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TECHNICAL
REPORT

Scoping Aerospace

Tracking Federal Procurement and R&D Spending in the Aerospace Sector

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Lawrence S. Painter

Prepared for the Office of the Secretary of Defense

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

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Preface

This report assesses the scope of external federal spending within the aerospace industry. The study provides a detailed examination of the Federal Procurement Data System (FPDS), with the specific purpose of tracking all government aerospace procurement and research and development (R&D) expenditures from 1993 to 2003. The resulting data are used to analyze trends in government aerospace spending during the past decade.

This study's findings will be of greatest interest to analysts and scholars who seek to understand changes in government aerospace spending in the post–Cold War era. It should also help policymakers better understand recent trends that have led to the decline in external aerospace expenditures.

This research was sponsored by the Commission on the Future of the United States Aerospace Industry and conducted within the Acquisition & Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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Summary

In 2002, the Commission on the Future of the United States Aerospace Industry (Aerospace Commission) approached the RAND Corporation to assist it by scoping the breadth of federal procurement spending on air systems, missile systems, and space systems—including research and development (R&D). This effort was not intended to identify all government aerospace expenditures, but was instead meant to approximate the amount of *external* (as opposed to internal) federal spending within the aerospace industry.[1] RAND presented its findings to the Aerospace Commission in fall 2002; the commission, in turn, used the RAND data in its final report. This follow-on document is intended to explain RAND's methodology and update and expand upon our initial findings.

We chose to use a definition of *aerospace industry* that was developed by Stanley Weiss and Amir Amir:

> Assemblage of manufacturing concerns that deal with vehicular flight within and beyond the Earth's atmosphere. (The term aerospace is derived from the words aeronautics and spaceflight.) The aerospace industry is engaged in the research, development, and manufacture of flight vehicles, including unpowered gliders and sailplanes, lighter-than-air craft, heavier-than-air craft (both fixed-wing and rotary-wing), missiles, space launch vehicles, and spacecraft (manned and unmanned). Also included among its concerns are major flight-vehicle subsystems such as propulsion and avionics (aviation electronics) and key support systems necessary for the testing, operation, and maintenance of flight vehicles. In addition, the industry is engaged in the fabrication of nonaerospace products and systems that make use of aerospace technology.[2]

With this definition in mind, we analyzed aerospace procurements and R&D expenditures within three subsectors: air systems, missile systems, and space systems. This analysis looked at eleven years (1993–2003) of data gleaned from the Federal Procurement Data System. Our intent was to provide a picture of recent trends in external federal aerospace spending, as requested by the Aerospace Commission.

Our study revealed a clear downward trend in federal aerospace procurement and R&D expenditures during the past decade.[3] The analysis suggests that this decline was felt in

[1] The results only approximate external spending because they do not include classified military programs, which could not be identified using the Federal Procurement Data System (the database utilized for this study).

[2] Stanley I. Weiss and Amir R. Amir, "Aerospace Industry," available at *Encyclopedia Britannica Online*, accessed 19 July 2004.

[3] This general trend includes spending by the two major aerospace agencies (DoD and NASA) as well as smaller actors such as FAA, DOT, NOAA, and GSA.

each of the primary aerospace sectors—air systems, missile systems, and space systems. Overall, air system spending fell 35 percent and missile system spending fell 50 percent. Space system expenditures dropped by a somewhat lower amount—10 percent. We found some evidence that this trend may be reversing itself—specifically, a large increase in Department of Defense (DoD) spending in 2003. This was most likely caused by a change in presidential administrations and regular military procurement cycles (particularly with relation to air systems); however, the turnaround did not become evident until 2003 because of a typical lag between budgeting and actual spending.

Our examination revealed a potentially worrisome trend in military airframe procurements, which had declined by 50 percent before a one-year spike in 2003.[4] This decrease in spending could be explained by regular procurements cycles and federal budgetary priorities, but such a sharp drop suggests that military expenditures may remain far below Cold War–era levels. Full air system procurements (which include engines, components, and infrastructure) also dropped during the period studied, although not as steeply as did airframe spending. One possible reason for this slower decline could be that the military has had to maintain some spending for engines and major air system components as it attempts to field an ever-smaller number of operational airframes. One potential outcome, if airframe procurements do not fully recover, is that engine and major component expenditures may eventually decrease as the military transitions to a smaller suite of air assets. We also found that overall DoD aerospace-related R&D spending dropped dramatically after the Cold War—these expenditures were cut in half during the period studied. Overall, external military spending (for air systems, missile systems, space systems, and aerospace R&D) declined by over 40 percent during the period examined.

Our findings regarding the National Aeronautics and Space Administration (NASA) are only slightly more favorable. The agency has seen a 35 percent decline in its external spending during the past decade. It has been able to maintain its level of space system expenditures during this period (they decreased by only 10 percent), but many other areas have suffered. Our data reveal three ways that NASA has maintained most of its program-centric spending: drastically reducing infrastructure expenditures, increasing its dependence on technical service providers, and cutting R&D spending by over 40 percent during the past decade. These findings reveal that NASA's leaders have made hard decisions (e.g., deferring critical infrastructure repairs) to maintain a relatively aggressive slate of mission priorities while the agency's real buying power has been falling. The question that remains, however, is whether these strategies can be maintained indefinitely.

[4] DoD figures do not include all "black" (classified) aerospace programs.

