Chapter 9

# The Political Economy of Spaceflight

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Political economy has a long, distinguished history, going at least as far back as the eighteenth century. Adam Smith's *Wealth of Nations* (1776) is the most famous of these early works; it discussed the complex relationships between economic and political activities while at the same time laying the foundation for classical economic theory. At that time, and indeed continuing to this day, the question of appropriate government policies to spur economic activity to national advantage has remained of paramount importance to national leaders. Spaceflight is a prime candidate for political-economic analysis, largely because the government-industry nexus has remained tightly interlocked. Free-market or laissez-faire policies have seldom if ever applied to space activities, and the classical economic theories that assume the existence of a free market have correspondingly little traction in describing the economics of spaceflight. By contrast, political economic approaches are directly applicable, due to the continuous and intimate interactions of government, industry, and academia in space activities. This essay offers a preliminary exploration of the political economy approach to the subject of spaceflight, so as to provide a few paths upon which future researchers may tread.[1]

1. This approach has been tried at least once before. See M. A. Holman, *The Political Economy of the Space Program* (Palo Alto, CA: Pacific Books, 1974). Many things have changed since that time, most prominently the massive growth of telecommunications and navigation, and the end of the cold war.

## WHY PAY TO GO INTO SPACE?

To begin to understand the political economy of spaceflight, investigators must first understand the reasons why humans are willing to devote significant resources to going into space. Put another way, what do people "demand" that going into space can "supply"?[2]

Rocketeers achieved the first trips into space with the German V2 ballistic missile during World War II. Given that other weapons existed to deliver explosives at long distances, what characteristic made the development of ballistic missiles appealing? It was not merely the ability to deliver at a long distance, because the German Luftwaffe had bombers for that purpose. Rather, it was the ability to do this automatically (without human pilots) and at such high speeds as to make interception impossible (their relative invulnerability in flight) that made them of such great interest. Many nations realized that once the V2 attained operational status a new and enormously destructive weapon now existed, one possessing great speed and invulnerability.[3]

Immediately, space became the new "high ground," coveted by military and intelligence organizations for the same reasons they have always wanted to control the high ground. From high locations, one can see for very long distances to monitor the activities of adversaries. Vast resources have gone into the development of reconnaissance satellites of various kinds. The very first satellite development program in the U.S. was an Air Force reconnaissance program. Although the military was the first to point telescopes and cameras at Earth, science too can take advantage of the high ground to observe various natural and human-made changes to Earth's land, seas, and atmosphere. Weather prediction is vastly improved by viewing the atmosphere from space.

Finally, the sheer difficulty of going into space has posed a challenge and an adventure, which makes for dramatic entertainment and, if successful, garners respect. The space race between the U.S. and the Soviet Union had many facets, but the human flight program in particular was significantly influenced by the challenge and drama of putting and maintaining humans in space. Launches have been and remain a very dangerous affair; the space race in the 1960s put time pressures on both sides to cut corners and try ever-more complex and risky activities, from

2. This is another way of looking at rationales for spaceflight, as in Roger Launius' recent article on the subject. This section differs from Launius' account in that I search for specific characteristics of the space environment that make it useful, whereas Launius' article stresses the reasons typically given by politicians, leaders, and others. Those reasons and rationales often simply assume, without any discussion or direct statement, the characteristics I discuss here. See Roger D. Launius, "Compelling Rationales for Spaceflight? History and the Search for Relevance," in *Critical Issues in the History of Spaceflight,* Steven J. Dick and Roger D. Launius, ed. (Washington, DC: NASA SP-2006-4702, 2006), pp. 37–70.

3. Benjamin King and Timothy Kutta, *Impact: The History of Germany's V-Weapons in World War II* (Rockville Centre, NY: Sarpedon, 1998); Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (New York: The Free Press, 1995).

extravehicular activities (EVAs) to putting men on the Moon. Though less dramatic, the Soviets set many long-duration space records on the *Salyut* and *Mir* space stations as their response to American lunar success.

The robotic space race also had its sense of adventure and exploration, as the U.S. and Soviet Union sent probes farther and farther out into the solar system, with the U.S. in particular making amazing discoveries that caught the attention of the world. More recently, the ability to create "virtual exploration" through Mars rovers in the 1990s and 2000s brought the space program into the homes of anyone with a computer hooked up to the World Wide Web. This form of exploration became increasingly popular to a generation brought up on computer games and the Internet.

The drama of human flight and the wonder of astronomical discoveries interest young people as well as adults. This fact provides another justification for spaceflight: its ability to lure young people to careers in science and engineering. Developed economies require scientists and engineers to function and to continue to spur economic growth through the development of new technologies, making education in mathematics, science, and engineering a priority. Spaceflight lures students into these fields (the "space and dinosaurs" phenomenon), and hence one of its justifications for government spending is as a mechanism to increase the supply of technically capable citizens.

Technical advances often bring economic opportunities and growth. Without question, spaceflight has created or propagated a number of technical advances, some of which have had significant impacts on Earth. Examples include digital imagery enhancement, which is now often used in medical applications; fireproof space suit materials, which are now used in firemen's gear; and testing of food for astronauts, which contributed to food testing programs worldwide. These so-called spinoffs have frequently been cited as reasons for funding the space program. What has made space a particularly effective generator of spinoffs is the fact that the space environment is extreme or unusual in a variety of ways. These differences force scientists and engineers to think in new ways about how to accomplish tasks in space, which in turn create novel technologies and new ideas. Spinoffs have thus become another classical argument for government funding of space activities.[4]

4. NASA publishes its annual magazine *Spinoff* to advertise this aspect of space. See also David Baker, *Inventions from Outer Space: Everyday Uses for NASA Technology* (New York: Random House, 2000). The counter-argument is that you can spend the money directly on those applications on Earth and get more "bang for the buck." The counter-counter-argument is that just allocating money to those Earth applications does not guarantee that people would have conceived of those solutions. In other words, the uniqueness of the application requires people to think differently than they otherwise would do, regardless of the money spent. My opinion is that spending money in two different places gets you two different sets of technology, both of which may be useful but in different ways. There has also much debate about the exact quantity and quality/nature of space spinoffs. Some argue that space programs are very conservative and hence are not really innovators. Others note that in the 1950s and 1960s they were not so conservative. My view leans more toward the innovative side. Some areas have been consistently at the forefront of technologies, such as telecommunications, autonomy, lightweight materials, and certain human physiology applications.

In the long run, space offers the potential of the resources of the universe, which will likely become increasingly important as Earth's resources dwindle through exploitation and use. To date, the only space resource that has been used has been solar power to power spacecraft, but the potential for mineral resources on asteroids and other celestial bodies exists, should the advance of technologies and the economics on Earth or in space make it viable.

One truly final argument has attracted lower levels of interest and funding, although the argument itself goes back to the beginning of modern space activities. In the late nineteenth century, Lord Kelvin argued that the theories of thermodynamics implied that the Sun was only some tens of millions years old and is continuing to cool, implying that life on Earth had not been around that long and furthermore could not survive much longer.[5] Since then, scientific discoveries and theories have furthered arguments about the potential future of longevity of life on Earth. By the 1950s astrophysicists theorized that the Sun will eventually become a red giant star, burning out any life on Earth, though billions of years in the future.[6] However, by the 1990s, scientists had evidence that a massive asteroid hitting Earth millennia ago had caused the extinction of the dinosaurs and many other species on Earth. A similar strike would likewise almost certainly destroy humanity. Finally, the invention of the atomic bomb and the hydrogen bomb by the early 1950s showed that humans had the potential to destroy all human life with human-made weapons.

For all of these ills, many space enthusiasts argue that humans must leave the planet in order to survive. In this case, space is simply "anywhere but Earth," since in the long run Earth is doomed. A more positive view is that humans can build a new utopia away from the perils and contaminating influences of Earth. In both its negative survival and positive utopian forms, this argument entices some to support space advocacy groups and to become involved in the space program. Although this "ultimate motivation" is quite important for many individuals to become involved in space activities and to get space activities started when little funding is available, in practice this has had little economic impact because funding generally requires an appeal to hard-headed politicians and non-space leaders who require near-term, practical uses. The main discernible results of these concerns are modest increases of scientific funding in the 1990s and early twenty-first century to search for near-Earth asteroids.

In summary, space has several enticing features that lure military, civilian, and commercial organizations and individuals to spend money to take advantage of them. Understanding the political and economic processes and structural features by which this money is spent is the task of political economy. Several approaches to

5. Joe D. Burchfield, *Lord Kelvin and the Age of the Earth* (Chicago: University of Chicago Press, 1975, 1990), p. 43 in the 1990 edition.

6. Jean-Louis Tassoul and Monique Tassoul, *A Concise History of Solar and Stellar Physics* (Princeton, NJ: Princeton University Press, 2004).

space economics and commerce appear in the research and trade literature, each of which sheds light on different aspects of the subject.

## The Uses and Abuses of Economic Data

To gauge the economic impact of space activities, it is frequently desirable to provide quantitative measures.[7] As with many other efforts to quantify social activities, this is an activity fraught with methodological dangers and problems. Enumerating a few of the more common complications of providing quantitative measures will provide a counterbalance to the danger of believing too literally some of the more typical quantitative measures provided by various government and nongovernment sources.

In general, we can characterize economic activities as chains of suppliers and consumers. For example, DISH Network provides television service in my home, and I am thus a consumer of a particular satellite service and DISH Network is the supplier. DISH Network in turn purchases satellites from manufacturers such as Boeing or European Aeronautic Defence and Space Company (EADS). In this linkage, DISH Network becomes the consumer and Boeing or EADS the supplier. Similarly, Boeing and EADS purchase thousands of components from various subsystem and component vendors, and so on.

One unfortunately common problem is to count the purchases or revenues at more than one location along the chain, thus doubling or tripling the estimated sector size. There are at least two ways to battle this problem. The simplest is to pick one consistent link in the chain and measure at only that location. Depending on the interest of the analyst, different links will be of more or less interest as the measuring location of choice. This works well to measure the size of a given space sector, such as satellite manufacturing or space telecommunications. Another method is to count only the locations where the money is actually spent on people, which ideally correlates to measuring the number of personnel involved at each link along the chain. This method is helpful in determining structural changes in a sector, such as determining the relative sizes and change in sizes of different companies in a supply chain. For example, analysis shows that in the European aerospace industry, prime contractors have grown in comparison to subsystem contractors in the early years of the twenty-first century.[8]

Another issue is selection of revenues or expenditures to measure money flows. Although it is typical and often required for companies to provide revenue figures, it may be more useful to measure expenditures because expenditures also include

7. The best overview of space economic data sources is Henry R. Hertzfeld, *Space Economic Data* (Washington, DC: U.S. Department of Commerce, Office of Space Commercialization, December, 2002).

8. ASD-Eurospace, *Facts and Figures, The European Space Industry in 2005* (Paris: ASD-Eurospace, June, 2006).

funding acquired through stock sales, bank loans, or other borrowing mechanisms. For example, if one tried to measure the economic impact of the Communications Satellite Corporation in the mid-1960s, measuring revenues would be deceptive because its revenues were very small in comparison to expenditures, as it spent funds raised from stock offerings.[9] A similar problem applies to assessing the impact of the Iridium venture in the 1990s. In this case, the company went bankrupt and thus its money spent to acquire telecommunications satellites ultimately came from outside investors who received little or no return on their investment. In both cases, these expenditures created a temporary spike in satellite communications economic activity.

Government data sources, when available, are often reliable measures but they only cover certain topics of interest to those government institutions. Thus one can get accurate figures on government expenditures, including those to government contractors. Some organizations, such as NASA, gather their statistics into historical data books that are extremely useful for this sort of research. The U.S. Department of Defense's (DOD) space expenditures are well documented and can be extracted for those who have the patience to go through the defense budget line by line, except for "black" programs, which are hidden throughout the defense budget. NASA is required to publish its annual *Aeronautics and Space Report to the President*, which provides a quick and useful overview of government air and space expenditures. The Department of Transportation publishes quarterly reports that provide excellent data on the politics and economics of launchers, whereas the Department of Commerce's Office of Space Commercialization performs a variety of studies and provide occasional reports on major space sectors. The U.S. Census Bureau has its own economic classification system for industries in the U.S., with aerospace products and parts manufacturing (North American Industry Classification System [NAICS] 3364) being the primary category in which space activities are classified. Other nations usually have similar documentation, but access to the data can be difficult for noncitizens and, even when available, the nuances of each system require significant amounts of time and effort to learn. Thus, an international picture of government space expenses is remarkably difficult to acquire. The Space Policy Institute of George Washington University performed an annual survey of civilian space programs and results published annually in *Aerospace America*. Unfortunately, in recent years, this survey has been halted due to increasing national barriers to release of this information.[10]

For corporations, space business is often only one of several product lines, and extracting the proportion that is space-related cannot be easily done unless the companies themselves release data that separates them. *Space News* has annual surveys leading to publication of its "top 50" space manufacturers, and other lists for the top telecommunications operators,

9. David J. Whalen, *The Origins of Satellite Communications 1945-1965* (Washington, DC: Smithsonian Institution Press, 2002).

10. Hertzfeld, *Space Economic Data*, p. 14; e-mail, Hertzfeld to author, 8 April 2007.

direct broadcast companies, and so on. The data are only as reliable as the companies' efforts and willingness to provide accurate data, but are readily available and occasionally useful.

Industry associations also collect a variety of economic data on the aerospace industry. The Aerospace Industries Association (AIA) publishes its annual *Aerospace Facts and Figures* for the United States, while Eurospace provides its *Eurospace Facts and Figures* for the space industry in Europe. The two associations use different methodologies for somewhat different objectives. The AIA data focus on overall aerospace manufacturer revenues and employment, and separates them into air and space domains. Eurospace uses a sophisticated methodology to track expenditures at different industrial levels to do structural analyses, as well as to track the overall revenue and employment figures.

Finally, it is important to use launch statistics, which each nation is required by the Registration Convention to supply to the United Nations. These data, by their nature, are a straightforward "apples-to-apples" comparison of what actually goes into space, without the complications of currency conversions or measurement complexities (though one needs to distinguish between launch attempts and launch successes). Simple comparisons and assessments of launches and the satellites placed in orbit provide an excellent counterbalance to economic data. A couple of examples show the criticality of using these data. One major problem in the assessment of space activities is estimating the economic importance of secret reconnaissance programs, since the economic data remains classified. To get around this problem, by using declassified information about the Corona program and its design we can estimate the rough costs of a Corona satellite.[11] The cost of Thor-Delta launchers of the period can also be estimated from civilian launch data. Combining this with the number of Corona/reconnaissance launches that occurred (which can be extracted from the launch data), one can estimate annual expenditures on these programs.

Another troubling economic problem is estimation of the economic value of Soviet and Russian or Chinese programs. In the case of the former Soviet Union or China, budget figures are not available or, in the few cases where they are, they are unreliable due to the lack of convertibility between capitalist and socialist economic systems. In the case of Russia, the value of the ruble is extremely low compared to the dollar or euro, so reports of Russian government expenditures on space programs lead to a significant underestimate of its economic importance in Russia and worldwide. For all of these types of cases, launch data can provide a means to provide a first order of magnitude estimate.

Overall, it is important to compare the data from these various sources to assess their reasonability, while recognizing the means by which, and the purposes for which, they were gathered. Only in this way can we avoid glaring mistakes and also avoid the all-too-easy belief in the absolute validity of the various enumerations that exist.

11. Despite official classification of Corona satellite costs, this came out in public literature in an interview of a major participant, Frank Buzard, as $5 million per Corona and about $500,000 per camera, for a total of some $5.5 million per Corona satellite. "An Interview with Frank W. Buzard," *Quest* 13/4 (2006): p. 36.

