason Behind Power Problem on BS-3a Satellite," Space News, p.16, March 18-24, 1991

[77] K. Dawson, "Japanese Satellite Broadcast Gap Looms," Space News, p.4, April 29-May 5, 1991

[78] P. de Selding, "French, German Suppliers at Odds Over TDF-1," Space News, p.8, Oct. 1-7, 1990

[79] D.J. Marcus, "NHK to Boost Use of New TV Format," Space News, p.4, March 11-17, 1991

[80] D.J. Marcus, "Surging Mobile Satellite Services Lead U.S. Space Industry Growth," Space News, p.4, Oct.29-Nov.4, 1990

[81] R. Saunders, "Low-cost Inmarsat Units Ready for Use," Space News, p.24, Oct. 1-7, 1990

[82] K. Dawson, "Sony Unveils New GPS Terminal," Space News, p.10, July 15-28, 1991

[83] P. de Selding, "Skepticism Over Location Services Spells End for Locstar," Space News, p.7, July 15-28, 1991

[84] C. Voute, "Some Consequences of the Commercialization of Satellite Remote Sensing," Space Policy, pp.307-312, November, 1987

[85] R. Stoddard, "The Selling of Remote Sensing," Satellite Communications, pp.14-20, December, 1988

[86] NASDA Brochure on ERS Project, printed by B.C.C., Japan, 1988

[87] D.J. Marcus, "Japanese Tout International Earth Satellite Agency," Space News, p.15, February 25-March 3, 1991

[88] L. David, "Future Satellites to Carry Advanced Technologies," Space News, p.18, Oct. 22-28, 1990

[89] "Mitsubishi Electric Diversifying Efforts for Space Advances," Aviation Week and Space Technology, pp.81-83, August 25, 1986

[90] "Space Industry - 10-year Survey," Space Policy, pp.250-259, August, 1990

[91] P. de Selding, "Arianespace Foresees Slower Launch Market in Late 90s," Space News, p.16, March 11-17, 1991

[92] G.M. Stephens, "Remote Sensing: Opportunity Waiting to Happen," Satellite Communications, pp.14-16, May, 1991

[93] W. Cook, "The Edge of Infinity," US News and World Report, pp.52-60, May 15, 1989