Acronyms

AAS	Army Air Service
ABMA	Army Ballistic Missile Agency
ACR	Air Commerce Regulation
AIA	Aerospace Industries Association
ARDC	Air Research and Development Command
CAA	Civil Aeronautics Authority
CAB	Civil Aeronautics Board
CSM	Command Service Module
DDR&E	Director, Defense Research & Development
DMSP	Defense Meteorological Support Program
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOJ	Department of Justice
DOT	Department of Transportation
DVA	Department of Veterans Affairs
FAA	Federal Aviation Administration
FFRDC	Federally Funded Research & Development Center
FPDS	Federal Procurement Data System
FY	fiscal year
GALCIT	Guggenheim Aeronautical Laboratory of the California Institute of Technology
GPS	Global Positioning System
GSA	General Services Administration
HHS	Department of Health and Human Services
ICAR	Individual Contract Action Reports
ICBM	intercontinental ballistic missile
IDCSP	Initial Defense Communication Satellite Program

JATO	Jet Assisted Takeoff
JPL	Jet Propulsion Laboratory
LEM	Lunar Module
Milsatcom	Military Satellite Communications
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics & Space Administration
NDRI	National Defense Research Institute
NOAA	National Oceanographic and Atmospheric Administration
NTSB	National Transportation Safety Board
PSC	product or service code
R&D	research & development
RaDiUS	Research & Development in the United States
S&T	science & technology
SIC	Standard Industrial Classification
TVA	Tennessee Valley Authority
USA	United Space Alliance
USAF	United States Air Force
WWII	World War Two

CHAPTER ONE

Study Background

The Commission on the Future of the United States Aerospace Industry was created under the auspices of the 2001 National Defense Authorization Act (P.L. 106-398). The Commission was established to "study the issues associated with the future of the United States aerospace industry in the global economy, particularly in relationship to . . . the importance of the domestic aerospace industry for the economic and national security of the United States." The commission was chaired by former House Science Committee chairman Bob Walker and consisted of six members appointed by the White House and six members appointed by Congress.[1] Due to the role of the aerospace industry as one of the most important economic sectors within the national economy (the commission found that the sector accounted for 15 percent of the nation's gross domestic product and 11 million jobs), the goal of the commission was to determine federal departmental and agency actions that could maintain a robust American aerospace industry well into the 21st century.

In its charter, the commission was specifically tasked with evaluating the adequacy of projected aerospace research and development (R&D) and procurement budgets. Over the course of 12 months (from November 2001 to November 2002), the commission conducted extensive deliberations to answer this and other questions. As these deliberations continued, the commission staff approached the RAND Corporation to assist it by scoping the breadth of federal spending on air systems, missile systems, and space systems—including R&D. This effort was not intended to identify all government aerospace expenditures, but was instead meant to approximate the amount of *external* (as opposed to internal) federal spending within the aerospace industry.[2] The study was sponsored by the Director, Defense Research and Engineering (DDR&E) and was conducted jointly by RAND's Acquisition and Technology Policy Center (part of the RAND National Defense Research Institute, a federally funded research and development center) and the RAND Science and Technology (S&T) research unit. The resulting report was intended to provide policymakers with a tool for better understanding the federal government's role in fostering the health of the U.S. aerospace industry.

RAND presented the results of this research to the Aerospace Commission in fall 2002. The commission, in turn, presented the RAND data in an appendix to its report (as

[1] Commission members were F. Whitten Peters, Buzz Aldrin, Edward M. Bolen, R. Thomas Buffenbarger, John W. Douglass, Tillie K. Fowler, John J. Hamre, William Schneider, Jr., Robert J. Stevens, Neil deGrasse Tyson, and Heidi R. Wood.

[2] The results only approximate external spending because they do not include classified military programs, which could not be identified using the Federal Procurement Data System (the database utilized for this study).

well as in the chapter addressing government promotion of aerospace). The objectives of this document, a follow-on to the original RAND submission, are threefold:

1. To explain the methodology that RAND employed to derive the data charts included in the Aerospace Commission report
2. To update the results of this analysis with two additional fiscal years of data and inclusion of re-categorized spending items (particularly for NASA)
3. To expand on the analysis with additional breakouts of federal aerospace procurements and R&D by agency, performer type, state of performance, and funding mechanisms.

We discuss the above items in the next chapter. Below, we discuss RAND's methodology for this analysis.

The approach taken by RAND to "scope" government activities aimed at fostering the aerospace industry was to use procurement data that are systematically collected on all contracts awarded by federal departments and agencies (both national security and civilian) to identify budgetary resources that fund programs within the air, missile, and space sectors. Specifically, the study team used the Individual Contract Action Reports (ICARs) contained in the Federal Procurement Data System (FPDS) to identify all air system, missile system, and space system expenditures—including extramural R&D spending. This information was used to identify the government departments and agencies engaged in funding aerospace activities. These data were initially gathered for fiscal year (FY) 1993 through FY 2001 to facilitate the identification of possible short-term trends (the present report expands the range to 2003 to provide a full decade of data).

Among the specific data elements that were extracted from each ICAR were the FIPS 95 code, which identifies the

- awarding federal unit
- Standard Industrial Classification (SIC) code, which classifies the industrial affiliation of the receiving entity
- amount of the contract awarded
- product or service codes (PSCs).

The PSCs were by far the most critical.[3] They provided the detailed information needed to identify the range of efforts that, when grouped together, could reasonably be

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[3] The following three- and four-digit PSCs were used for this study: 1510, 1520, 1540, 1550, 1560, 1610, 1615, 1620, 1630, 1650, 1660, 1670, 1680, 1710, 1720, 1740, 2620, 5821, 5826, 5831, 5841, 2810, 2840, 2845, 2915, 2925, 2935, 2945, 2995, 1270, 1280, 6340, 1340, 1045, 1055, 1105, F001, T009, F002, B539, V111, V211, P200, C111, V121, V227, V221, 1905, 1730, 4920, Y121, Y122, Y123, Y124, Y125, Y127, Y129, H215, H216, H217, H228, H315, H316, H317, H328, N015, N016, N017, N028, X121, X122, X123, X124, X125, X127, X129, W015, W016, W017, W028, J015, J016, J017, J028, Z121, Z122, Z123, Z124, Z125, Z127, Z129, K015,K016, K017, K028, M121, M122, M123, M124, M125, M127, M129, H915, H917, H928, E121, E122, E123, E124, E125, E127, E129, H115, H116, H116, H117, H128, 4927, L015, L016, L017, L028, 1410, 1420, 1425, 1427, 1430, 1440, 1336, 1115, 1337, 1338, 1127, Y126, H214,4935, H314, N014, X126, W014, J014, Z128, 1450, K014, M126, H914, E126, H114, L014, 1810, 1820, 1830, 1840, 1860, 1337, 1338, J028 (space systems only), H218, H228 (space systems only), V126, H318, H328 (space systems only), N018, N028 (space systems only), W018, W028 (space systems only), J018, K018, K028 (space systems only), H918, H928 (space systems only), H118, H128 (space systems only), 1850, 4960, L018, L028 (space systems only), AR1, AT3, AS1, AC1, AJ1, AJ2, AJ3, AJ4, AJ5, AJ6, AJ7, AJ9, AC2, AR2, AR3, AR4, AR5, AR6, AR7, AR9.