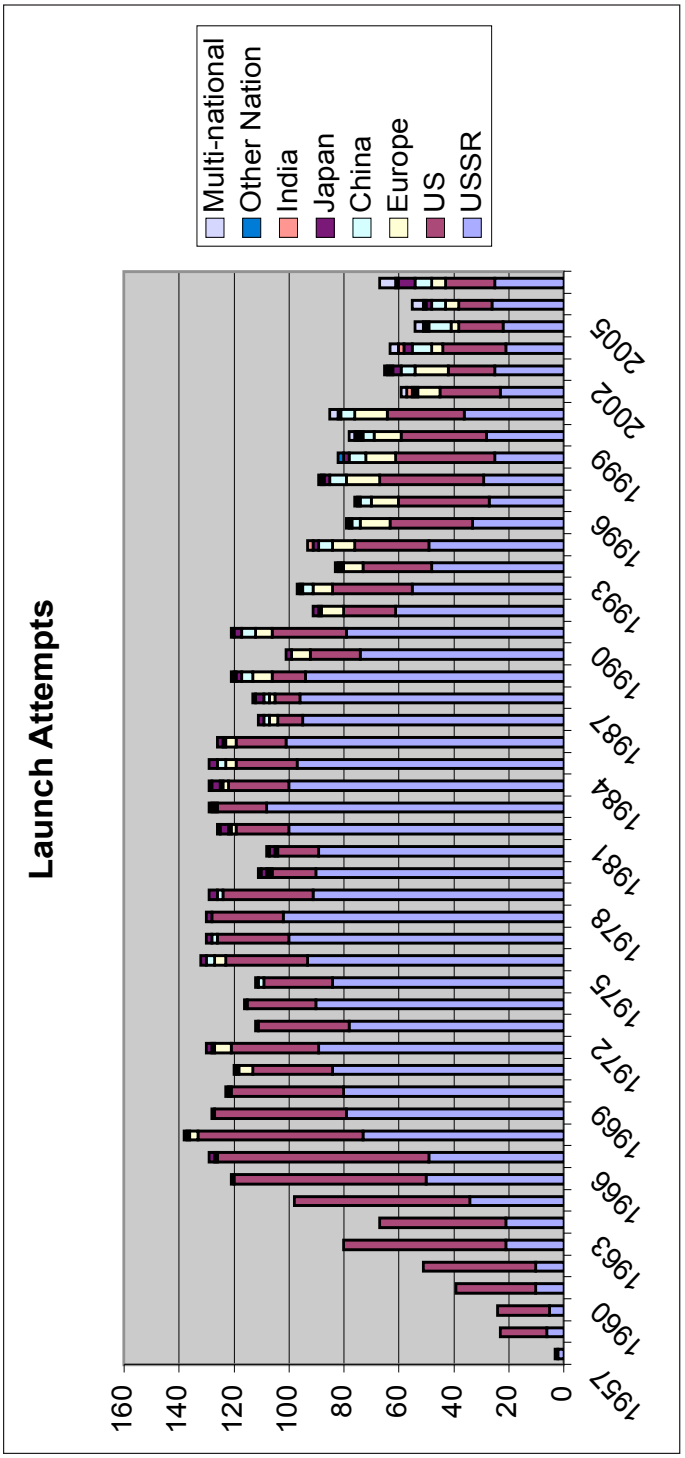


Figure 9.1—Launch attempts by nation, 1957–2005.[12]

12. Data compiled by author, using several sources, including the *1996 TRW Space Log*, the *Aeronautics and Space Report of the President* (annual), the *Quarterly Launch Reports*, Department of Transportation (quarterly), and European Space Vehicle Launcher Development Organisation records from the ESA Historical Archives of the European University Institute. There are several discrepancies between these sources, which I have tried to resolve.

## National View

One common viewpoint from which to assess space programs is a "national view," in which the space activities of each nation are compared. Thus one can compare national government space funding levels, commercial contracts of corporations categorized by nation, the space policies adopted by various nations, the number of satellites launched by each nation, and so on. The emphasis of this sort of classification is usually to assess the relative effectiveness of a nation's government policies as compared to other nations' policies, typically to improve economic competitiveness vis-à-vis other nations.

To take a simple example, an annual tabulation of all orbital launch attempts—categorized by nation and projected from 1957 to the present—gives a simple indicator of the relative scale of investment by each nation in space activities. Shown in figure 9.1, this way of assessing space activities shows that the U.S. and the Soviet Union and its successors have been by far the dominant space powers. Although this is not particularly surprising, what is surprising is how many more spacecraft the Soviet Union launched during the 1970s and 1980s than did any other nation. This seems to indicate that the Soviet Union was the dominant space power during this time. In addition, any thought of the supposed recent demise of Russia as a space power should be exorcised by the continued frequency of Russian launches, both to launch spacecraft from other nations as well as satellites from Russia and the other former Soviet republics.

When we compare instead national government budgets as shown in figure 9.2, we get an entirely different view of the relative economic significance of the U.S. versus the Soviet Union. Here, the U.S. appears as the overwhelmingly dominant space power. Instead of a time series, I here only show a single year because it is extraordinarily

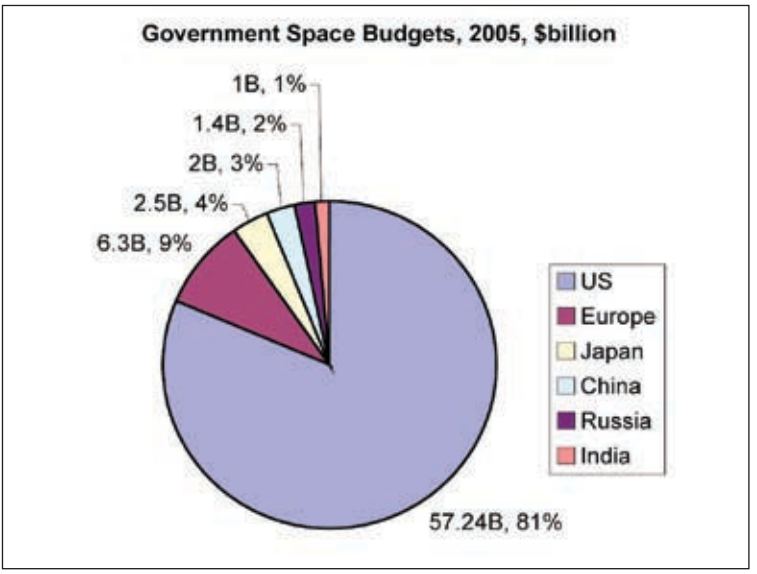


Figure 9.2—Government space spending, 2005.[12]

difficult to compare budget figures for capitalist nations to their communist counterparts. Even when the budget figures can be compared—when both nations are "capitalist" and their exchange rates theoretically reflect the relative value of their currency—these figures remain problematic. Is it really true, for example, that Russia's program is less important at an international level than, say, Japan's? This seems implausible, given the number of launches of each nation.[13]

Even such simple comparisons as government spending have inherent difficulties. To make a fully legitimate comparison, each nation must gather the relevant statistics and those statistics must be comparable from nation to nation. In general, however, the statistics, even when they are gathered, are not strictly comparable. In some cases, the statistics exist but remain classified. Reconnaissance and intelligence budgets are a classic example. Or, in the case of Russia, some of its government space institutions are "commercial" in that they sell their services. For example, is U.S. government funding of Russia to build International Space Station modules to be tracked as a U.S. or Russian figure? Similarly, if South Korea's government purchases a communications satellite from a European vendor, does this reflect South Korean or European space competitiveness? It depends on the question the analyst is trying to answer.

Another way to assess the relative importance of a nation's space program would be to compare the number of citizens employed in that nation's space industry. This is probably a more reliable way to make apples-to-apples comparisons, but the data are difficult to acquire.

Although most national space policies are focused on particular space sectors such as communications or navigation, a few affect many space activities. The most prominent of these in the U.S. are the International Traffic in Arms Regulations (ITAR). Since space technologies are by their nature tied to a host of military concerns, they are subject to ITAR. This has been particularly important in the export of communications satellites. In 1999, Congress, responding to perceived technology transfer of American satellite technologies to China, placed communications satellites on the "munitions list," governed by ITAR. The transfer of export licensing authority from the Department of Commerce to the Department of State significantly hurt American manufacturers, as the regulations have slowed and in some cases prevented export of American satellites, to the benefit of European companies.[14]

The purpose of these national comparisons is often to assess relative national economic competitiveness so as to determine the effectiveness of space policies. Although in a general sense these figures provide a relative scale of activities by different nations, they are largely useless for policy assessment. This is because space policies largely refer to specific sectors of space, such as navigation, space launch, remote sensing, human flight, or science. In other cases, the policies refer to intergovernment

13. ASD-Eurospace, *Facts and Figures, The European Space Industry in 2005* (Paris: ASD-Eurospace, June, 2006), p. 12. European Governments spent €2.662 billion on space products in 2005.

14. James A. Vedda, "Space Commerce," in *Space Politics and Policy: An Evolutionary Perspective,* ed. Eligar Sadeh (Dordrecht, The Netherlands: Kluwer Academic Publishers, 2002), pp. 219–220.

relations, technology transfer, regulations over foreign corporate ownership, and so on. It is very difficult to translate from a policy decision or proposal to an unambiguous impact on the overall space budget or launch figures. These figures are generally too high to be of direct utility. We must use other means to be politically useful.

## Functional View

Another typical way to assess space activities is by functional view: military, civilian, and commercial. This tripartite division recognizes that there are three very different motivations, and usually three very different sets of organizations, that are involved in space.

The military, which for the purposes of this paper will include civilian intelligence-gathering organizations, exists to provide national security. For millennia, the military has had its own unique set of institutions, starting with armies and navies, expanding to include air forces in the early twentieth century, and space assets with the advent of the Space Age. Initially controlled by the military, space endeavors were the province of one or more of the armed services.

In the Soviet Union there was no strict separation of military and civilian efforts and, of course, no commercial activities in the socialist state. The Ministry of Armaments controlled the development of ballistic missile and space programs until 1965, when they were transferred to the Ministry of General Machine Building. The Air Force trained cosmonauts, and from 1959 to 1981 the Strategic Missile Forces, a branch of the military, operated all ballistic missile and space systems.[15] Was the launch of Yuri Gagarin in April 1961 a "civilian" activity, even though it was operated by the military? Similarly, the Soviet space station program of the 1970s and 1980s consisted of stations for both military (Almaz) and civilian (DOS—Long Duration Station) purposes, but both programs were operated by the military and all were called *Salyut* and proclaimed to be civilian systems.

Initial space efforts in the U.S. were divided between the three military services: Army, Navy, and Air Force. All three services began developing ballistic missiles and satellites. The Army's primary space organizations, the Army Ballistic Missile Agency and the Jet Propulsion Laboratory, were transferred to NASA by 1960, at which point Army space efforts focused on antiballistic missile systems and satellite communications. While the Navy's Vanguard program and personnel were transferred to NASA, the Navy managed to retain most of its space organizations, which concentrated on space navigation, communications, and with the National Reconnaissance Office, reconnaissance. The Air Force garnered the lion's share of military space programs, with the primary roles for space system development and space launch. It was involved with space reconnaissance, communications, navigation, tracking, and a host of other functions.

15. Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA SP-2000-4408, 2000), pp. 891–895.

The U.S. civilian space program came into official existence in 1958 when NASA was created to manage the civilian space effort separately from military space activities. Civilian space programs are intended for the "public good," including programs for weather forecasting, technology development, national prestige, education, and science. Separation of civilian from military space efforts in the U.S. is not always obvious. For example, the U.S. Navy ran the Vanguard program, which was intended for "civilian" scientific purposes. Although generally categorized as a military space activity because the Navy ran the program, its function was civilian in intent. Many science and technology programs are similarly difficult to classify. So, for example, the Clementine probe to the Moon was a military program to test technologies but it performed civilian science functions. Many geodetic satellites are run by civilian institutions but were mainly motivated by military purposes, such as ballistic missile targeting. It has been customary to consider all nonmilitary government space expenditures (that is, money spent by any government institution not part of the DOD, with the exception of intelligence) as "civilian."

Other civilian space programs came into being in a number of nations soon thereafter, sometimes as national civilian agencies, such as France's Centre National d'Études Spatiales (CNES), and sometimes divided among a variety of institutions, as occurred in the United Kingdom, West Germany, and Japan.

Commercial space efforts began very early in the U.S., with the launch of American Telephone & Telegraph's (AT&T) privately funded the Telstar satellite in 1962. The International Telecommunications Satellite Organization (Intelsat) came into being in 1964 as a multinational consortium to run the international communications satellite network. Although the U.S. created a private corporation, the Communications Satellite Corporation, to manage its shares in the new organization, other nations usually assigned government organizations to represent their interests in Intelsat. This is because most nations ran their telephone networks as national public services. So, although Intelsat has usually been classified as "commercial" by American analysts, other nations considered it a civilian activity.

Many private corporations depend mainly or even totally on government funding. For example, the private space company United Space Alliance, a joint venture of Boeing and Lockheed Martin that services the Space Shuttle, is totally dependent on the government. Is it "commercial"? A number of space companies that did not depend on government funding, such as PanAmSat and DirecTV came into existence by the 1980s and 1990s.

Other commercial-civilian hybrids abound. Arianespace and SPOT Image were established as commercial companies but were partly owned by the French government, whereas the launchers and satellites they operated were developed by governments (the European Space Agency [ESA] for Arianespace, and France for SPOT Image).[16]

16. J. Krige, A. Russo, and L. Sebesta, *A History of the European Space Agency 1958–1987*, Volume II (Noordwijk, The Netherlands: ESA SP-1235, 2000), pp. 472–481.

After the collapse of the Soviet Union, the Russian government institution Khrunichev sold launch services to other nations and to private entities, and owns shares of private companies. In the space launch industry, it is customary to classify any launch that is up for bid by launch providers as commercial. This can be true even if the launch provider (supply) and the satellite owner (demand) are government-owned! Commercial often means "competed," not necessarily "private." Other confusing cases have existed in the past, such as when private companies Martin Marietta and General Dynamics competed with the U.S. government (NASA) and with the European public-private hybrid company Arianespace to launch Intelsat satellites in the early 1980s. Certainly there was competition, but in this competition private entities such as Martin Marietta and General Dynamics stood little chance against the rival governments. Of course, one can also question how "commercial" Martin Marietta and General Dynamics really were, since the vast bulk of their funding (and many upgrades to their launch vehicles) were funded by the U.S. government.[17]

One government's military or civilian expenditure is often a commercial company's profit or another government's revenue, so it is often a matter of choice or convenience to decide whether an expenditure or revenue is military, civilian, or commercial. Even with all of the complications just described, the tripartite division of military, civilian, and commercial does provide more visibility into the relative scale of activities, now divided by major function: national security, public good, or economic profit. This gives a somewhat more informative view of the relative scale of activities for these different national functions.

Figure 9.3 shows the relative size of military, civilian, and commercial activities in the U.S. in 2005, as defined by government expenditures for military and civilian purposes, and by revenues for commercial activities. Strictly speaking, these are not the same things and so the comparison is not as direct as one would like, but the statistics on commercial activities are usually based on revenues, not expenditures. If one could construct similar statistics for other nations, national comparisons could be made regarding the relative priorities of each nation. It is quite clear that after the collapse of the Soviet Union, U.S. military space expenditures far exceed those of any other nation, with Russia probably remaining in second place and China third, with Europe not too far behind China. Figure 9.4 shows the relative proportions of European space activities, which shows the much smaller proportion of expenditures on military space as compared to civilian and commercial activities. Expenditures by all other nations are significantly smaller than these four. Israel's space activities also have a large military slant, and recently Japan has funded military space activities for communications and reconnaissance.

17. Joan Lisa Bromberg, *NASA and the Space Industry* (Baltimore, MD: Johns Hopkins University Press, 1999), pp. 124–132.