deemed to comprise the totality of unclassified federal activities in the aerospace industry (not including internal aerospace efforts).[4] This further allowed the study team to parse these activities among the various sectors that make up the aerospace industry (air systems, missile systems, and space systems). Since RAND had already pulled the ICARs involving federal R&D from the FPDS to place in the Research and Development in the United States (RaDiUS) database,[5] the study team needed only to identify the non-R&D contracts that involved air system, missile system, and space system procurements. This was accomplished by classifying all contract categories in the FPDS catalog that appeared to be associated with one of these areas. Although this approach may slightly underestimate the amount of federal money going to the aerospace industry (because it does not capture all contracts that are classified in hard-to-distinguish categories), the study team believes it provides a relatively accurate approximation of external federal activities in this area.

Although the Aerospace Commission was formed to examine the condition of the aerospace industry, it did not provide a comprehensive definition of what business segments make up the industry. Interested readers can refer to Appendix A for a discussion of the development of the aviation, missile, and space sectors. This historical summary was used to inform our selection of a guiding definition of *aerospace industry.* The most comprehensive definition we found was in an article by Stanley Weiss and Amir Amir:

> Assemblage of manufacturing concerns that deal with vehicular flight within and beyond the Earth's atmosphere. (The term aerospace is derived from the words aeronautics and spaceflight.) The aerospace industry is engaged in the research, development, and manufacture of flight vehicles, including unpowered gliders and sailplanes, lighter-than-air craft, heavier-than-air craft (both fixed-wing and rotary-wing), missiles, space launch vehicles, and spacecraft (manned and unmanned). Also included among its concerns are major flight-vehicle subsystems such as propulsion and avionics (aviation electronics) and key support systems necessary for the testing, operation, and maintenance of flight vehicles. In addition, the industry is engaged in the fabrication of nonaerospace products and systems that make use of aerospace technology.[6]

We used this definition to guide our examination of external federal government spending in the aerospace industry. The next chapter provides a detailed analysis of federal procurements and R&D expenditures during the past decade, with specific emphasis on spending in the three main areas of aerospace activities: air systems, missile systems, and space systems.

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[4] Although PSCs provided the overwhelming guidance in defining each category, we sometimes used the SIC codes to assist with additional refinement when the same PSC could apply to multiple categories.

[5] RAND operates the RaDiUS database for the National Science Foundation to track federal R&D spending and activities.

[6] Stanley I. Weiss and Amir R. Amir, "Aerospace Industry," available at *Encyclopedia Britannica Online*, accessed 19 July 2004.

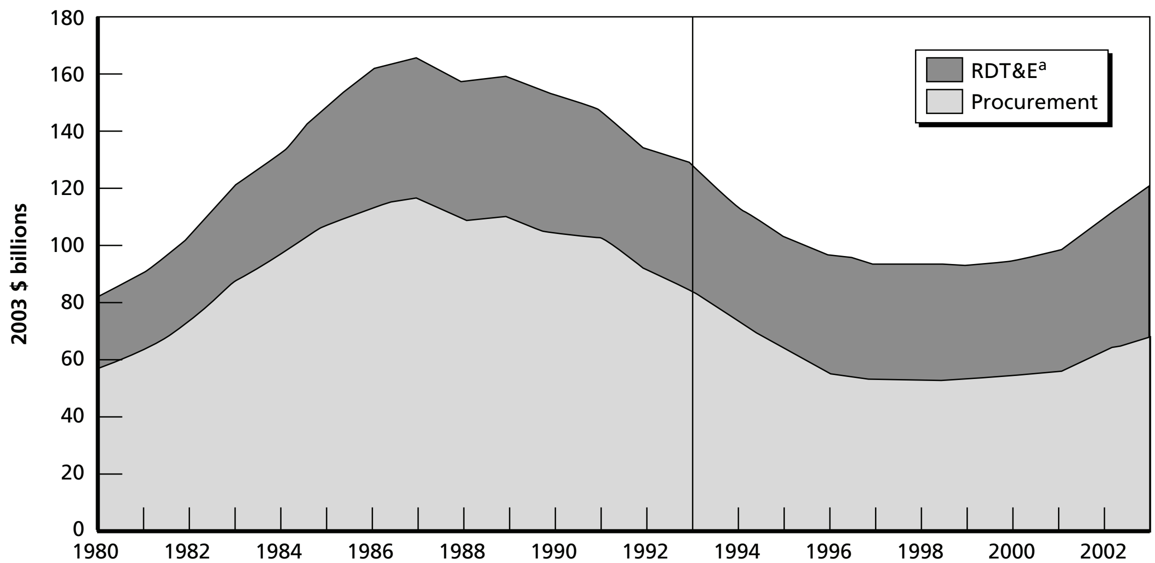
CHAPTER TWO

State of the Aerospace Sector from 1993 to 2003

In the two years since RAND delivered the results of its initial analysis of external federal spending in the aerospace sector, additional data have become available. In addition, we have made an effort to correct errors in the original data—these corrections have the effect of increasing total NASA spending. This chapter builds on the original analysis to include the past two fiscal years and produce increased fidelity in the examination of spending by DoD and NASA. The end result is a fuller discussion of federal sponsorship of contractor activities intended to meet government requirements in the aerospace arena.