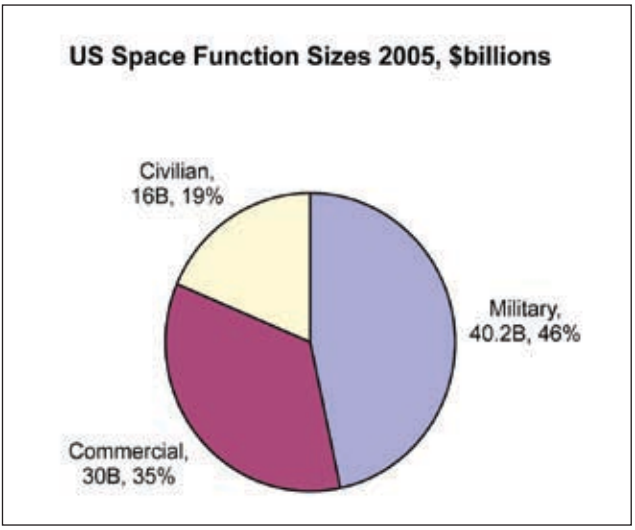


Figure 9.3—Relative size of U.S. space functions, 2005.[18]

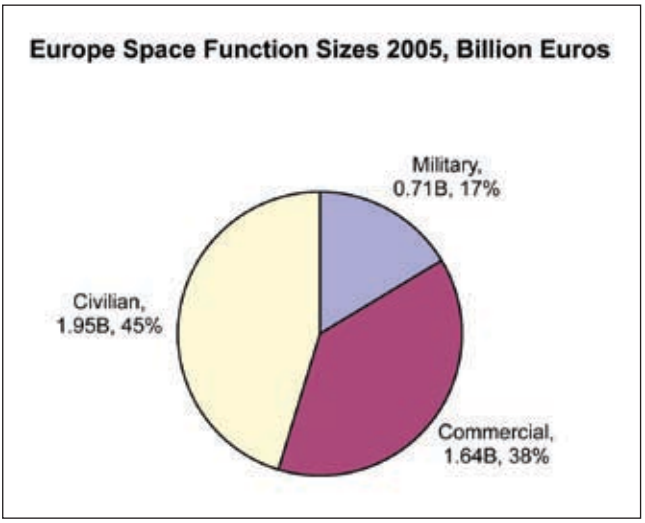


Figure 9.4—Relative size of European space functions, 2005.[19]

18. These civilian and military figures come from the 2005 U.S. national budget, Budget of the United States Government, Washington, DC: Government Printing Office. It can be found online at *http://www.gpoaccess.gov/usbudget/* (accessed January 2007). The commercial figures is a rough estimate derived from several sources, including Space Foundation, *The Space Report 2006* (Colorado Springs, CO: Space Foundation, 2006), the International Space Business Council, and Department of Commerce publications.

19. ASD-Eurospace, *Facts and Figures, the European Space Industry in 2005* (Paris: ASD-Eurospace, 2006), p. 12.

The major trend over the nearly 50 years of spaceflight has been the growth of commercial activities relative to civilian and military expenditures. From essentially zero in the 1950s, by the early twenty-first century the commercial aspects of space have grown to significance, with revenues in the tens of billions of dollars each year. Military spending has remained relatively constant or growing over the years, whereas civilian space spending has remained essentially fixed after the initial bump of the 1960s space race.

## Institutional Structure

A typical economic view of an industry subdivides that industry into the major suppliers and then lower-tier companies down the supply chain. The lowest tier provides small components to the next higher tier, which integrates them into larger units, and then ultimately to the top-tier provider, which provides the full system or service to the consumer. This type of analysis can be applied to the space industry or, more accurately, to the aerospace industry.[20]

While some "pure" space companies exist, many space products are supplied by larger companies with diversified product lines. In most, though not all, cases, these are aerospace companies that provide a host of aviation, space, and defense products to governments and to other companies. Boeing is one of the best known, being most famous as a commercial airline manufacturer. However, in 2006 Boeing also manufactured the Delta launcher, a variety of commercial, civilian, and military satellites, and many other defense-related products, along with a few other smaller lines of business. The EADS is the largest European aerospace manufacturer, with a similarly diversified portfolio.

The largest companies, which supply entire launch vehicles, satellites, aircraft, and missiles, are known as prime contractors. After decades of consolidation, in the U.S. and Europe these had been reduced to a very small number: Lockheed Martin, Boeing, Northrop Grumman, Raytheon, EADS, and Alcatel. These gigantic companies consisted of what had formerly been many smaller companies, though in their time these had been considered large prime contractors in their own right, such as Douglas, Martin, Messerschmidt, Hawker Siddeley, McDonnell, Grumman, Sud-Aviation, Dornier, North American, and so on.[21] The massive prime contractors

20. Definitions of prime, subcontractors, and component suppliers can be found in U.S. General Accounting Office, "Best Practices: DoD Can Help Suppliers Contribute More to Weapon System Programs," (March 1998) GAO/NSIAD-98-87. See also Keith Hayward, *The World Aerospace Industry: Collaboration and Competition* (London: Duckworth & RUSI, 1994), p. 6.

21. Roger E. Bilstein, *The American Aerospace Industry* (New York: Twayne Publishers, 1996), pp. 117, 176–177, 215–218; Bromberg, *NASA and the Space Industry*, pp. 12–13; European Aeronautic Defence and Space Company, *On the Wings of Time: A Chronology of EADS* (2003), found online at *http://www.eads.com/1024/en/eads/history/wings_of_time/wings_of_time.html* (accessed January 2007); Alcatel-Lucent Web site, *http://www.alcatel-lucent.com* (accessed July 2007).

engaged in horizontal consolidation (merging with their peer prime contractors) and vertical consolidation (acquiring lower-tier companies that supplied components, subsystems, and services to them). One can see Marxist capitalist dynamics behind many of these mergers. During economic slowdowns, less profitable companies exit the market, go out of business, or are acquired by more successful firms.

These mergers could not have occurred unless the governments of the relevant nations approved, or at least declined to intervene to prevent them.[22] Antitrust regulations in the U.S. and Europe meant that mergers were reviewed to ensure they did not unduly hamper competition. In Europe, additional complications ensued because the mergers needed to create companies on the scale of the American behemoths had to cross national lines. No single European nation had a large enough aerospace industry to compare with the American domestic market. In both the U.S. and Europe, many mergers occurred from the late 1940s through the 1960s, and then again in the 1990s and early 2000s. The truly massive companies that exist in 2006 came into being only after the DOD—no doubt in consultation with other parts of the U.S. government—told the major aerospace companies in 1993 that now that the cold war had ended there was not enough business to support them all at the levels to which they were accustomed, that there would be fewer of them after a few years, and that the U.S. government would look favorably on consolidation.[23]

Observing events in the U.S., European aerospace officials in both private industry and government concluded that they could not compete with the U.S. unless they, too, allowed the formation of truly massive companies. By the early 2000s, the European consortia and so-called national champion companies merged into the multinational aerospace companies EADS and Alcatel, on scales nearly the size of Boeing and Lockheed Martin.[24] One could argue that Marxist dynamics apply—governments, responding to or in submission to the large companies, allow them to merge, though many of the conditions attached to various mergers somewhat weaken the argument.

Below the giants are second-tier companies. These are often very large companies in their own right, often with significant or preponderant business interests outside of aerospace. In the U.S., these include companies such as Honeywell, well known for building thermostats for private homes but also a primary builder of avionic systems in aerospace; International Business Machines (IBM), the world's largest computer manufacturer; Bendix, supplier of a variety of electronic

22. For a general discussion of these mergers prior to 1994, see Keith Hayward, *The World Aerospace Industry: Collaboration and Competition* (London: Duckworth & RUSI, 1994), chapter 3.

23. Walter J. Boyne, *Beyond the Horizons: The Lockheed Story* (New York: St. Martin's Press, 1998); John A. Tirpak, "The Distillation of the Defense," *Air Force Magazine* (July 1998), *http://www.afa.org/magazine/July1998/0798industry.asp* (accessed 13 January 2007).

24. European Aeronautic Defence and Space Company, *On the Wings of Time: A Chronology of EADS* (2003). Alcatel-Lucent Web site, *http://www.alcatel-lucent.com*, (accessed July 2007).

components; Litton, manufacturer of gyroscopes and other electronic systems; Pratt & Whitney, builder of jet and rocket engines; rocket engine manufacturer Aerojet; and a number of others.

Some second-tier suppliers also build full systems as well as components. They are considered second-tier mainly because they are much smaller than the giants. Orbital Sciences is a typical example, building small satellites and launchers. Ball Aerospace, which is a part of the larger Ball Corporation known to homemakers as the maker of fruit jars, has built many scientific satellites over the years and is a manufacturer of star trackers.

Below the subsystem suppliers are component suppliers. These consist of hundreds of small companies, each of which typically specializes in a small set of products. Examples include Adcole, a well-known maker of sun sensors; Eagle-Picher, the manufacturer of most space-qualified batteries; and Moog, which manufactures actuators.[25]

One can analyze the relative success of these tiers, as shown in figure 9.5. From 1997 to 2002, second-tier companies in Europe declined dramatically in comparison to first- and third-tier corporations, based on the political-economic dynamics of the mergers during that period.

Political factors influenced the formation of collaborations between private companies and with governments. European companies formed complex alliances, becoming official consortia starting in the late 1960s and 1970s to ensure that each nation that contributed to a space project's funding would benefit by contracts to companies in their nations in return. In 1995, Lockheed Martin and Rockwell International (later Boeing) created a joint venture known as United Space Alliance to operate the Space Shuttle, as the U.S. government pressed for privatization of Shuttle operations. The fall of the Soviet Union presented new opportunities for multinational joint ventures between launcher companies and organizations, such as International Launch Services (Lockheed Martin and Khrunichev State Research and Production Space Center),[26] Starsem (Arianespace, EADS, Russian Federal Space Agency, and Samara Space Center),[27] and Sea Launch (Boeing, Rocket and Space Corporation Energia [RKK Energia], SDO Yuzhnoe [Ukraine], and Kvaerner ASA).[28] These organizations, which had both Russian and Western ownership, made it easier for the U.S. and European governments to purchase Russian launches. Because Western companies profited by the purchase of Russian launch services, purchasing the significantly cheaper Russian launches was made more politically palatable.

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25. Many examples of various-sized suppliers can be found in, for example, *2004 North American Space Directory,* 7th ed. (Bethesda, MD: Space Publications LLC, 2004), *http://www.SpaceBusiness.com* (accessed January 2007). Similar directories exist for Europe.

26. International Launch Services Web site, *http://www.ilslaunch.com/aboutus/legacy/* (accessed 13 January 2007).

27. Starsem Web site, *http://www.starsem.com/starsem/starsem.html* (accessed 13 January 2007).

28. Sea Launch Web site, *http://www.boeing.com/special/sea-launch/* (accessed January 2007).

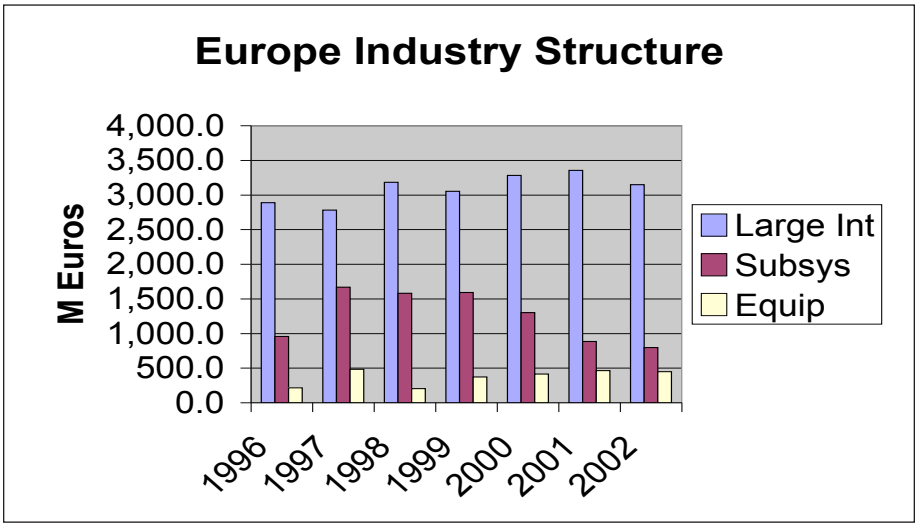


Figure 9.5—Turnover of first-, second-, and third-tier suppliers in Europe from 1996–2002 *(Source: Eurospace).*

Some joint ventures, such as International Launch Services, included government organizations as partners in a commercial enterprise. In other cases, such as Arianespace, SPOT Image, and RKK Energia, governments owned some shares in the otherwise private companies. In many of these cases, the owning governments turned over designs, hardware, or facilities to the company they owned, with the agreement that the private company merely had to cover the operational costs but not the development costs of the systems given to them. Governments also create commercial arms of their organizations, such as Antrix Corporation, the commercial arm of India's Department of Space.[29]

Governments also hired or created nonprofit organizations to perform various functions related to space activities. In the U.S., The Aerospace Corporation and Mitre Corporation were both created with the guidance and approval of the U.S. Air Force (USAF) to provide "systems engineering and technical direction" to private contractors building space systems. The Aerospace Corporation, created in 1960, performed these functions initially for the USAF ballistic missile programs and later for USAF space satellite programs.[30] Mitre did the same for electronics and command and control systems such as the complex built at Cheyenne Mountain, Colorado, for the North American Aerospace Defense Command (NORAD).[31]

29. Antrix Web site, *http://www.antrix.gov.in/* (accessed 13 January 2007).

30. The Aerospace Corporation, *The Aerospace Corporation: Its Work, 1960–1980* (El Segundo, CA: The Aerospace Corporation, 1980).

31. Davis Dyer and Michael Aaron Davis, *Architects of Information Advantage: The MITRE Corporation since 1958* (Newport, RI: Community Communications Corporation, 1998).

Other nonprofit institutions were hired to perform functions normally run by government organizations, such as the California Institute of Technology's Jet Propulsion Laboratory (JPL), which was initially hired by Army Ordnance to build ballistic missiles. It then became, in effect, a NASA field center, building and managing most of NASA's deep space probes and its Deep Space Network. JPL often hired and managed contractors just as other true government organizations did.[32] The Johns Hopkins University Applied Physics Laboratory (APL) became a prime contractor both for the DOD and for NASA, competing against profit-making corporations to integrate and operate satellites.[33] The Charles Stark Draper Laboratories of the Massachusetts Institute of Technology built components, such as the Apollo inertial guidance system, and Stanford University built the Gravity Probe B satellite for NASA.

Government space organizations also vary significantly from country to country. Although many nations, including the U.S. and France, quickly centralized their civilian space programs, others, including Japan, Canada, the Soviet Union, Germany, and the United Kingdom, operated space programs for decades before creating national space agencies. Many smaller nations continue to operate their space programs without a centralized civilian space agency. NASA initially centralized civilian space programs but, since the 1960s, other civilian and commercial institutions have gained access to, and eventually some control of, various space programs, such as the National Oceanic and Atmospheric Administration's (NOAA) operation of weather satellites and some remote sensing satellites.

Military programs also showed a variety of institutional forms. Generally speaking, tension existed between the civilian and military institutions and also between the regular armed services (Army, Navy, Air Force) and other military and intelligence institutions over control of space activities. In the U.S., the USAF was the predominant space organization but the Army and Navy retained significant programs; the intelligence agencies maintained significant interests and their own programs, either individually or shared with the military services. The DOD established its own space organizations at times, such as the Missile Defense Agency, the descendant of the Strategic Defense Initiative Organization. Early on, the Soviet Union created separate organizations to control many space activities as part of its Strategic Rocket Forces. In 2001 these became the Space Forces.

By the nature of the communist state, the Soviet Union developed all of its initial space programs as government institutions. Initially these were "special design bureaus" (OKBs) that performed the research and development activities to create

32. Clayton Koppes, *JPL and the American Space Program: A History of the Jet Propulsion Laboratory* (New Haven, CT: Yale University Press, 1982).

33. William K. Klingaman, *APL—Fifty Years of Service to the Nation: A History of the Johns Hopkins University Applied Physics Laboratory* (Laurel, MD: Applied Physics Laboratory, 1993).

the novel technologies of ballistic missiles and spacecraft. The design bureaus were either newly created or modified from former scientific research institutes (NIIs). Once designed, manufacturing of these systems was assigned to manufacturing facilities, most typically old World War II plants. Over time, alliances between the design bureaus and manufacturing plants stabilized, and in the 1970s they were combined into scientific-production associations (NPOs). With the collapse of the Soviet Union, some of these NPOs were privatized, such as RKK Energia, while others remained government institutions, such as Khrunichev.[34]

## SECTOR VIEW

Perhaps the most useful way to view space activities is by sector, which for the purposes of this paper is defined as an economic division in which the suppliers compete to provide a specific product line that consumers wish to purchase. Space transportation provides examples of how this definition applies. All spacecraft must be launched into space, and those who have spacecraft to place there are consumers of the space transportation product. At this level of analysis, all launch providers are potential suppliers to the spacecraft operators because spacecraft operators will generally investigate all possible suppliers and may ask for bids to launch. In responding to requests for bids, the launch providers must be aware of their competition and set their prices and services based partly on the potential prices and services of their competitors. This self-grouping of suppliers and consumers defines economic sectors.

This seems straightforward, but there are always complications. In the transportation sector, although it is true that all suppliers are potentially competitors for all launches, in practice this is not the case. Some launches, such as U.S. military and intelligence satellites, can by law only be provided only by U.S. suppliers. Similar restrictions exist for military satellites of other nations. Some European civilian launches are restricted to using the Ariane launcher, and so on. After the *Challenger* accident of 1986, the Space Shuttle was prohibited from commercial launches and soon the military pulled its payloads from the Shuttle as well. Other limitations are technical. Although, in principle, small satellites could be placed in orbit on any launcher (in some cases by multiple small satellites on a single launcher), large satellites can be put in orbit only by large launchers. Only the U.S. Space Shuttle, the Russian Soyuz, and the Chinese Long March can place humans in orbit. For some purposes we can consider space transportation a single sector, but in practice one can argue it consists of several subsectors that are semi-independent of each other. Similar reasoning applies to other sectors and subsectors.

34. Siddiqi, *Challenge to Apollo*, Table 3.

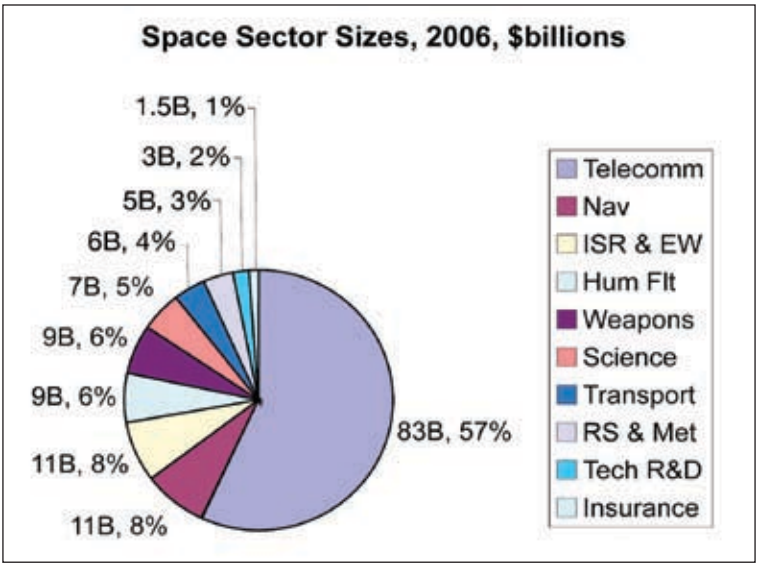


Figure 9.6—Space sector sizes, 2006.[35]

Politics is another reason to group economic activities by sector. In general, national laws and policies affect only one or two sectors. For example, a variety of laws and policies relate to the development of private remote sensing satellites and the regulations that govern sale of imagery from them. These laws have little or no bearing on other sectors. Similar sector-specific policies relate to transportation, navigation, communications satellites, and so on, making the sector view one of the most important ways of understanding economic activity.

A quick tour of the major sectors provides a view of the scope and scale of space endeavors. Figure 9.6 provides an estimate as of 2006 of the relative scale of the major space sectors. The most obvious deduction from this chart is that the communications sector is by far the largest, at roughly $83 billion. It is interesting that historical research into space activities gives little indication that this is the case, with the overwhelming majority of both academic and nonacademic writing focused on the human flight and science programs, with secondary emphases on satellite reconnaissance programs and space politics. The other large sectors are of approximately equal size: science (including both microgravity and physical sciences); navigation; human flight; intelligence, surveillance, and reconnaissance (ISR); and early warning (EW). Remote sensing and meteorology, and transportation, are of roughly equal size, in the range of $5–$11 billion annual expenditures. Technology research and development is in the $2–$3 billion per year range, and the insurance sectors are smaller, from $1–$2 billion annually.

35. Author's estimate, based on assessment of several sources that are described in this chapter.

## TRANSPORTATION

No spacecraft arrives in space unless transported there by some launch vehicle. Launchers originally derived from ballistic missile designs and were therefore initially controlled exclusively by the military. By the late 1950s and early 1960s, however, both the Soviet Union and the U.S. realized that the initial ballistic missile designs that used liquid cryogenic propellants were poor choices for weapons, compared to solid and liquid storable designs. Cryogenic systems using liquid oxygen provided greater performance and thus continued to be used to put spacecraft in orbit, whereas ballistic missiles switched to storable technologies that could be launched within minutes or seconds instead of the hours or days required for cryogenic systems.

The connection of ballistic missile with space launcher technologies has remained a primary facet of space transportation politics and largely explains the fact that throughout the twentieth century no privately funded space launch system has succeeded, despite some attempts. Governments have generally sought to develop launch technologies for both military and civilian purposes and have generally prohibited the export or sale of these technologies (or at least current versions of these technologies) to others. The U.S., in particular, has taken a variety of measures to prevent export of its own launcher technologies (with some exceptions, such as the sharing of Delta launcher technology with Japan), and has also attempted to prevent the export of ballistic missile technologies by other nations, such as Russia's sale of KVD-1 rocket engines to India in the 1990s.[36]

National control of launcher technologies is the only way to guarantee national access to space. No nation or group of nations that has long-term space ambitions or military interests in space can afford to rely solely on other nations to put their commercial or military payloads in orbit. Europe developed its integrated launcher programs, first Europa in the 1960s and then Ariane in the 1970s, to ensure that it could launch its own commercial communications satellites in the face of American resistance. China's ballistic missile and launcher programs derived from its desire for military, economic, and cultural independence from both Soviet and American models.

The rise of a commercial space launch industry to provide space transport for private or semiprivate payloads posed problems for the national control idea. Initially, NASA negotiated with other nations to provide launch services for their payloads, though its system of reimbursement was extremely cumbersome—continuing to bill nations for services months and years after their payload was launched, as NASA's government accounting system figured out all of the expenses involved. NASA essentially purchased launchers from corporate manufacturers and then integrated the payload and launched the vehicles itself. In the 1970s, NASA promoted the Space Shuttle as a means to dramatically lower the cost of access to space, which forced European nations (then developing the Ariane launcher through the ESA) to reconsider its organizational and pricing mechanisms. NASA's advertised Shuttle

36. Brian Harvey, *Russia in Space: The Failed Frontier?* (Chichester, U.K.: Springer-Praxis, 2001), pp. 257–260.

prices were based not on actual costs, but on a variety of mathematical models of future Shuttle operations as well as on the prices of expendable launchers such as Delta and Atlas, because the Shuttle had to charge less than these systems to make the Shuttle economically competitive. This, of course, would put American vendors of expendable launch vehicles (Martin Marietta, McDonnell Douglas, and General Dynamics) out of business, while Europe would have to meet the challenge of Shuttle pricing even if it meant selling Ariane launches at a loss. Both sides preemptively set very low initial prices as a means to lure customers to their vehicles.[37]

These policies clashed with the Ronald Reagan administration's ideology of the superiority of free enterprise over government activities. Although NASA aimed to lure all payloads to the Shuttle (hence, putting all other competitors out of business), the Reagan administration and the Europeans worked to develop and promote private industry. The Europeans created Arianespace, the first private space launch company, though it was partially owned by European governments and only manufactured and operated vehicles whose development was fully funded by the ESA. The Reagan administration sanctioned the development of commercial launchers, to be licensed by the Department of Transportation (not NASA) only after the government-funded manufacturing infrastructure was sold back to industry. Commercial launches would not be viable if the Shuttle delivered on its promise of cheap and reliable space access. Unfortunately for NASA, the Shuttle never did achieve these goals, and the Reagan administration pressed NASA to set its prices closer to the actual Shuttle costs. The coup de grâce was the *Challenger* accident of January 1986, which ultimately led the Reagan administration to prohibit NASA from commercial launches. This, along with other regulations that loosened the military's grip on the contractors, paved the way for the emergence of American commercial launch companies to compete with Arianespace.[38]

Unfortunately for all Western nations, in the late 1980s and early 1990s the collapse of the Soviet Union and China's first steps to earn cash from the West meant that Russian and Chinese organizations began to offer launch services as well. Due to the very low wages in both nations, both could offer their launchers at very low prices that could still earn huge profits while remaining far below Western costs. Left unhindered, they would destroy the American and European commercial launch industries (the noncommercial launch industry would still survive by guaranteed launches from domestic markets). American policy makers faced the dilemma of wanting to integrate the Chinese, and especially the Russians, into the capitalist system to stabilize the Russian economy and bind Russia to the West, while simultaneously trying to protect the Western space launch industry and enable cheaper launches for the American communications satellite industry.

37. J. Krige, A. Russo, and L. Sebesta, *History of the European Space Agency 1958–1987, Vol. 2, The Story of ESA 1973-1987* (Noordwijk, The Netherlands: ESA SP-1235, 2000), chapter 11.

38. Joan Lisa Bromberg, *NASA and the Space Industry* (Baltimore, MD: Johns Hopkins University Press, 1999), chapter 6.

Two solutions prevailed. The first was to sign agreements with China (1989), Russia (1992), and Ukraine (1995) to place a quota on the number of Chinese, Russian, and Ukrainian commercial launches and ensure that they charged prices comparable to Western companies. Put bluntly, the U.S. forced Chinese, Russian, and Ukrainian companies to charge high prices and make very large profits so as not to tempt American and other satellite operators to choose exclusively non-Western launchers.[39] For Russia and Ukraine, this policy came to an end in the early 2000s.

The second solution was the integration of Russian, Ukrainian, and Western companies into corporate joint ventures so that Russian companies could bid for Western launches; the Russians could learn how to do business with the West; and to ensure that some of the money going for Russian launches benefited Western companies. This resulted in a number of joint ventures, including International Launch Services (Lockheed Martin and Khrunichev), Sea Launch (Boeing, RSC Energia, Kvaerner, Yuzhnoe), Starsem (EADS, Arianespace, Russian Federal Space Agency, and Samara Space Center), and Eurockot (EADS and Khrunichev).[40]

Spurred by the prospect of hundreds of satellite launches for medium-Earth orbit constellations of communications satellites, a number of purely private companies formed in the middle to late 1990s to build space launchers. Companies such as Kistler, Beal Aerospace, Pioneer Rocketplane, and Rotary Rocket spent tens and hundreds of millions of dollars before the bottom fell out of the prospective satellite boom in 1999 and 2000. Most of the companies went under, and those that remained sought government funding to survive. The November 2005 announcement by NASA Administrator Michael Griffin that private companies could bid for government contracts to deliver water and other bulk materials to space provided some encouragement to these efforts, but as of 2007 the result of this program is yet to be seen.[41]

In the United States, U.S. military funding on the procurement and operation of military launchers exceeded $1.4 billion in 2006.[42] The ESA's 2006 budget

39. "Memorandum of Agreement Between the Government of the United States of America and the Government of the People's Republic of China Regarding International Trade in International Launch Services," 26 January 1989, Document III-24, in *Exploring the Unknown, Volume IV: Accessing Space,* John M. Logsdon, ed., et al. (Washington, DC: NASA SP-4407, 1999), pp. 497–502.

40. Roger Handberg, *International Space Commerce: Building from Scratch* (Gainesville, FL: University Press of Florida, 2006), pp. 106–109.

41. Andrew J. Butrica, "Reusable Launch Vehicles or Expendable Launch Vehicles? A Perennial Debate," in *Critical Issues in the History of Spaceflight,* Steven J. Dick and Roger D. Launius, ed. (Washington, DC: NASA SP-2006-4702, 2006), pp. 319–320; *Reusable Launch Vehicle Programs and Concepts* (Washington, DC: Associate Administrator for Commercial Space Transportation, January 1998). See also various articles in *Space News* in the late 1990s and early 2000s on the various commercial vehicles. Michael D. Griffin, "NASA and the Business of Space," speech to American Astronautical Society 52nd. Annual Conference, 15 November 2005.

42. U.S. Government Budget, 2006. Budget of the United States Government, Washington, DC: Government Printing Office. It can be found online at *http://www.gpoaccess.gov/usbudget/*, accessed January 2007. Evolved Expendable Launch Vehicle Acquisition $864.4; Medium Launch Vehicles acquisition, $111.2 million; Space Launch Operations & Maintenance, $443.4 million.

allocated roughly €531 million ($640 million) for launchers, primarily the Ariane and Vega programs.[43] NASA has invested hundreds of millions of dollars per year on launchers in some years, particularly in the 1990s and early 2000s, such as its $284 million spent in 1997 on reusable launch vehicles, and the later Space Launch Initiative; however, by 2006 its launcher funding was going into the Crew Launch Vehicle, or Ares I program, in support of human flight.

## Technology Research and Development

The research and development sector is characterized by a confusing competition among government, academic, corporate, and nonprofit organizations for research and development (R&D) funding. It is a specific sector because these funds are largely dispersed by government organizations with their own separate budgets allocated for the purpose of developing new technologies. The DOD and NASA dominate these funds in the U.S., whereas their equivalents in other nations distribute these moneys according to equivalent procedures. Within the DOD, research appears in the Research, Development, Test, and Evaluation (RDT&E) budgets. Research is allocated in Basic Research and Applied Research funds, whereas development funding appears in Advanced Technology Development, Advanced Component Development and Prototypes, and System Development and Demonstration, with other related support showing up in RDT&E Management Support line items.[44] Within NASA, these funds have historically been in the Office of Aerospace Research and Technology budgets and their predecessors, though as of 2007 these are now folded into Exploration, Science, and Operations budgets.

In the former Soviet Union, competition existed among the scientific research institutes such as Mstislav Keldysh's NII-1, which performed aerodynamic research, and the various development design bureaus. This competition was just as stiff and certainly more devious than in the U.S., due to institutional secrecy and the Byzantine nature of the Soviet state.

Competition for technology R&D funds is fierce, but typically government funding is restricted to domestic suppliers due to the criticality of technology development for national economic and strategic aspirations. Since the bulk of these funds are distributed by governments, government institutions have priority access to these funds when they believe they should run the program. In the U.S., government policy dictates that the majority of funding should go to industry, but because governments must also train their personnel, technology R&D is a prime location to gain experience. University researchers have obviously been strong competitors for technology R&D funding, since their jobs require them to

43. Peter B. de Selding, "ESA Budget Emphasizes Independence, Satcom Technology, *Space News* (23 January 2006).

44. See U.S. Government Budget, Department of Defense, for these categories.

advance the state of the art. Similarly, nonprofit institutions such as The Aerospace Corporation and the MITRE Corporation need to keep their knowledge at the state of the art, and they perform a variety of technology R&D studies. Finally, corporations compete for these same funds, winning a significant proportion of them while also committing their own.

Outside of the U.S., similar dynamics apply, though the separation between government and industry is often less clear. It is notable that in Europe all member states contribute to technology R&D programs and all member states benefit. This is one major exception to the usual policy of restricting technology development funding to domestic suppliers only.[45]

In 2006, DOD Basic and Applied Research Budgets allocated more than $520 million to space technologies, with $223.8 million of that budget coming from the Defense Advanced Research Projects Agency. This does not account for U.S. Army and U.S. Navy basic and applied research into space technologies, which are not readily apparent from the top-level budget figures given by the U.S. government. NASA set aside $693 million for Exploration Systems Research and Technology and $624.1 million for Human Systems Research and Technology in its 2006 budget.[46] The ESA's 2006 budget allocated roughly €126 million ($152 million) for technology development.[47]

## Astronomy and Planetary Science

Astronomy has been a popular topic for centuries, as it has dealt with fascinating questions such as the nature of the universe, its history, and Earth's (and hence humanity's) place in the cosmos. Satellites to observe the cosmos (with the Hubble Space Telescope being the most famous) and probes to visit other planets (such as Voyager's flybys of Jupiter, Saturn, Uranus, and Neptune) have been among the most captivating space programs. As such, they have garnered political support to entice young people into science, engineering, and mathematics, and hence to improve the technological competitiveness of the U.S. NASA's educational programs feature large doses of space science.