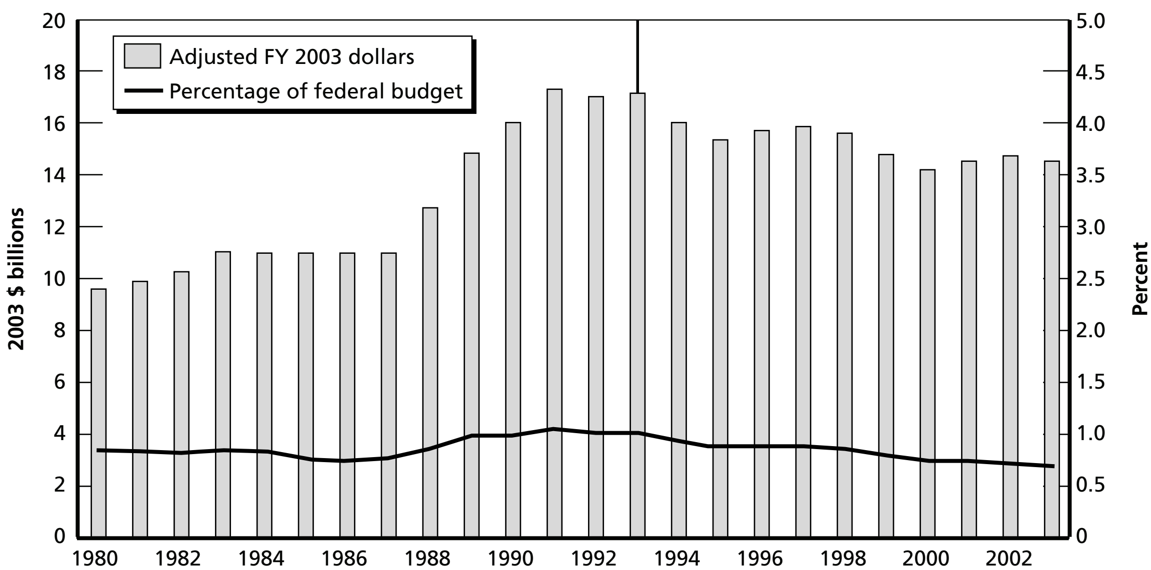
Before commencing on a more detailed discussion of our specific findings, it is important to understand where our eleven years of data fit into longer-term procurement and R&D cycles. RAND's RaDiUS project began in 1993, which is why we selected that year as the first for our study. To place this initial year within the larger context of government spending and contemporary developments in the aerospace sector, we examined the federal budget and industry statistics compiled by the Aerospace Industries Association (AIA). The federal budget reveals that, from a DoD perspective, 1993 was near the midpoint of a slide in military procurements (and to a lesser degree R&D expenditures) that began after the Reagan administration's defense buildup and continued through the late 1990s (see Figure 2.1). From a NASA perspective, on the other hand, 1993 was part of a three-year peak when the space agency's appropriation rose above 1 percent of the federal budget for the first time during the post-Apollo era (it had reached a high of approximately 4.4 percent in 1966). During the subsequent decade, the agency experienced a slow decline in its annual allocation in constant 2003 dollars (see Figure 2.2). To appreciate how these larger trends affected aerospace spending, we turned to industry-specific statistics compiled by AIA. These statistics provide evidence that the overall slide in military procurements was also felt in the aerospace sector. AIA data regarding industry sales to DoD suggest that military aerospace spending had begun falling in the late 1980s and did not level off until the late 1990s (see Figure 2.3). The picture is slightly different for NASA. AIA data show that industry sales to the space agency held relatively steady from the late 1980s through the early part of the 21st century. This suggests that despite decreases in NASA's buying power during this period, the agency was able to maintain (and even slightly increase) its external spending. In sum, these data reveal that overall external aerospace spending by federal agencies fell in the years leading up to 1993—primarily driven by the drop in military procurements. The remainder of this chapter attempts to determine whether these overarching trends can be validated utilizing the FDPS and RaDiUS.

Figure 2.1
DoD Procurement and RDT&E Spending, 1980–2003



SOURCE: RaDiUS database.
[a]RDT&E = Research, development, test and evaluation.

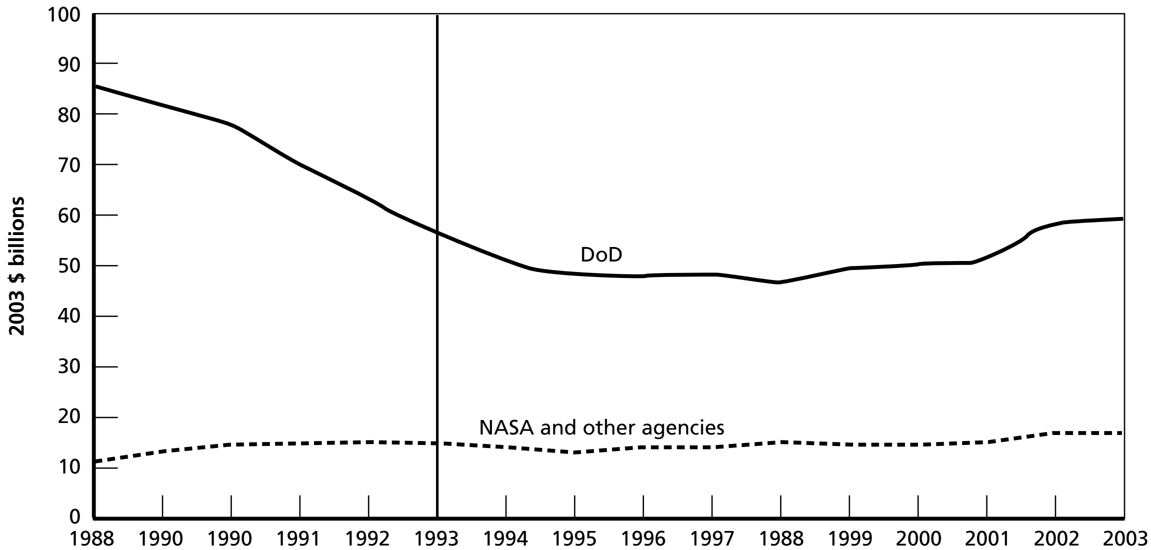
Figure 2.2
NASA Budget, 1980–2003



SOURCE: RaDiUS database.

The original data provided to the Aerospace Commission displayed unadjusted federal spending from 1993 to 2001. For this updated analysis, we expanded the data range to include two additional years (2002 and 2003) and adjusted spending to constant 2003 dollars—which provides a more realistic look at procurement and R&D trends by taking inflationary changes into account. In addition, two categories of NASA expenditures were

Figure 2.3
Aerospace Industry Sales by Customer, 1988–2003

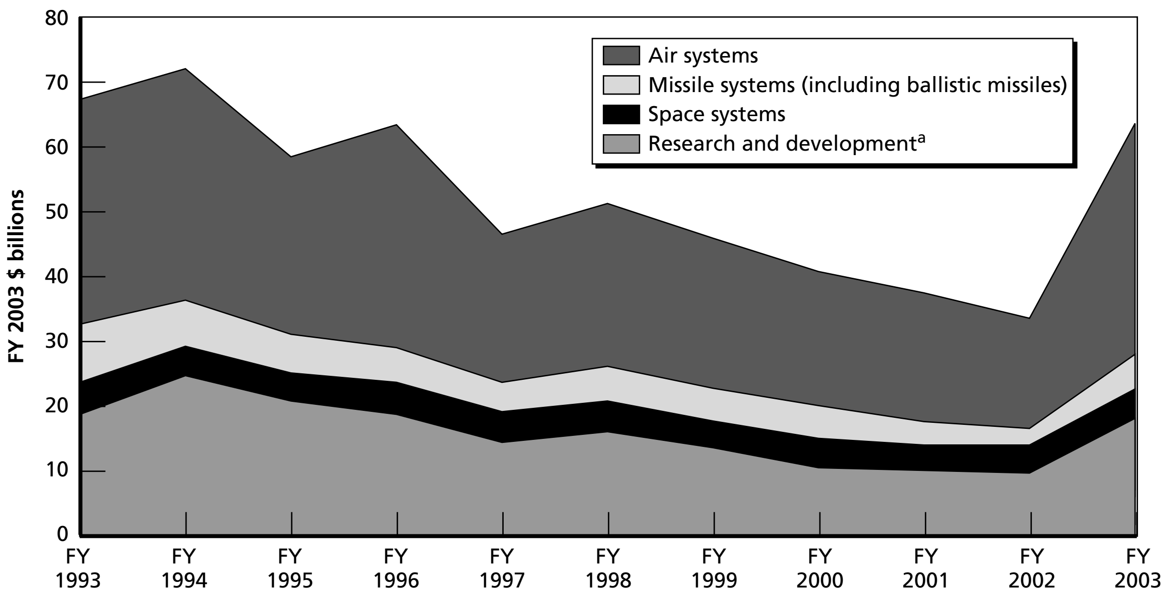


SOURCE: AIA (2004).

recategorized for this revision: The first category takes into account the work conducted at the Jet Propulsion Laboratory (a federally funded research and development center operated by the California Institute of Technology for NASA); the second includes professional engineering and technical services (such as those conducted by the United Space Alliance, which operates the Shuttle program). These two categories were initially classified as nonaerospace because that is how they were reported to FPDS. After further reflection, however, it seemed prudent to classify them as aerospace activities in our updated study to provide a more accurate picture of NASA's activities in the aerospace industry. This correction resulted in an increase in NASA's external spending of an average of $3.3 billion per year over the period examined. We believe this represents an improvement over the original data provided to the Aerospace Commission. Despite this correction, the overall federal trends identified in the first report provided to the commission are still supported by the adjusted data, particularly in light of the inflationary modification of the spending figures (see Figure 2.4).

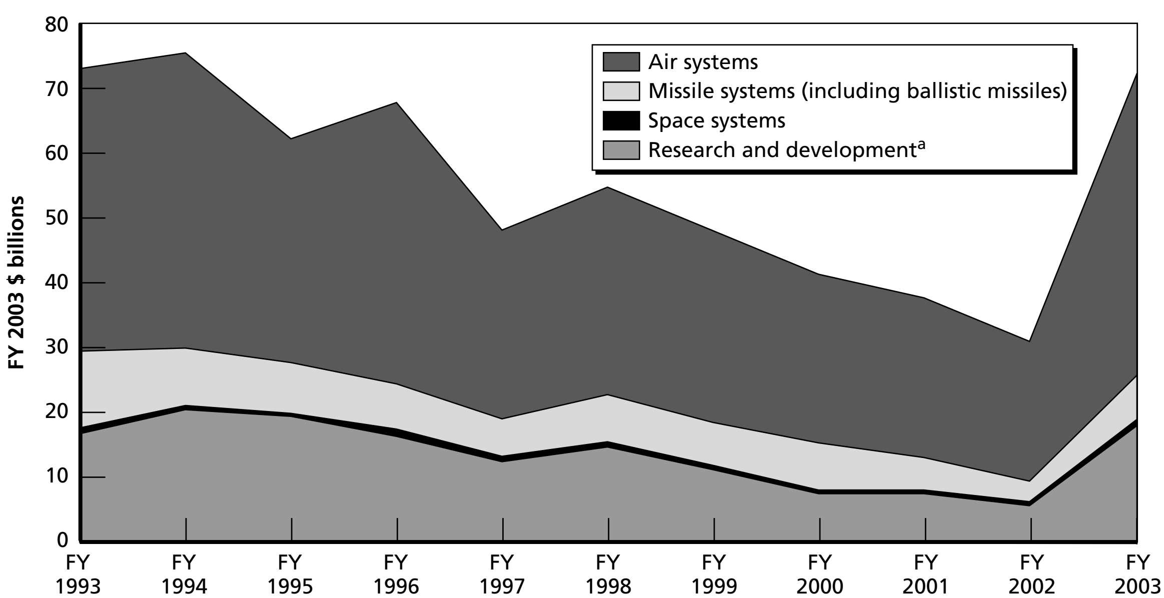
An examination of Figure 2.4 shows that there were dramatic shifts in aerospace spending during the past decade. The largest fluctuations occurred in air system procurements. Expenditures in that category dropped from $28.6 billion in 1993 to only $16.6 billion in 2002, before making a major jump in 2003 to $35.5 billion (all figures are in adjusted 2003 dollars). Several factors contributed to this variability in federal spending over such a short period of time. First, the initial ten years of data clearly show a steady decline in overall federal expenditures in this area—which, as Figure 2.5 shows, occurred mostly in DoD procurements. (Figure 2.6 shows that NASA air system spending is very limited.) This is likely the result of the end of the Cold War, which led to a reduction in the need for as many new aircraft procurements. Second, the decline over the first ten years examined could be explained as the natural result of regular cycles in major aircraft system procurements by the military. Within the fighter aircraft arena, in particular, expenditures for existing aircraft

Figure 2.4
Federal Aerospace Spending, FY 1993–2003



[a]Includes only activities conducted outside the government.
SOURCE: RaDiUS database.