Another major use of space science has been as a political diplomatic tool. During the International Geophysical Year of 1957–1958, the early U.S. space program was used explicitly as a means to improve foreign relations with allies,

45. Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency* (Cambridge, MA: Harvard University Press, 1994), p. 25.

46. President's FY 2007 Budget Request for NASA, NASA Web site, *http://www.nasa.gov/about/budget/* (accessed February 2007).

47. Peter B. de Selding, "2006 ESA Budget Emphasizes Independence, Satcom Technology," *Space News* (23 January 2006).

while at the same time paving the way for overflights of reconnaissance satellites over the Soviet Union. During the late 1950s and 1960s, the space race between the U.S. and the Soviet Union included the so-called robotic races—first to the Moon and then to Venus and Mars. The winner of these races accrued benefits in national prestige and perceived technological prowess, a proxy for the long-term viability and strength of the capitalist and socialist visions.

NASA's charter explicitly included international cooperation, and under International Programs Chief Arnold Frutkin, in its early years created dozens of agreements and cooperative programs with nations around the world as an active element of American foreign policy. These initiatives included free launches of foreign scientific payloads; foreign instruments on American scientific satellites and vice versa; establishment of communications ground stations for scientific satellites; and a variety of other scientific information exchanges. Not to be outdone, the Soviet Union ran similar programs for its socialist allies, and soon for capitalist or nonaligned nations to woo them away from American interests. Europe, through the European Space Research Organisation (ESRO), and later the ESA, made space science part of its mandatory program that all member states had to support.[48] From the inception of the Space Age, and even before, space science has been a popular, cooperative diplomatic tool, which helps to explain its significant and stable funding.

Corporations typically (though not always) build the satellites, whereas academic, government, and corporate researchers usually build the instruments placed on-board. With relatively few spacecraft put in orbit, the competition to build the satellites and the instruments has always been fierce. Corporations like to build science-craft because it provides an opportunity to advertise their capabilities in ways not possible with often-secret military programs. For scientists, getting an instrument in space can make or break their careers and reputations.

Though the politics of determining the relative priorities and funding of space science programs has made or broken the hopes of many scientists, total space science funding has remained fairly stable over the years, and by 2006 reached roughly $6–$7 billion worldwide. This stability owes much to the use of science as a diplomatic tool, since it is much more difficult to cancel a program that has foreign partners.[49]

48. Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency* (Cambridge, MA: Harvard University Press, 1994), chapter 2.

49. John Krige, "The European Space System," in John Krige and Arturo Russo, *Reflections on Europe in Space* (Noordwijk, The Netherlands: ESA HSR-11, January 1994), pp. 7–8.

## COMMUNICATIONS

As early as 1945, when Arthur C. Clarke first published a paper proposing the use of the geosynchronous orbit as promising location for telecommunications satellites, the potential utility and profitability of space communications beckoned. Military, civilian, and commercial organizations all began to develop communications satellites in the U.S. by the early 1960s.

All of the military services had interests in communications satellites (comsats) for command and control, as part of a worldwide military communications system. In part responding to Kennedy administration concerns about the potential that AT&T would extend its communications monopoly into space by developing a purely private system, NASA funded its own experimental satellites. AT&T's launch of Telstar in 1962 fueled these government fears, leading to the passage of the Satellite Telecommunications Act of 1962 that created Communications Satellite Corporation to build and manage the international satellite communications system. Military and NASA funding built several strong competitors to AT&T, including Hughes Aircraft Corporation, Philco Corporation, and Radio Corporation of America. The successful 1963 launch and operation of Hughes's NASA-funded Syncom satellite proved the viability of geosynchronous telecommunications satellites. The U.S. then opened negotiations with European nations, Canada, and Japan regarding the management of the international telecommunications system.[50]

Although the U.S. wanted to negotiate on a bilateral basis with each nation, the Europeans quickly banded together to negotiate with greater strength as a group, forming the European Conference for Satellite Telecommunications (French acronym CETS) in 1963. The resulting negotiations created the International Telecommunications Satellite Organization (Intelsat) the next year, with Communications Satellite Corporation as the organization's manager. Though the Americans dominated Intelsat in the 1960s, the Europeans acquired one major concession—to renegotiate Intelsat's terms in 1971. In the meantime, the United Kingdom, Germany, France, and Italy began development of their own national satellite programs, while working through CETS and ESRO to create an integrated European satellite program.[51]

During this period, the U.S. had monopoly power over spacecraft launches, and U.S. policy dictated that the U.S. would not launch any satellite that threatened Intelsat's international monopoly. "Experimental" satellites were launchable, but

50. David J. Whalen, *The Origins of Satellite Communications 1945-1965* (Washington, DC: Smithsonian Institution Press, 2002).

51. A. Russo, "The Beginning of the Telecommunications Satellite Programme in ESRO," in J. Krige and A. Russo, *A History of the European Space Agency 1958–1987, Volume I, The Story of ESRO and ELDO 1958-1973* (Noordwijk, The Netherlands: ESA SP-1235, 2000), chapter 9.

not regional or international systems. Convinced that the U.S. was attempting to retain control of satellite telecommunications, the Europeans, led by France, pushed to develop their own launcher to ensure that European comsats would get to orbit. Ultimately, this resulted in the development of the Ariane and was a major factor in the negotiations that led to the creation of the ESA. Intelsat's permanent agreement of 1973 reallocated shares in Intelsat based on actual usage of the system, and allowed for regional as well as domestic systems. American shares shrank from more than 50 percent to the range of 25 percent to 30 percent, and hence control of Intelsat passed out of American hands by the late 1970s. ESA began development of the Orbital Test Satellite, the first of several ESA-developed systems from that time forward.[52]

From the 1970s through the 1990s, many nations built or purchased comsats for domestic purposes, while several private companies orbited systems that leased transponders to government and private customers. The growing demand led to many negotiations over the use of the frequency spectrum through the International Telecommunication Union (ITU). Nations own the spectrum rights and geosynchronous orbital slots, and thus this provided a mechanism for governments to control both government and corporate uses of space communications. Many countries ensured that their domestic systems were government-owned or -controlled. The most profitable use of comsats turned out to be direct broadcast television, with companies such as DirecTV, Echostar, and SES selling dozens and eventually hundreds of broadcast channels directly to millions of consumers. Direct-broadcast radio, led by XM, Sirius, and Worldspace, began in 1998 and was growing rapidly by the first decade of the twenty-first century.[53]

Mobile communications for ships, aircraft, and eventually telephones and computers began from military experiments in the U.S. Systems such as Tactical Satellite (TACSAT), launched in 1969, proved the concept of using relatively small ground antennas that could be ported on ships, trucks, and other vehicles. The U.S. and Soviet navies desperately needed such systems for fleet communications, and merchant ships would also be obvious beneficiaries.[54] The International Maritime

52. Ibid., and A. Russo, "The Early Development of ESRO's Telecom Programme and the OTS Project," in Krige and Russo, *A History of the European Space Agency, Volume 1,* chapter 10; John L. McLucas, *Space Commerce* (Cambridge, MA: Harvard University Press, 1991), pp. 40–43.

53. McLucas, pp. 75–80. To see the growth of direct broadcast television, see Office of Space Commercialization, *Trends in Space Commerce*, prepared by Futron Corporation (Washington, DC: Department of Commerce, 2001), chapter 3. On satellite radio market growth, see International Space Business Council, *2004 State of the Space Industry* (Bethesda, MD: Space Publications, 2004), pp. 23, 42–43.

54. Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-Centric Warfare* (Annapolis, MD: Naval Institute Press, 2000), chapter 5; William W. Ward and Franklin W. Floyd, "Thirty Years of Space Communications Research and Development at Lincoln Laboratory," in *Beyond the Ionosphere: Fifty Years of Satellite Communication,* Andrew J. Butrica, ed. (Washington, DC: NASA SP-4217, 1997), pp. 84–86.

Communications Satellite Organisation (Inmarsat) was established in 1976 to provide worldwide mobile commercial service for shipping. Unlike Intelsat, in which the Soviet Union and other Communist-bloc nations refused to participate, the Soviet Union and other socialist countries became members of Inmarsat.[55]

In the 1990s, Iridium, Globalstar, and ICO developed large constellations of medium-Earth orbit comsats to provide worldwide mobile telephone and data services. By the first years of the twenty-first century, all three systems had been deployed and all three companies had gone bankrupt after raising and spending billions of dollars; they had overestimated the demand for global service and underestimated the competition from ground-based cellular telephone systems.[56]

Both ground-based and space-based private competition put pressure on the international and domestic government systems, making some of them economically obsolete. Both Intelsat and Inmarsat were privatized in response to U.S. demands; if these systems wanted to compete for domestic U.S. business, they could no longer be owned by governments.[57] However, military demand continued to grow rapidly, leading to the leasing of many commercial transponders for military purposes and the development of more-capable military systems that were less susceptible to jamming or radiation effects (such as Milstar), and with greater bandwidth to send imagery and intelligence data from reconnaissance and intelligence satellites and from various sensor systems to military users around the world.[58] In 2006, the DOD was budgeted more than $2.9 billion to develop and acquire communications satellites,[59] and more than $340 million to procure USAF and U.S. Army satellite communications ground terminals.[60] Precise numbers to operate military communications satellites are difficult to estimate from the DOD overview budgets, but are certainly in the hundreds

55. McLucas, *Space Commerce*, pp. 46–50; Edward J. Martin, "The Evolution of Mobile Satellite Communications," in Butrica, ed., *Beyond the Ionosphere*, pp. 265–281.

56. Roger Handberg, *International Space Commerce: Building from Scratch* (Gainesville, FL: University Press of Florida, 2006), pp. 144–145.

57. Intelsat Web site, *http://www.intelsat.com* (accessed January 2007). Inmarsat Web site *http://www.inmarsat.com* (accessed January 2007).

58. David N. Spires and Rick W. Sturdevant, "From Advent to Milstar: The U.S. Air Force and the Challenges of Military Satellite Communications," in Butrica, ed., *Beyond the Ionosphere*, pp. 65–78.

59. From the U.S. Government 2006 budget: $1,194.3 million for Advanced Extremely High Frequency Satellite Acquisition; $835.8 for Transformational Satellite Communications Acquisition; $166.4 million for Wideband Gapfiller Acquisition; $28.7 million for USAF Military Satellite Communications Procurement; $2.185 million for USAF Polar Military Satellite Communications RDT&E; $541.98 million for U.S. Navy Satellite Communications RDT&E; $71.8 million for U.S. Navy Satellite Communications Systems Procurement.

60. From the U.S. Government 2006 budget: U.S. Army, DSCS Ground Systems Program Acquisition, $66.5 million; USAF, Management Support for MILSATCOM Terminals, $273.974 million. U.S. Navy satellite terminal procurements are buried in other budget lines.

of millions of dollars per year.[61] By 2005, the satellite communications sector was more than $80 billion annually—by any estimate, the largest space sector by a wide margin.[62]

## Reconnaissance and Remote Sensing

The technologies of reconnaissance and scientific or commercial remote sensing are essentially the same, though the specific characteristics of the sensors vary depending on what the satellite is trying to sense. High-resolution, often black-and-white (panchromatic) imagery tends to be most useful for intelligence gathering, whereas lower-resolution color (multispectral) imagery is useful for environmental monitoring. Monitoring of volcanoes, clouds, ice, ocean, and land features are each optimized with the use of different portions of the spectrum, with infrared bands looking for heat sources best for volcanic activities, and various shades of green for vegetation monitoring, for example. High-resolution imagery is not particularly useful to monitor large-scale weather fronts but it is crucial to differentiate one kind of airplane from another.

Military and intelligence organizations developed the first reconnaissance systems, starting in the mid-1950s with the USAF's WS-117L, which led to the Central Intelligence Agency (CIA)-sponsored Corona and the Air Force SAMOS projects. The Eisenhower administration secretly created the National Reconnaissance Office in 1960 to manage the spy satellite programs.[63] Also in the late 1950s, the U.S. Army began to investigate weather satellites, but these study results and projects were soon transferred to NASA, becoming the Tiros program, first launched in 1960. The USAF, needing weather imagery over the Soviet Union to better utilize Corona, created what was eventually called the Defense Meteorological Satellite Program (DMSP).[64] The Soviet Union created its equivalent systems, Zenit (based on the Vostok capsule) for reconnaissance, and Meteor for weather.[65]

61. These U.S. Government 2006 budget figures are part of the Operations and Maintenance budgets, including the U.S. Navy's $156.8 million for Space Systems and Surveillance; the USAF's C3I and Early Warning's $1.201 billion; and the U.S. Army's O&M budget, which does not have any specific "space" line items. Original numbers, from which I make these estimates, are drawn from International Space Business Council, *2005 State of the Space Industry* (Bethesda, MD: Space Business.com, 2006). SIA/Futron, and the U.S. military communications satellite and operational budgets.

62. This includes approximately $42 billion for direct-broadcast, fixed, and mobile satellite revenues. I estimate some $5 billion for acquisition of government-paid communications satellites worldwide ($16 billion for ground systems), assuming some two-thirds of all ground system are for communications antennas and related equipment, and another $3 billion of government-paid operational (launchers, launch operations, and mission) budgets to launch and operate communications satellites.

63. Dwayne A. Day, John M. Logsdon, and Brian Latell, ed., *Eye in the Sky: The Story of the Corona Spy Satellites* (Washington, DC: Smithsonian Institution Press, 1998).

64. R. Cargill Hall, "A History of the Military Polar Orbiting Meteorological Satellite Program," *Quest: The History of Spaceflight Quarterly* 9, no. 2 (2002): pp. 4–25.

65. Bart Hendrickx, "A History of Soviet/Russian Meteorological Satellites," *Space Chronicle, The Journal of the British Interplanetary Society* 57, Supplement 1 (2004): pp. 56–102.

Classified reconnaissance programs evolved rapidly in both the U.S. and Soviet Union. Early systems generally used film that had to be returned to Earth, which meant that space reconnaissance required many launches every year. In 1977, the first American Keyhole (KH)-11 satellite was launched. This program helped create charged-coupled device (CCD) technology that allowed for digital capture and radio transmission of imagery to Earth.[66] The Soviet Union soon followed this lead, as its Yantar series evolved to include Yantar Terilen, the first Soviet satellite with electro-optical capabilities, first launched in 1982.[67] China began development of its own reconnaissance systems by the late 1970s,[68] and other nations such as France and Israel developed their own reconnaissance systems by the 1990s. Many nations now have access to American high-resolution commercial satellite imagery, which became available in 1999 with the launch of Space Imaging EOSAT Company's Ikonos 1, which provided ~3-foot (1-meter) resolution. These companies have remained viable only through major government imagery purchases and direct subsidies for satellite development. The costs of classified reconnaissance systems remain classified, but some estimate that the funding of the National Reconnaissance Office, which manages U.S. imagery intelligence, exceeds $7 billion per year in the early twenty-first century.[69] The costs of the U.S. reconnaissance program in the 1960s may have ranged in the same order of magnitude as the Apollo program, which totaled roughly $21 billion in then-year dollars.