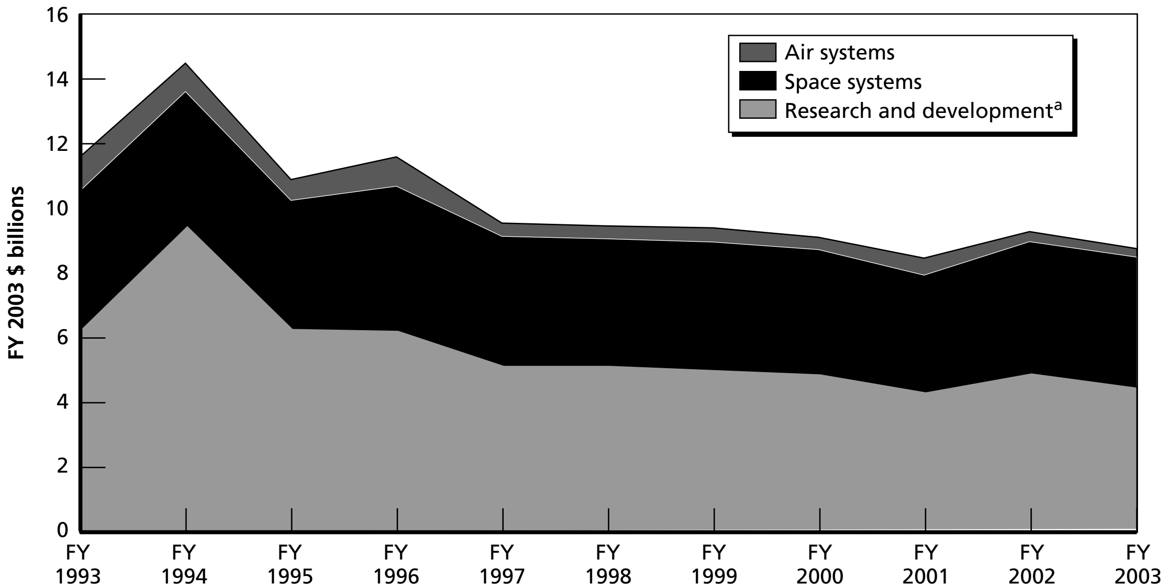
Figure 2.5
DoD Aerospace Spending, FY 1993–2003



[a]Includes only activities conducted outside the government.
SOURCE: RaDiUS database.

have been slowly falling as the DoD prepares to bring new systems online—most importantly the F-35 Joint Strike Fighter. Finally, the rapid increase in aircraft system procurements in the final year examined can likely be explained by a redirection in budget priorities

Figure 2.6
NASA Aerospace Spending, FY 1993–2003



[a]Includes only activities conducted outside the government.

SOURCE: RaDiUS database.

resulting from a change in presidential administrations. This shift did not become evident in the data until 2003 because of a lag between budgeting and actual spending.

Within the area of missile systems, we see similar trends during the same period. The level of these expenditures stood at $7.4 billion in 1993, but they had fallen to only $2.6 billion by 2002. In 2003, they doubled back to $5.2 billion. Unlike the air system arena, however, these decreases were not steady over time. During the war in Kosovo, where the U.S. military waged a large air war that relied heavily on guided missiles, there were small spending spikes. There was also a large spike that can be accounted for by increased missile utilization during the Afghanistan and Iraq wars. Despite these temporary increases in expenditures, however, spending did not rebound to the levels of the early 1990s. This may indicate that missile spending is heavily influenced by fluctuating demands resulting from armed conflict. It also supports the conclusion that overall spending on missile systems decreased in the post–Cold War era. We can also see by looking at Figures 2.5 and 2.6 that the DoD accounted for all of the spending in the missile system arena.

Within the area of space systems, federal spending has held relatively steady during the past decade. Although there have been some ups and downs, space systems have enjoyed stable support compared with the other major spending areas. Governmentwide space expenditures equaled $4.8 billion in 1993, and—although they fluctuated over the subsequent decade (reaching a low of $4 billion and peaking at $5 billion)—they had returned to 1993 levels by 2003. Unlike air systems and missile systems, which experienced marked declines in spending before benefiting from increased expenditures under the Bush administration, space systems encountered a small, steady overall decrease over the same period.

Figures 2.5 and 2.6 also show that the vast majority of space system expenditures were by NASA. The space agency spent over $4 billion in 2003 whereas DoD spent only $850 million. This apparent disparity is likely the result of the different accounting methods used by NASA and DoD and the fact that many space system expenditures are kept within the agencies' R&D budget lines. Another factor contributing to this variation is the fact that a considerable amount of DoD's space system spending is hidden within classified budget lines for which data are not publicly available (see the next section for an expanded discussion of classified budgets). The main point regarding space systems, however, is that overall spending in this area remained relatively stable during the past decade.

In the R&D area, there has been a general decline in federal spending during the past decade. As in other areas, however, there was a noticeable spike in expenditures in 2003. Although both DoD and NASA R&D spending declined during the past decade, there was a noticeable increase in 2003 expenditures for DoD but not for NASA, which maintained its lower investment level. Before the 2003 readjustment, overall air and space R&D had declined from a high of $24.8 billion (in 1994) to a low of $9.6 billion (in 2002). Thus, over the course of a single decade, federal spending on R&D in the aerospace industry declined by nearly two-thirds in real terms. It is important to remember that these figures do not account for R&D activities that are carried out internally by government researchers (personnel costs alone would likely add a few billion dollars to the overall figure), but they still represent a startling decline in R&D investments. And although both DoD and NASA experienced general declines in R&D spending, the military cuts were much deeper (a 66 percent annual loss)[1] than civilian cuts (a 27 percent annual loss). Nearly all the increased spending in 2003 (almost $9 billion) went to military R&D programs—NASA actually experienced a $500 million decline that year. While it remains to be seen whether this one-year increase in funding represents the beginning of a new upward trend, these data indicate a disturbing overall decrease in federal spending on air and space R&D programs.

Federal air and space spending is distributed widely throughout the government. Agencies ranging from DoD to the General Services Administration (GSA) to the Tennessee Valley Authority (TVA) purchased aerospace goods and services during the period studied (see Table 2.1). Only five agencies, however, spent more then $1 billion on aerospace products and services from 1993 to 2003—DoD, NASA, the Department of Transportation, GSA, and the Department of State. In fact, DoD and NASA jointly accounted for 98 percent of all spending during the period. Military procurements equaled 79 percent of all aerospace spending and NASA procurements equaled 19 percent. All other government entities combined accounted for less then 2 percent of all spending (see Figure 2.7).

Although the joint DoD–NASA dominance has been consistent throughout the 11-year period examined, the space agency increased its share of spending relative to the military during this time. In 1993, DoD expenditures amounted to 82 percent of all spending compared with NASA's 17 percent. Within a decade, however, DoD expenditures had fallen to 69 percent compared with NASA's 28 percent. In 2003, however, with renewed funding for the military coming online, the comparative spending had shifted dramatically and stood at 85 percent versus 14 percent. Due to the clear dominance of the DoD and NASA in the aerospace arena, the remainder of this analysis will focus primarily on spending trends for those two agencies.

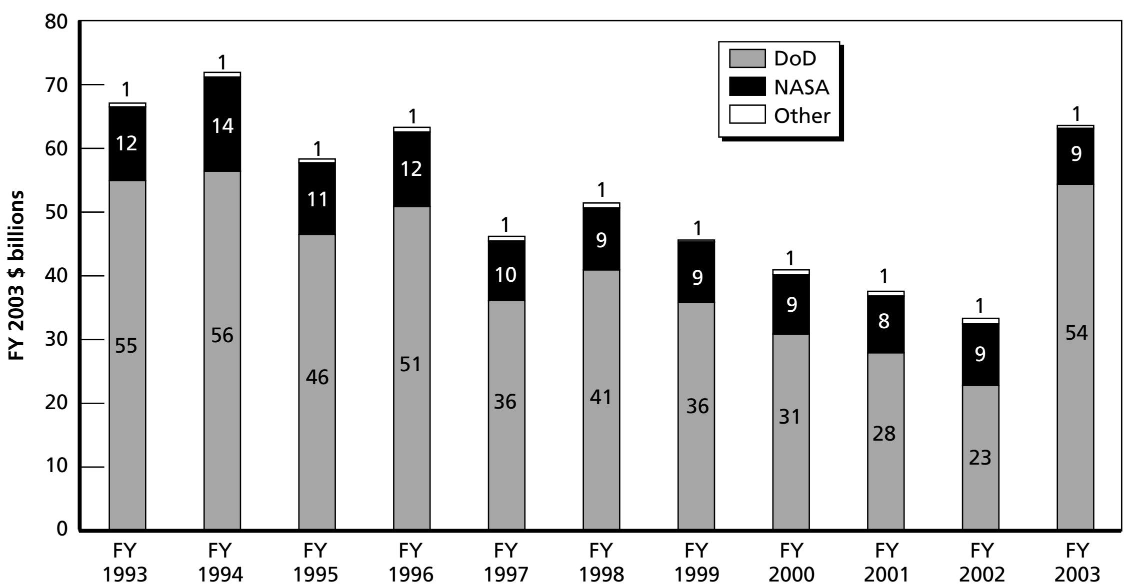
[1] This figure does not take into account the FY 2003 spending spike.

Table 2.1
Aerospace Spending by Agency (FY 2003 $ millions)

AGENCY	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
DOD	$54,684	$56,469	$46,472	$50,699	$35,899	$40,909	$35,778	$30,866	$28,171	$23,057	$54,087
NASA	$11,502	$14,489	$10,898	$11,578	$ 9,547	$ 9,460	$ 9,390	$ 9,147	$ 8,400	$ 9,233	$ 8,715
DOT	$ 310	$ 409	$ 446	$ 219	$ 252	$ 343	$ 166	$ 134	$ 125	$ 92	$ 78
GSA	$ 109	$ 101	$ 138	$ 117	$ 31	$ 41	$ 46	$ 163	$ 211	$ 48	$ 41
STATE	$ 37	$ 26	$ 39	$ 173	$ 25	$ 21	$ 44	$ 72	$ 209	$ 229	$ 139
TREA	$ 119	$ 81	$ 97	$ 87	$ 77	$ 58	$ 65	$ 81	$ 94	$ 113	$ 74
DOJ	$ 33	$ 51	$ 40	$ 31	$ 116	$ 53	$ 48	$ 92	$ 98	$ 108	$ 50
DOI	$ 68	$ 76	$ 35	$ 85	$ 56	$ 60	$ 61	$ 73	$ 39	$ 102	$ 82
DOE	$ 11	$ 12	$ 22	$ 34	$ 19	$ 52	$ 48	$ 46	$ 38	$ 40	$ 38
USDA	$ 21	$ 25	$ 32	$ 34	$ 24	$ 22	$ 19	$ 29	$ 44	$ 33	$ 40
DOC	$ 21	$ 21	$ 61	$ 18	$ 27	$ 16	$ 15	$ 8	$ 8	$ 6	$ 2
HHS	$ 20	$ 10	$ 49	$ 19	$ 8	$ 9	$ 12	$ 14	$ 19	$ 345	$ 59
TVA	$ 2	$ 5	$ 16	$ 5	$ 3	$ 5	$ 3	$ 4	$ -	$ -	$ -
DVA	$ 3	$ 2	$ 4	$ 4	$ 1	$ 2	$ 1	$ 4	$ 2	$ 1	$ 3
OTHER	$ 2	$ 4	$ 7	$ 14	$ 2	$ 1	$ 6	$ 2	$ 9	$ 9	$ 9

SOURCE: RaDiUS database.
NOTE: See Acronyms for full names of agencies.