The development of commercial remote sensing began with NASA's Landsat program (first launch 1972, final launch of Landsat 7 in 1999), a civilian project to provide satellite imagery of landforms and vegetation for scientific purposes. The program soon developed a clientele of users that included mining companies, land use planners, and others who were not scientists.[70] These commercial applications lent weight to arguments to privatize Landsat. Congressional legislation led to the privatization of Landsat operations in 1985 by the Earth Observation Satellite Company (EOSAT). Certain conditions of the legislation hampered EOSAT's business activities, while the large increase in image prices alienated Landsat's scientific clientele. Congress repealed the legislation in 1992, returning control of Landsat to the government but also creating procedures for companies to develop

66. William E. Burrows, *Deep Black: Space Espionage and National Security* (New York: Berkley Books, 1988).

67. Peter A. Gorin, "Black 'Amber': Russian Yantar-Class Optical Reconnaissance Satellites," *Journal of the British Interplanetary Society* 51/8 (August 1998): pp. 309–320; Harvey, *Russia in Space: The Failed Frontier?*

68. Phillip S. Clark, "Development of China's Recoverable Satellites," *Quest: The History of Spaceflight Quarterly* 6, no. 2 (1998): pp. 36–43.

69. Federation of American Scientists Web site, *http://www.fas.org* (accessed January 2007).

70. Pamela E. Mack, *Viewing the Earth: The Social Construction of the Landsat System* (Cambridge, MA: MIT Press, 1990).

commercial high-resolution remote sensing, which EOSAT and others quickly pursued. This was spurred by the success of international competitors, such as France's Satellite pour l'Observation de la Terre (SPOT), first launched in 1986; India's Indian Remote Sensing (IRS) satellites (1988); and others, all of whom sold imagery on the commercial market.[71]

France and India sold SPOT and IRS imagery, respectively, through private companies SPOT Image and Antrix, respectively, but these companies did not have to develop or launch the spacecraft. Other nations sold the imagery directly from government organizations. Commercial remote sensing has thus developed as an international competition among governments and government-supported private companies. None of the organizations makes enough revenues from imagery sales to fund the development of the satellites, but the imagery sales have defrayed some small fraction of government costs. Commercial space imagery sales worldwide in 2004 were less than $600 million annually, while reconnaissance satellites cost several hundred million each.[72]

Despite the unpromising economics, when the U.S. in 1992 created provisions for private companies to build high-resolution remote sensing satellites, several companies jumped at the opportunity. The first high-resolution commercial remote sensing satellite, Ikonos, was orbited in 1999, with two other companies following soon thereafter. However, the revenues from imagery sales never met expectations, and survival of the American commercial companies depended on large government contracts for imagery and also for direct government subsidies to fund their next-generation satellites. The National Geospatial Intelligence Agency obligingly awarded imagery contracts, and then provided $500 million manufacturing subsidies, to DigitalGlobe in 2003 and to Orbimage the next year, but not to EOSAT, leading to Orbimage's purchase of EOSAT to form GeoEye.[73]

Most users are not able to use raw remote sensing images. Instead, the so-called value-added services sector processes raw imagery and adds other information to make it useful. This sector is usually estimated as having revenues an order of magnitude larger than the raw imagery market. Numerous small companies create and market to the many small niche markets providing processed imagery to government, scientific, and commercial users, often through Geographic Information Systems.[74]

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71. Joanne Gabrynowicz, "The Perils of Landsat from Grassroots to Globalization: A Comprehensive Review of U.S. Remote Sensing Law with a Few Thoughts for the Future," *Chicago Journal of International Law* 6 (2005).

72. *2004 State of the Space Industry*, p. 23.

73. John C. Baker, Kevin M. O'Connell, and Ray A. Williamson, ed., *Commercial Observation Satellites: At the Leading Age of Global Transparency* (Santa Monica, CA: RAND, 2001). See relevant articles by *Space News* and *http://www.space.com* on the NGA contracts.

74. Office of Space Commercialization, *Trends in Space Commerce*, prepared by Futron Corporation (Washington, DC: Department of Commerce, 2001).

Governments have borne the entire costs of weather satellites throughout their history, and thus have provided a steady demand for these systems and several hundred million dollars annually worldwide for their development and operation. In the United States, the U.S. Army started such work but soon transferred it to NASA, where it became the Tiros series, first launched in 1960. That same year, the Corona program finally succeeded in taking images of the Soviet Union, finding out that much of its precious film recorded cloud tops. This led the National Reconnaissance Office and the USAF to develop what eventually became known as the Defense Meteorological Satellite Program (DMSP), initially derived from the Tiros design. Organizational issues plagued the civilian program because NASA specialized in satellite development, but the users of satellites were in the National Weather Service (NWS). NASA preferred to push the technological envelope, whereas NWS forecasters wanted a reliable system that typically used tried-and-true techniques. Thus, in the mid to late 1960s, while NASA developed Nimbus satellites, the NWS purchased systems derived from the military's DMSP due to their perceived greater operational utility and proven design. These same issues continued to characterize relationships between NASA and the user community, and continued through the development of the Geostationary Operational Environmental satellites and Polar Operational Environmental satellites. All the while, the possibility of combining military and civilian systems continued, leading in the 1990s to the decision to create the joint civilian-military National Polar-Orbiting Environmental Satellite System (NPOESS), scheduled to launch in the early twenty-first century.[75]

In 2006, NOAA was funded to spend $782 million to acquire weather satellites, another $97 million to operate them, $53 million to distribute data, and $11 million to integrate Landsat sensors onto NPOESS.[76] That same year, the USAF spent an additional $323 million on NPOESS and $71 million on DMSP.[77]

Other nations recognized the practical utility of weather satellites and developed their own, starting with the Soviet Union's Meteor program, the first of which launched in 1964. Europe, through the ESA, developed its Meteosat series, first launched in 1977, and eventually operated through Eumetsat, established in 1986. India combined weather observation with communications in its Indian National Satellite series, while Japan developed its Geostationary Meteorological Satellites and China its Feng Yun series. The Coordination of Geostationary Meteorological Satellites (CGMS) organization formed in 1972 to coordinate worldwide satellite

75. Frederik Nebeker. *Calculating the Weather: Meteorology in the 20th Century* (New York: Academic Press, 1995).

76. R. Cargill Hall, "A History of the Military Polar Orbiting Meteorological Satellite Program," *Quest* 9/2 (2002): pp. 4–25. Budget data from 2006 NOAA budget, available on NOAA Web site, *http://www.corporateservices.noaa.gov/~nbo/* (accessed January 2007).

77. U.S. Government Budget, 2006. DMSP figures are $67.2 for Procurement and $3.908 million for RDT&E Management Support.

weather monitoring from geostationary satellites. In 1992 the organization expanded its purview to include polar-orbiting satellites, and became the Coordination Group for Meteorological Satellites. Among other activities, the group coordinated the use of one nation's satellite when another nation's satellite had problems.[78]

## Electronic Intelligence and Early Warning

Closely related to imagery collection is electronic data collection, which gathers data from various nonvisible portions of the electromagnetic spectrum. These data can be used for strategic assessments of national capabilities or for tactical military purposes. Strategic uses, such as intelligence gathering by the U.S. National Security Agency and its Russian equivalents, remain highly classified; they started in the early 1960s. Tactical uses include monitoring of shipping and naval signals, as well as strategic early warning systems that monitor infrared signatures of ballistic missile launches or actively send radar signals to reflect off targets. Another application is the tracking of objects in space, which is necessary to distinguish between a ballistic missile and a meteor hitting Earth. In all cases, these are purely government-controlled functions. The U.S. contracted to industry for the satellites while the government operated them, whereas the Soviet Union and later Russia developed and operated its systems purely through government organizations.[79]

Electronic intelligence-gathering budgets, like the satellite programs themselves, remain classified, so their costs remain highly speculative. Some analysts estimate their costs in the range of $3 billion per year in the U.S. and presumably significantly lower in Russia.[80] Naval reconnaissance systems, such as the American White Cloud system or the Russian EORSAT, also remain classified, along with their funding. Early warning systems, by contrast, have official published budgets in the U.S. Published figures from the 1960s through the mid-1980s show early warning budgets ranging from a low of $45.6 million in 1967 to $707.2 million in 1984.[81] In 2006, the USAF budgeted $1.21 billion on procurement of early warning and space tracking systems.[82]

78. Eumetsat, *The History of Eumetsat—European Organisation for the Exploitation of Meteorological Satellites* (Darmstadt: Eumetsat, 2001); Bart Hendrickx, "A History of Soviet/Russian Meteorological Satellites," *Journal of the British Interplanetary Society* 57/1 (2004): pp. 56–102.

79. Friedman, *Seapower and Space*; William E. Burrows, *Deep Black: Space Espionage and National Security* (New York: Berkley Books, 1988); James Bamford, *Body of Secrets: Anatomy of the Ultra-Secret National Security Agency* (New York: Anchor Books, 2001).

80. Federation of American Scientists, *http://www.fas.org*, accessed January 2007.

81. Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945–1984* (Ithaca, NY: Cornell University Press, 1985), Table 2, pp. 256–257.

82. From the U.S. Government Budget, 2006. It includes $756.6 million to procure the Space-Based Infrared Systems-High; $225.8 million for a Space-Based Radar system; $151 million to support its Space Tracking efforts; $32.8 million on Nuclear Detection; and $42.7 million for RDT&E Management Support to its older Defense Support Program system.

## WEAPONS

Space weapons refer on one hand to ballistic missiles, and on the other to weapons to destroy ballistic missiles (antiballistic missile system) and satellites (antisatellite systems). As with intelligence-gathering satellites, space weapons have been the exclusive domain of governments, with the exception of contracting to industry in Western nations. The very first space expenditures were for the development of ballistic missiles, which received major funding first in Nazi Germany in the mid-1930s, and by the mid to late 1940s in the U.S. and Soviet Union, followed quickly by Great Britain and France, and somewhat later by many other nations including China, India, Pakistan, Iran, North Korea, and others. Even though some of the budget figures for ballistic missile, antiballistic missile, and antisatellite programs are unclassified, working through the maze of government budgets to determine actual spending on space-related research, development, facilities, and operations is not trivial.

One significant exception is the budget of the Missile Defense Agency, the descendant of the 1980s Strategic Defense Initiative Organization. From a budget of $1.6 billion in 1985, the agency's budget jumped to $7.8 billion in 2002 and remained in the $7 to $9 billion range through 2006 as the George W. Bush administration began to deploy a national missile defense system in Alaska.

Ballistic missiles consumed enormous amounts of funding in the U.S. and Soviet Union in the 1950s and 1960s in particular, leveling off somewhat in the 1970s and 1980s, and declining significantly after the end of the cold war in the 1990s and early twenty-first century. For example, in 1959, the Atlas, Titan, and Minuteman programs consumed $1.321 billion, which, when converted to 2006 dollars, is equivalent to more than $7 billion.[83] And that is not all, as in that year there were several other ballistic missile programs ongoing, including the Navy's Polaris, the Army's Corporal, Redstone, and Sergeant systems, and the USAF's Thor Intermediate-Range Ballistic Missile. By contrast, in 2006, the USAF spent $791 million on intercontinental ballistic missile acquisition[84] and the U.S. Navy spent $936.1 million on Trident II submarine-launched ballistic missile modifications and another $830 million to operate its fleet ballistic missile systems.[85]

83. Data from Jacob Neufeld, *Ballistic Missiles in the United States Air Force 1945–1960* (Washington, DC: Office of Air Force History, 1990), pp. 198, 229. Atlas: $641.5, Titan $495.4, Minuteman $184 (all in millions).

84. U.S. Government Budget, 2006. USAF Minuteman III Modifications, $672.6; Missile Replacement, $41.6; ICBM RDT&E, $44.67; ICBM Components, $32.42 (all in millions).

85. U.S. Government Budget, 2006.

## Navigation

Satellites assist navigation on Earth by providing targets with known positions in space, from which objects on Earth can triangulate their position. This was particularly useful for naval operations, where navigation on featureless oceans has historically been particularly difficult. However, given sufficient reliability, accuracy, and timeliness, it is also useful for movement of vehicles and people on land and in the air. The first application of satellite navigation was for American and Soviet submarines to determine their positions with sufficient accuracy such that their nuclear-tipped ballistic missiles could hit cities in the opposing countries. For this purpose, the U.S. Navy funded the Transit program, the first satellite of which launched in 1960. The Soviet Union countered with its Tsiklon satellites, first launched in 1967. Both systems provided two-dimensional (not vertical) accuracy of several hundred feet, with update rates on the order of tens of minutes in the worst case. This was sufficient for slow-moving naval vessels but not fast-moving aircraft at various altitudes.[86]

Naval success spurred further studies and research, leading both nations to create more capable navigational systems. In the U.S., the tri-service Global Positioning System (GPS) program began in 1973, with its first experimental satellite launch in 1978. The full 24-satellite constellation was not operational until 1995. The Soviet Union's equivalent, the Global Navigation Satellite System (GLONASS), put its first satellite into orbit in 1982, with its full 24-satellite constellation in place in 1996. While the U.S. maintained its GPS constellation, Russia was unable to maintain its GLONASS constellation, with only 14 satellites operating by late 2005.[87] The Transit system was relatively cheap, with acquisition costs at roughly $20–$30 million per year in the 1960s.[88] GPS is much more capable and also much more expensive. In 2006, the USAF budgeted $719.6 million for acquisition of GPS satellites, which primarily paid Boeing for the latest generation of Block 2F satellites.[89]

The military uses of the satellite navigation systems were obvious and crucial, and soon expanded to include aircraft and land force positioning, and precision-guided weapons. The use of GPS has been a key element in the dramatic enhancement of U.S. military capabilities so apparent from the two Iraq wars in 1991 and 2003. Certain civilian and commercial uses were also clear from the beginning,

86. Friedman, *Seapower and Space,* chapter 4.

87. Harvey, *Russia in Space: The Failed Frontier?,* pp. 130–136.

88. Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945–1984* (Ithaca, NY: Cornell University Press, 1985), table 2, pp. 256–257.

89. U.S. Government Budget, 2006.

such as for merchant shipping, air transport, and air traffic control. However, the military did not expect the tremendous surge in commercial applications that blossomed in the 1990s and 2000s. Once in place, the satellite navigation signals were essentially a free resource that individuals and commercial firms could tap into for their own uses simply by purchasing the appropriate receivers. Receiver sales were roughly $800 million in 1994; by 2005, estimates of GPS equipment sales ranged from $5 billion to $22 billion, with American and foreign firms splitting the market roughly 50-50.[90]

Such a wide discrepancy in estimates says much about the difficulty of estimating the size of this market. However, it should be noted that, historically, many if not most estimates of current and future commercial space market sizes have been overestimated. For GPS in particular, the market estimate depends a great deal on what is counted. For example, for a precision weapon, does the entire weapon count or merely the GPS receiver in the weapon? For a handheld cellular phone or a GPS fish finder with a GPS chip, does the entire phone or fish finder count or merely the GPS chip? There are many ways to estimate the entire market size, each of which starts with different assumptions and yields radically different answers.[91]

By 2006, with GPS receivers available for under $100 and packaged in many products, commercial uses included car and boat navigation, surveying, animal and child tracking, cellular telephone positioning, and various recreational purposes such as locating precise positions and distances on a golf course or fish finders on lakes. Civilian purposes grew to include various emergency services such as fire, police, and search and rescue, and scientific research in geodesy and geology. Civilian and commercial applications dwarfed military ones in terms of receiver sales by the early twenty-first century.

Europe and China were the first to develop space-based navigation capabilities independent of the old superpowers. China launched three Beidou satellites in 2000–2003, most likely to support its small intercontinental ballistic missile force. In 2002, the Europeans began development of the Galileo system, but as a civilian commercial

90. Office of Space Commercialization, *Trends in Space Commerce*, prepared by Futron Corporation (Washington, DC: Department of Commerce, 2001). The high estimate, $13 billion, comes from the RNCOS Web site, "GPS Market Update (2006)," April, 2006, *http://www.rncos.com/Report/COM33.htm* (accessed 28 December 2006). The low estimate, $4.8 billion, comes from International Space Business Council, *2004 State of the Space Industry* (Bethesda, MD: International Space Business Council, February 2004), p. 23. The $22 billion figure comes from ABI Research, in Space Foundation, *The Space Report 2006* (Colorado Springs, CO: Space Foundation, 2006), footnote 262.

91. Discussion with Scott Sacknoff, head of the International Space Business Council (ISBC), 28 December 2006. The ISBC methodology is a "conservative" one that will tend to yield lower estimates by parsing out the GPS components from the overall products. It also adds up revenues of major market players, such as Garman and Trimble, to compare with other estimates that add up the total number of cars produced, for example, and estimating the percentage of those cars that have GPS receivers.

venture. The GPS signal is free but potentially interruptible should the U.S. deem it necessary, whereas the Galileo system would provide coarse signals for free but could provide higher-precision signals (for a price) to users. China, Israel, India, Saudi Arabia, Ukraine, and Morocco have decided to participate in the program as well, making it a global venture to ensure independence from the U.S. The project, as of 2006, was projected to cost some €3.8 billion, with European costs split 50-50 between the European Commission Transport Directorate and the ESA. Germany is the largest single national contributor, with some €500 million committed to the project. The funding goes primarily to a European industrial consortium, Galileo Industries, which consists of EADS, Alcatel Space, and Alenia Spazio. The first Galileo experimental satellite went into orbit in December 2005.[92]

Several nations, including the U.S., Europe, Japan, and India, developed systems to augment the capabilities of the GPS. The U.S. Wide Area Augmentation System was developed to aid precision flight approaches. Europe deployed the European Geostationary Navigation Overlay System. Japan placed navigational capability in its Multi-functional Transport Satellite, which is primarily a meteorological satellite, first launched in February, 2005. In parallel, it developed the Quasi-Zenith Satellite System to enhance regional navigation in Asia and the Pacific region.[93] By 2006, the Indian Space Research Organisation was developing its Geo-augmented Navigation (Gagan) Satellite System, which was to augment GPS signals primarily for aircraft navigation in south Asia.[94]

Since the deployment of GPS, the military, civilian, and commercial success of navigational systems has generated global interest in navigational capabilities, generating political and economic opportunities and conundrums. For the U.S., the key issue has become the debate between military and civilian control of GPS signals. The military maintains the authority to shut down certain capabilities in wartime, yet civilian and commercial uses have become so important that it is clear that GPS signals cannot merely be shut down. Russia's major problem is finding the cash to maintain its GLONASS constellation. Other nations debate whether to create very expensive, independent capabilities so as not to depend on the U.S., as

92. Peter B. de Selding, "Initial Galileo Satellite Navigation Bid Exceeds ESA's Budget," *Space News Business Report*, *http://www.space.com*, 22 March 2004 (accessed January 2007); "EU Launches First Satellite in Galileo Navigation Program," 28 December 2005, *http://www.galileo-navigationsystem.com/Archiv/galileo-archive1.htm* (accessed January 2007); "Contract Signed for Second Phase of Galileo Navigation Satellites," 19 January 2006, *http://www.galileo-navigationsystem.com/Archiv/galileo-archive1.htm* (accessed January 2007).

93. Japan Meteorological Agency, MTSAT Web site, *http://www.jma.go.jp/jma/jma-eng/satellite/about_mt_index.html* (accessed 28 December 2006).

94. "ISRO, Raytheon complete tests for GAGAN Satellite Navigation System, IndiaDefence Web site, *http://www.india-defence.com/reports/2239* (accessed 28 December 2006).

Europe and China have done, or to enhance existing and forthcoming systems, as Israel, Japan, and India have chosen. European motivations include the desire to make significant profits from European sales of Galileo receivers, but as of 2006 it is not obvious whether this wish will be fulfilled, since American, European, and Japanese commercial vendors already compete to use signals from GPS and GLONASS and will simply expand their repertoires to include Galileo. Commercial vendors will combine signals from several navigational systems to enhance local performance, regardless of who funds and maintains the space-based systems.[95]

## HUMAN SPACEFLIGHT

By far the most well-known space activity is human spaceflight, which has been the primary political arm of space programs around the world. The primary initial motivation for human spaceflight in the late 1950s and 1960s was competition for prestige, as the U.S. and Soviet Union sought to project their technological capabilities in an ideological battle for the hearts and minds of people around the world. The Soviet Union gained an early lead in the space race by putting the first man, Yuri Gagarin, into space in 1961, and other firsts such as the first woman in space, the first multi-man mission, and the first spacewalk. However, Soviet efforts to move beyond the R7 launcher and Vostok capsule designs fizzled in bureaucratic infighting, while the American response surged forward. The Gemini program proved U.S. rendezvous and docking capabilities, and Apollo placed the first man on the Moon in 1969. Secret Soviet efforts to put a man on the Moon fizzled as the huge N-1 launcher failed in four test flights, while the political imperative disappeared with the American success.[96]

With the failure of their piloted lunar program, the Soviet Union moved to long-duration space station efforts, with the U.S. shifting its efforts to the Space Shuttle in the 1970s and the beginnings of its own space station program in the mid-1980s. With their *Salyut* space stations and *Soyuz* ferry vehicles, the Soviet Union set record after record in long-duration human spaceflight and proved that military uses of piloted space stations were not effective. The *Mir* station was the culmination of Soviet and Russian efforts. The Soviet Buran program, which mirrored the American Shuttle, was fielded in the late 1980s but was too expensive to survive the Soviet Union's collapse. The American Space Shuttle also proved to be very expensive, though the U.S. was willing to pay that price to keep the American astronaut program alive. It also proved too unreliable, with flight delays the norm and the loss of *Challenger* in 1986 and *Columbia* in 2003 causing the loss of 14 astronauts' lives. The American Space

95. Handberg, *International Space Commerce*, chapter 6.

96. There are many books on these subjects. A good place to start is William E. Burrows, *This New Ocean: The Story of the First Space Age* (New York: The Modern Library, 1998).

Station *Freedom* program also proved problematic, with many design changes as NASA struggled to determine its purpose.[97]

Although its initial motivation was superpower competition, the shuttle and space station programs of the two superpowers provided opportunities for international cooperation, though initially that cooperation remained fixed within ideological boundaries. The Soviet Union took advantage of its regular *Soyuz* crew replacement flights to its *Salyut* and *Mir* stations to offer its Communist-bloc allies the opportunity to put their citizens into space through the Interkosmos program. Similarly, the U.S., which had seven seats on each Shuttle flight, offered rides to its allies. The Space Shuttle program also included some opportunities for allies to build flight hardware, with Canada's robot arm and the Europeans' Spacelab module the most significant. Although partly motivated by the prestige factor, scientific and economic factors provide more significant motivations for these nations, particularly in their interest in developing and using microgravity facilities and developing niche capabilities in space.[98]

These international precedents were the basis for much more intimate and expansive cooperation in the International Space Station (ISS) program. Initially including the U.S., Europe, Japan, and Canada, the ISS came to include Russia as well. On the brink of cancellation in the early 1990s, the American space station program was saved by the opportunity for the U.S. to use it as a means to keep Russian technical talent working on peaceful programs as opposed to being forced by economic necessity to sell their services to nations such as Iran and North Korea. The Russians built ISS modules under contract to NASA and also as part of their own independent contribution. In addition, Russia supplies Progress ferry vehicles for supplies and its reliable *Soyuz* transfer vehicles for crews. With the American Shuttle fleet grounded from early 2003 to mid-2005 due to the *Columbia* accident, Russia provided the only access to the ISS. This situation has shown the wisdom of international partnerships and their alternative means to keep programs alive when one partner has difficulties.[99]

Separate from the U.S. and the ISS program, China started its own Shenzhou program to put Chinese yuhangyuan (astronauts) into space. After a number of test flights, it finally succeeded in this ambition in 2003, with the launch of Yang Liwei in *Shenzhou 5*. China's motives appear quite similar to that of the U.S. and Russia: to garner world prestige and to inspire its own people, particularly young people, to study technical subjects.[100]

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97. Robert Zimmerman, *Leaving Earth: Space Stations, Rival Superpowers, and the Quest for Interplanetary Travel* (Washington, DC: Joseph Henry Press, 2003); Dennis R. Jenkins, *Space Shuttle: The History of the National Space Transportation System, the First 100 Missions,* 3rd ed. (Cape Canaveral, FL: Dennis R. Jenkins, 2001).

98. Zimmerman, *Leaving Earth*; Michael Cassutt, *Who's Who in Space*, 3rd ed. (New York: Macmillan, 1998).

99. D. M. Harland and J. E. Catchpole, *Creating the International Space Station* (Chichester, U.K.: Springer-Praxis, 2002).

100. Brian Harvey, *China's Space Program: From Conception to Manned Spaceflight* (Chichester, U.K.: Springer-Praxis, 2004), chapters 1, 10.

In early 2004, the George W. Bush administration announced its Vision for Space Exploration, which directed NASA to replace the Space Shuttle, return humans to the Moon, and eventually go to Mars. By 2006 these plans had been translated into the Constellation program, whose first major systems are the Orion Crew Exploration Vehicle and Ares 1 Crew Launch Vehicle. NASA also began consultations with other nations regarding their future participation.[101]

NASA's overall human flight program costs are published, though sometimes the specific details are difficult to interpret, such as estimating the true cost of the Shuttle program. From the beginning of human flight, the U.S. has had by far the largest budget compared with other nations. NASA's historical human flight budget, shown in figure 9.7, shows a huge spike in the 1960s due to the Apollo program, but since that time has remained relatively stable, with a small spike to build the Shuttle *Endeavour* after the *Challenger* accident. The USAF spent significant funds on the Manned Orbiting Laboratory (MOL) program in the 1960s as well.

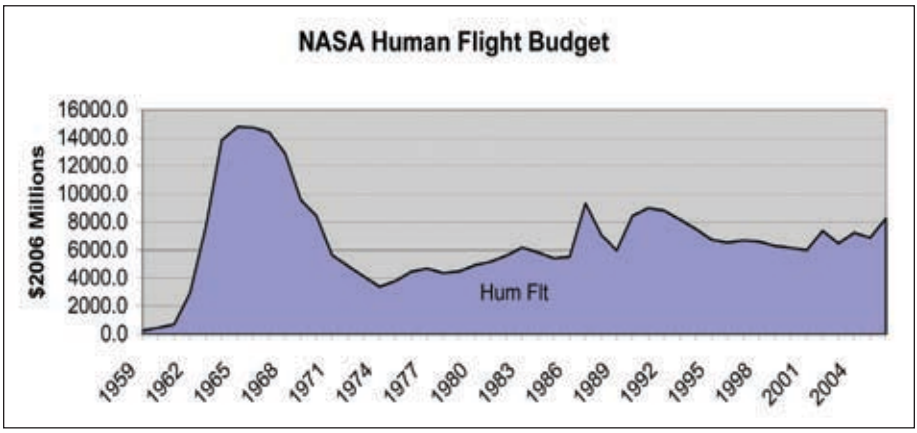


Figure 9.7—NASA human flight budget, 2006 dollars.[102]

Unfortunately, other budget figures are more difficult to acquire. The true costs of the Soviet human flight program may never be known, though all agree that Soviet and Russian costs have been significantly lower than U.S. costs. As compared to Apollo's cost, which has been estimated variously between roughly $21.8 and $25 billion in then-year dollars, the Soviet piloted lunar landing program has been estimated at roughly 4 to 4.5 billion rubles, or approximately $12–$13.5 billion.[103]

101. NASA Web site, *http://www.nasa.gov* (accessed January 2007).

102. Author's compilation. Based on data from NASA annual budget submissions, generally using previous year actuals, and the standard U.S. government deflator schedule.

103. Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race 1945–1974* (Washington, DC: NASA SP-2000-4008, 2000), p. 838. Brian Harvey estimates $4.5 billion in his *Russia in Space: The Failed Frontier?*, p. 13. This figure appears to come from Mishin's writings, though it is not footnoted.

The Energia-Buran program, which was significantly larger than the *Salyut* and *Mir* space station programs, cost some 14 billion rubles over 17 years from 1976 to 1993.[104] China's human flight program, Shenzhou, is reported to have cost ¥18 billion from inception to its first docking flight, or about ¥1.6 billion per year, starting in 1992, which equates roughly to $240 million per year in 2002.[105]

The Soviet and Russian Interkosmos program, which allowed guest flights to *Salyut* and *Mir*, also created the procedures that, with slight modification, allowed for paying customers to travel to *Mir*. In what is apparently the first private booking of a flight to space, the Tokyo Broadcasting System paid $12 million for reporter Toyohiro Akiyama to travel to *Mir* in December 1990.[106] British scientist Helen Sharman flew to *Mir* the next year, paid for by a pool of private companies in the United Kingdom. Starting in the late 1980s, the ESA and European nations paid between $12 and $40 million for European astronauts to visit *Mir*, the price depending on the length and complexity of the mission.[107] In the 1995, the first NASA astronaut arrived at *Mir*, as part of a larger agreement between the U.S. and Russia for the International Space Station. While the U.S. pressed Russia to end the *Mir* program, American entrepreneur Walt Anderson created MirCorp, registered in The Netherlands, to investigate saving *Mir* for commercial purposes. MirCorp delivered a $7 million down payment in January 2000, and Russia flew a MirCorp-paid mission to recommission the station. MirCorp then received funds from American technology investor Denis Tito for two flights, with himself riding on the second. These missions did not take place. *Mir* was deorbited in March 2001; for a reputed $20 million, Tito rode instead as the first "space tourist" on *Soyuz* to the International Space Station, over strenuous American and European objections.[108] Anousheh Ansari became the fourth tourist (and the first woman tourist) in 2006.[109] After losing the battle to keep Tito off the ISS, the U.S. and Europe reluctantly acquiesced in Russia's right to sell tourist seats.

Another route to space tourism opened in June 2004 when Burt Rutan's Scaled Composites Company spacecraft, *SpaceShipOne*, won the $10 million, privately funded X-Prize by reaching suborbital space twice within two weeks, at a cost of roughly $25–$27 million paid by Microsoft cofounder Paul Allen. Richard

104. Siddiqi, *Challenge to Apollo,* p. 841. Brian Harvey puts the cost of the Energia-Buran program at 20 billion rubles. He also translates this to approximately €4.4 billion, which at that time would be roughly equivalent to $4.4 billion.

105. Harvey, *China's Space Program*, p. 293.

106. Wikipedia claims this price was $28 million. *http://en.wikipedia.org/wiki/Space_tourism* (accessed 3 January 2007).

107. Harvey, *Russia, the Failed Frontier?*, p. 31.

108. David M. Harland, *The Story of Space Station Mir* (Chichester, U.K.: Springer-Praxis, 2005).

109. "Female Space Tourist Blasts Off," 18 September 2006, *http://www.CNN.com* (accessed 3 January 2007).

Branson's Virgin Galactic company started a joint venture with Scaled Composites to build *SpaceShipTwo*, which would start carrying tourists for suborbital flights in roughly 2008 for a price of $200,000 each. Founded by motel magnate Robert Bigelow, Bigelow Aerospace began testing inflatable habitats for a space hotel, with its first successful test of Genesis 1 in July 2006.[110] Bigelow created "America's Space Prize," a $50-million award for the first successful reusable spacecraft that could reach his orbiting hotel.[111] The U.S. began to take commercial spaceflight seriously, creating a licensing process through the Federal Aviation Administration's Office of Space Commercialization in 2005.

## MICROGRAVITY RESEARCH

Microgravity research differs from space physical sciences in several ways. First, it has historically been closely tied to human spaceflight because one of the major motivations has been to understand how the human body functions in zero gravity. Human spaceflight and the long-term movement of humans into space depend on deep understanding of microgravity effects both on humans and on other biological organisms. Materials research has generally required human-tended experiments in space and usually must return its samples back to Earth; thus, it also has had strong ties to the human spaceflight program because of the requirement to return astronauts and cosmonauts to Earth. Also, both material and biological research have often been portrayed as having commercial potential, such as purer crystals or proteins grown in space as opposed to on Earth. These promises have yet to be fulfilled, as the cost of doing business in space—despite its potential improved materials quality—is far higher than on Earth.[112]

The need for microgravity science to support human spaceflight, and the potential commercial possibilities of materials research, have led to large and direct government funding of this research and certainly to justifications to build various experiment modules in which to perform it, such as the Spacelab module for the Shuttle, the Japanese Experiment Module and Columbus module for the International Space Station, and various experimental stations on *Skylab*, *Mir*, and in the Space Shuttle payload bay. The various space programs provided funds to create microgravity research disciplines which, unlike the physical sciences, essentially did

110. Jeff Foust, "Bigelow Aerospace's Big Day at the Rodeo," *The Space Review* (24 July 2006), *http://www.thespacereview.com/article/667/1*, accessed January 2007.

111. "Space Tourism," Wikipedia, *http://en.wikipedia.org/wiki/Space_tourism* (accessed 3 January 2007).

112. Bromberg, *NASA and the Space Industry*, pp. 107–109, 167–174; Lou Dobbs with H. P. Newquist, *Space: The Next Business Frontier* (New York: ibooks, 2001).

113. A. Russo, "The European Use of Spacelab," in Krige et al., *A History of the European Space Agency, Volume II*, chapter 14.

not exist until human spaceflight programs required their existence. For example, the ESA had difficulties in the late 1970s when it realized that it was building the Spacelab module but had few researchers capable of using it.[113]

Microgravity research has also been a favorite educational tool, with NASA and other organizations providing major funding and subsidies to allow students from elementary school to graduate school to propose and create experiments such as how spiders build webs in space, how peas grow in space, etc. Microgravity science budgets have grown from essentially zero in the 1950s to tens of millions of dollars by the early twenty-first century so as to fill the experimental facilities of the International Space Station. In 2003, NASA allocated $304 million for biological science, $351 million for physical science research, and another $254 million for various research partnerships.[114] ESA allocated $120 million for microgravity science in 2006.[115]

## Support Services

The U.S. government places restrictions on the number of civil service positions available in its various agencies, but encourages private enterprise. This combination has led to the fact of far more work being assigned to civil service personnel than they can accomplish. To deal with this situation, support service contractors supply the arms and legs for the government personnel, working under government supervision to perform many of the tasks that the civil servants do not have the time to perform. These companies sprang up around all of the NASA facilities, frequently owned or operated by women, minorities, and small businesses so as to meet government guidelines and quotas in these categories. Although the businesses are often owned by people in these categories, the work itself is usually directly supervised by NASA civil servants, with relatively little direction or guidance from the companies.

These unusual political and technical circumstances lead to unusual dynamics. A common experience among these contractors is that one company that held an engineering service contract in one year would lose it to another company in the next. Many of the personnel from the losing company are immediately hired by the winner, such that the personnel doing the actual work often remain the same while the managerial and financial structures are shifted to the new organization. Some support service contractors develop core competences in certain technologies or capabilities, which allow them to compete for other hardware, software, or service contracts, or even to sell products in the nongovernment commercial marketplace. Others, such as SAIC and Teledyne Brown Engineering, become quite large, with parts of the business continuing with support service contracting and other parts with specialized

114. President's FY 2007 Budget Request for NASA, NASA Web site, *http://www.nasa.gov/about/budget/* (accessed January 2007).

115. Peter B. de Selding, "2006 ESA Budget Emphasizes Independence, Satcom Technology," *Space News* (23 January 2006).

expertise that allowed them to bid on manufacturing contracts. Through several legal rulings, NASA's Marshall Space Flight Center was involved with determining the legality and guidelines for the use of such contractors in the 1960s and 1970s. A lawsuit that challenged the legality of support service contracts was filed in 1968 and dragged on for years, but in 1978 was settled in NASA's favor.[116]

## INSURANCE

Governments funded all early spaceflight launches, and if one of the launchers or satellites failed, the government funded a replacement, occasionally in advance. For example, throughout the 1960s and 1970s, NASA typically funded two identical spacecraft on exploration missions to another planet, such as Mariner 1 and 2 in 1962. Targeted to fly by Venus, the first failed while the second completed the mission. The Voyager program of the 1970s built two matching pairs of spacecraft, while Viking had two identical orbiters and landers to ensure that at least one of them succeeded. Liability was another potential concern. Governments could not be sued if a rocket fell on its citizens' property, and could pay for damages through taxes.

Commercial companies were in a different situation. They could not afford to build two copies of each spacecraft to ensure that one worked. In addition, they could be quickly bankrupted should a commercial launch cause damage to private property. In 1965, Communications Satellite Corporation insured its Early Bird satellite for liability and for prelaunch damage to the satellite. Three years later, insurers covered the launch of Intelsat II, and by the 1970s created launch property damage and on-orbit coverage. The 1967 Outer Space Treaty and the 1972 Convention on International Liability for Damage required that nations pay for damage caused to other nations. This spurred the U.S., and later other nations, to set minimum liability insurance requirements on private companies. In the American case, the government requires private companies to obtain insurance to cover damages up to $500 million, and the government will cover any additional damages between $500 million and $2 billion.

Insurers in the U.S. and Europe typically set rates ranging from 15 percent to 20 percent for satellite loss, with several companies generally pooling their efforts for each launch. Liability and on-orbit rates were much lower, reflecting the much lower probability of damage to private property and of on-orbit failures compared to the loss of a satellite during ascent. From revenues of $5 to $10 million in the 1970s, insurance revenues by the 2000s typically ranged from $800 million to $1 billion per year, with loss payouts usually, but not always, smaller.[117]

116. Andrew J. Dunar and Stephen P. Waring, *Power to Explore: A History of Marshall Space Flight Center 1960-1990* (Washington, DC: NASA SP-4313, 1999), pp. 142–143.

117. Alden Richards, "The Early History of the Satellite Insurance Market," *Quest* 9/3 (2002): pp. 54–59.

Insurance companies hate failures that cause them to pay for losses, so when failures do occur they press the launcher and satellite organizations to understand and fix the problems before they would insure another launcher or satellite. The desire to enforce reliability on launcher and satellite organizations led to political problems. In the late 1980s, China entered the commercial launch market, creating Great Wall Industries Corporation to market its Long March rockets. When Long March rockets failed in 1992 and 1995, insurers launched investigations, which forced China (if it wanted to compete commercially) to open up its secretive processes and technologies. In addition, the insurers desired independent investigation committees, which included personnel from Hughes Aircraft, the leading satellite manufacturer, and Space Systems/Loral (SS/L), another major satellite vendor. In the ensuing interactions between the investigators and the Chinese, the U.S. government concluded that Hughes and SS/L had broken American laws regarding International Traffic in Arms Regulations (ITAR), leading to fines of $20 million and $32 million, respectively, on the satellite companies. Insurers in the U.S. and Europe complain that ITAR laws decrease their ability to get the information they need to underwrite policies.[118]

## Capital

Space activities require lots of money. In the past, most of it was provided by the government, but private activities have grown dramatically since the 1980s. Aerospace and space enterprises must occasionally acquire venture capital; the means by which they have done so has gone largely unnoticed by space historians. It is also worth mentioning the 2005 creation of the SPADE Defense Index and the Space Foundation's Space Index, the first indices directly tied to financial performance to defense, space, and homeland security companies.

## Burial Services

Celestis provides the service of sending a person's cremated ashes, for a fee, into space. To do this, Celestis Group first received a license from the Office of Commercial Space Transportation in 1984 to fly cremated remains aboard the Space Services International Conestoga rocket. Conestoga never flew and in 1994 a new company, Celestis Incorporated, negotiated with Orbital Sciences for a launch on its Pegasus launcher, which eventually did take place in 1997. Since then other flights have occurred, with prices ranging from about $495 to $12,500, depending on the amount of ashes and their ultimate destination.[120]

118. *The United States House of Representatives Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China* (Cox Report) (Washington, DC: Government Printing Office, 3 January 1999), chapter 8, "Commercial Space Insurance."

119. Space Foundation, *The Space Report 2006* (Colorado Springs, CO: Space Foundation, 2006), pp. 149–150, *http://www.spaceindex.com/* (accessed 14 January 2007).

120. Celestis Web site, *http://www.memorialspaceflights.com* (accessed 14 January 2007).

## MANAGEMENT, ECONOMICS, AND POLICY

The assessment of management, economics, and policy issues has spurred a small market of government and industry organizations. Management companies such as Booz Allen Hamilton, Inc. and McKinsey & Company have consulted for businesses and the government for years, occasionally including space organizations, such as McKinsey's support to JPL's reorganization efforts in 1959.[121] Economic issues have been a staple of industry associations, such as the Aerospace Industries Association in the U.S., or Eurospace in Europe. They gather and collate aerospace industry-wide data to assist member company marketing and lobbying.[122]

The Department of Commerce's Office of Space Commerce, founded in 1988, has performed political-economic analyses since that time. In 1998, Congress passed the Technology Administration Act, which founded the Office of Space Commercialization; it was transferred to the National Oceanic and Atmospheric Administration (NOAA) in 2004. It funded private companies like Futron Corporation and The Tauri Group to assess various political-economic issues.[123] The Commercial Space Launch Act of 1984 gave the Department of Transportation's Office of Commercial Space Transportation regulatory authority over commercial space launches. It was transferred in 1995 to the Federal Aviation Administration (FAA) as the Associate Administrator for Commercial Space Transportation (AST). AST publishes quarterly and annual reports of worldwide commercial space launch activities.[124]

## EDUCATION

As space activities developed, so too did educational programs to train space industry personnel. These started at institutions involved with early rocketry or satellite projects, such as California Institution of Technology's Jet Propulsion Laboratory (JPL), Massachusetts Institute of Technology's (MIT's) Lincoln Laboratory, and Johns Hopkins University's Applied Physics Laboratory (APL). These institutions created engineering and scientific programs to train their own employees and other government and industry personnel. Some programs and institutions were created based on government or commercial lobbying, such as Wernher von Braun's successful effort to create a research institute at the Huntsville

121. Stephen B. Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), p. 252, footnote 45.

122. See the Aerospace Industry Association, *Aerospace Facts and Figures* (Arlington, VA: Aerospace Industries Association), or Eurospace's *Eurospace Facts and Figures*, both published annually.

123. See the Office of Space Commercialization Web site, *http://www.nesdis.noaa.gov/space/* (accessed January 2007).

124. *Aeronautics and Space Report of the President, Fiscal Year 2004 Activities* (Washington, D.C.: Government Printing Office, 2005).

Extension Center of the University of Alabama, which was a major factor in the 1966 creation of the independent campus, the University of Alabama in Huntsville. Similar relationships occurred elsewhere, such as Stanford's relationship with the USAF and NASA's Ames Research Center, NASA Johnson's relationship with the University of Houston Clear Lake, or NASA Kennedy Space Center's relationship with the University of Central Florida. Some space organizations spun off from educational institutions, such as the Charles Stark Draper Laboratory spun off from MIT, MITRE Corporation created from Lincoln Laboratory, Aerojet from JPL, and so on. Diversified (not merely technical) programs such as the University of North Dakota's Department of Space Studies and the International Space University (Strasbourg, France) were created in 1987. Other specialized programs now exist in space systems management, politics, and other space-related topics. Private companies also provided technical courses and consulting. The political and economic dimensions of space education have gotten little attention to date, except for the creation of economic clusters such as those in Colorado Springs, the greater Los Angeles and Boston areas, and Florida's Space Coast.[125]

With strong Congressional support to ensure educational funding in every state, NASA created its own educational programs. The NASA Space Grant programs provide space educational materials to elementary and high school teachers, provide student scholarships, promote space education to minorities and disadvantaged groups, and support various university programs. NASA also creates educational programming on its own television channel, much of which is targeted to these same audiences. The economic and political effects of these programs has, to date, not been investigated, though tens of millions of dollars are spent annually.

Space camps to educate young people were created specifically to spur science and mathematics education, and hence technical development in their societies. Soviet space camps originated from Young Cosmonauts Groups, which came into being soon after Gagarin's 1961 flight. These spread across the Soviet Union and then into its allied European nations such as East Germany, Poland, and Hungary. The first U.S. space camp took place in 1982 in Huntsville, Alabama, at United States Space and Rocket Center, which had been founded earlier under the direction of Wernher von Braun. By the early twenty-first century, space camps existed worldwide.[126]

125. Ann Markusen, Scott Campbell, Peter Hall, and Sabina Deitrick, *The Rise of the Gunbelt: The Military Remapping of Industrial America* (Oxford, U.K.: Oxford University Press, 1991). William Barnaby Faherty, *Florida's Space Coast: The Impact of NASA on the Sunshine State* (Gainsville, FL: University Press of Florida, 2002).

126. Anne Baird and Robert Koropp, *The Official U.S. Space Camp Book* (1992); Pablo de Leon, "Space Camps," in Space Exploration and Humanity, 2 vols. (Santa Barbara, CA: ABC-CLIO, in press).

## PROFESSIONAL AND ADVOCACY GROUPS

As rocketry moved from amateurs to military organizations and corporations in the 1940s, the amateur rocketry groups matured into advocacy and professional groups. Professional groups such as the American Astronautical Society (AAS) and the American Institute for Aeronautics and Astronautics (AIAA), primarily acted as professional networking organizations, sponsoring conferences and publications for engineers and managers working in corporations and government organizations. Others, such as the British Interplanetary Society and the National Space Society (NSS), continued the tradition of space advocacy. Despite their small size, these organizations have significant political and economic impact, as they provide forums for technical and political interchanges between government, industry, and academic organizations.

## MEDIA

Space, with its inherent aura of mystery, risk, and danger, has always been a popular media topic, which a variety of media cater to and profit from. Some general media outlets cater to space activities, such as the "New Series in NASA History" by the Johns Hopkins University Press; the Public Broadcasting System's creation and airing of Carl Sagan's *Cosmos* series in the 1980s; Home Box Office's series *From Earth to the Moon* in the early twenty-first century, and *The Space Show*, a San Francisco radio show. Professional space organizations such as the AIAA, the AAS, and the British Interplanetary Society have their own in-house publication capabilities for trade journals, books, and newsletters; so do NASA, ESA, and other government space organizations. Some publishers publish mainly or only space topics, such as Apogee Press, Orbit Press, and Space Publications. Some publications are space-only or aerospace-only, such as *Space News* or *Aviation Week & Space Technology*. Though this sector is small in terms of money, its influence is much larger than its economic size indicates.

## CONCLUSION

Space historians select a variety of topics to study based on their own individual interests, but they should also take note of those subjects that humanity as a whole values, and of the wide variety of institutions that support activities in space. The money spent on particular areas is a proxy for the value that humans place on those activities. By this standard, space telecommunications has become, by the early twenty-first century, the most important space topic. Perhaps because its rise to prominence became significant in the 1980s and 1990s, it has yet to rate highly among historians—a fact this paper hopes to elevate. Also, the variety of economic activities that take place to support space endeavors is significantly broader than is typically portrayed. Topics such as space education, insurance, weaponry, and support services are subjects as worthy of analysis as are human flight and space

science. Analysis of the interaction of civilian, military, and commercial activities must take place within the context of these many sectors, as these interactions vary greatly from sector to sector.

In one respect, all of these interactions have a common characteristic—economic and political issues are tightly intertwined. A number of studies and analyses try to separate the economic and political realms. Advocates of private enterprise such as those in the so-called alt-space movement try very hard to divide true "commercial" endeavors from government-funded activities.[127] Unfortunately for them, separating government from space activities has been extremely difficult and is likely to remain so for a variety of economic, legal, and political reasons. Indeed, businesses in general seek any profitable markets, and governments are too large a market for space-related businesses to ignore. Dollars, after all, are just as green coming from the government as from other corporations or from individuals.

Space historians have the opposite bias because they have depended largely on government sources, which in turn have led to histories that take a government viewpoint—often with similar priorities to the governments themselves. Instead, we space historians need to provide a much better balance between government and private activities in our studies and analyses. Whether investigating governmental activities (where politics are the priority but economics the grease) or investigating private activities (where economics is often primary and politics unavoidable), a political-economic approach is a useful tool to ensure a proper balance of perspectives.

127. See, for example, Edward L. Hudgins, ed., *Space: The Free-Market Frontier* (Washington, DC: The Cato Institute, 2002); Paula Berinstein, *Making Space Happen: Private Space Ventures and the Visionaries Behind Them* (Medford, NJ: Medford Press, 2002), and Dobbs, *Space: The Next Business Frontier*.