Figure 2.7
DoD and NASA Dominance of Aerospace Spending

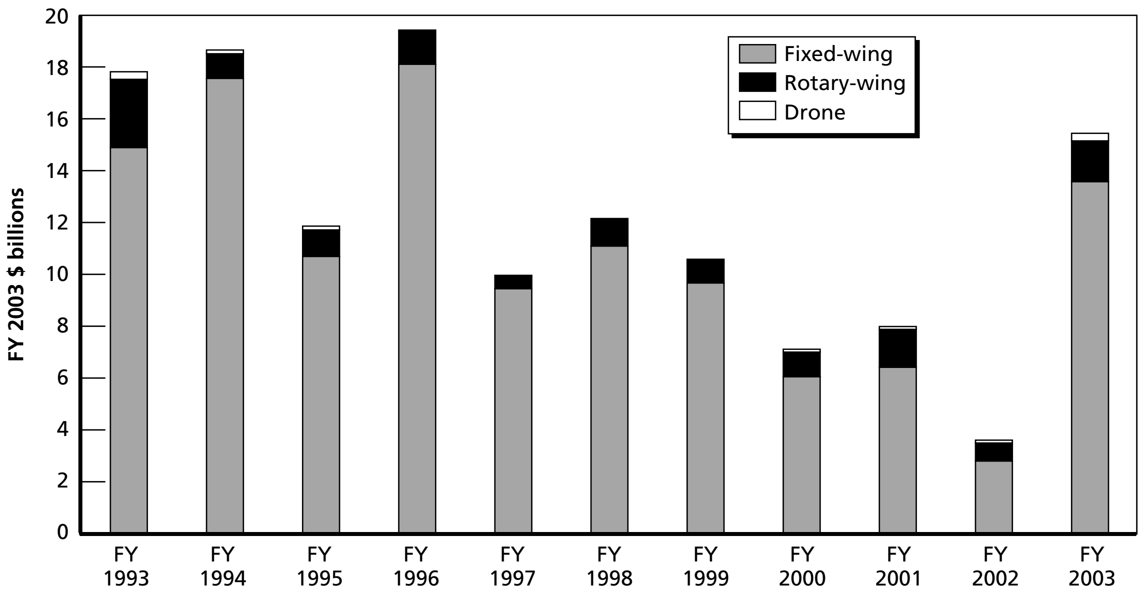


SOURCE: RaDiUS database.

DoD Aerospace Spending Overview: 1993–2003

As described above, DoD external aerospace spending experienced a general decline during the past decade before increasing rapidly in 2003. In the air systems area, this decline did not affect all aircraft types the same way (see Figure 2.8). Fixed-wing aircraft are the primary air

Figure 2.8
DoD Aircraft Procurements by Type



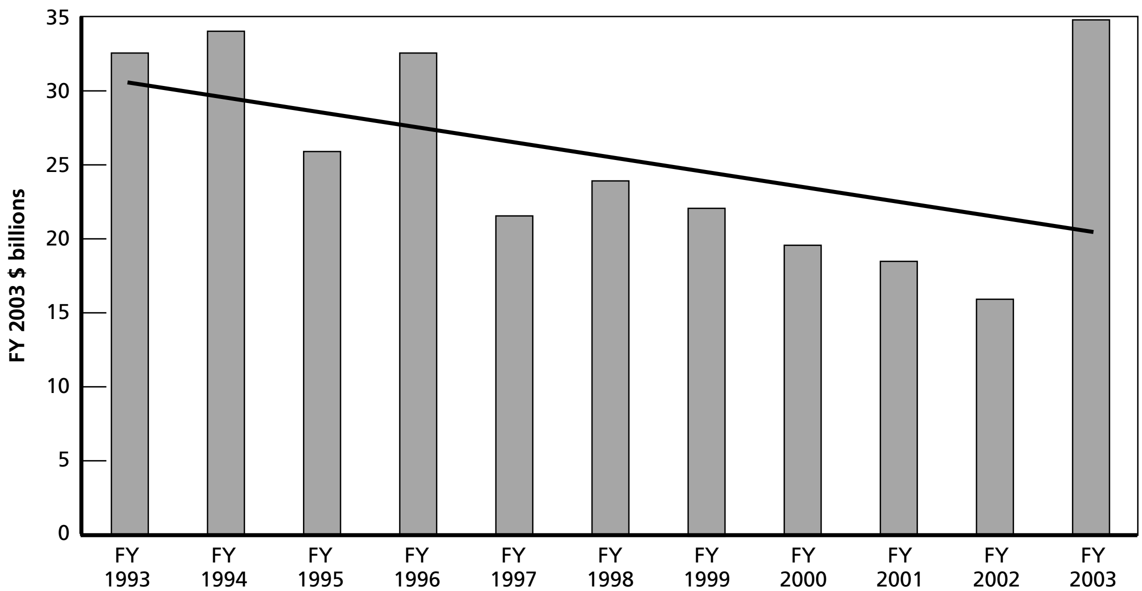
SOURCE: RaDiUS database.

vehicle type purchased by the military, representing 89 percent of all aircraft procurement dollars from 1993 to 2003. Spending on these aircraft was somewhat erratic during this period, although clearly heading downward. Procurements were $14.9 billion in 1993 but only $2.7 billion in 2002. There were three upward spikes during the period studied, however, with expenditures reaching $17.5 billion in 1994, $18 billion in 1996, and $13.5 billion in 2003. As suggested above, this variability may be the result of the end of the Cold War, regular procurement cycles, and changes in presidential budget priorities. Nevertheless, our trend analysis reveals an overall drop in fixed-wing aircraft procurements of approximately 60 percent from 1993 to 2003.

Rotary-wing aircraft, which represented only 10 percent of all air vehicle procurement dollars, did not see as sharp a decrease. After an initial drop of $1.7 billion from 1993 to 1994 (from $2.7 to $1 billion), rotary-wing aircraft purchases remained within a band from $0.5 to $1.5 billion. During this period, a trend analysis shows that overall spending decreased by approximately 30 percent—half the percentage decrease seen in fixed-wing expenditures. Drones, which make up only 1 percent of all air vehicle procurements, actually experienced a slight increase in spending (up 8 percent) if one includes data from 2003. If that year is excluded, however, spending on drones declined by approximately 69 percent over ten years. The best explanation for the huge spike in spending (nearly tripling in one year) in 2003 is the increased use of unmanned aerial vehicles in the Afghanistan and Iraq wars. The tactical importance of these aircraft accounts for the rapid increase in vehicle purchases. Taken as a whole, trends in aircraft procurements (including fixed-wing aircraft, rotary-wing aircraft, drones, and airframe structural components) show that airframe purchases dropped 50 percent from 1993 to 2003.

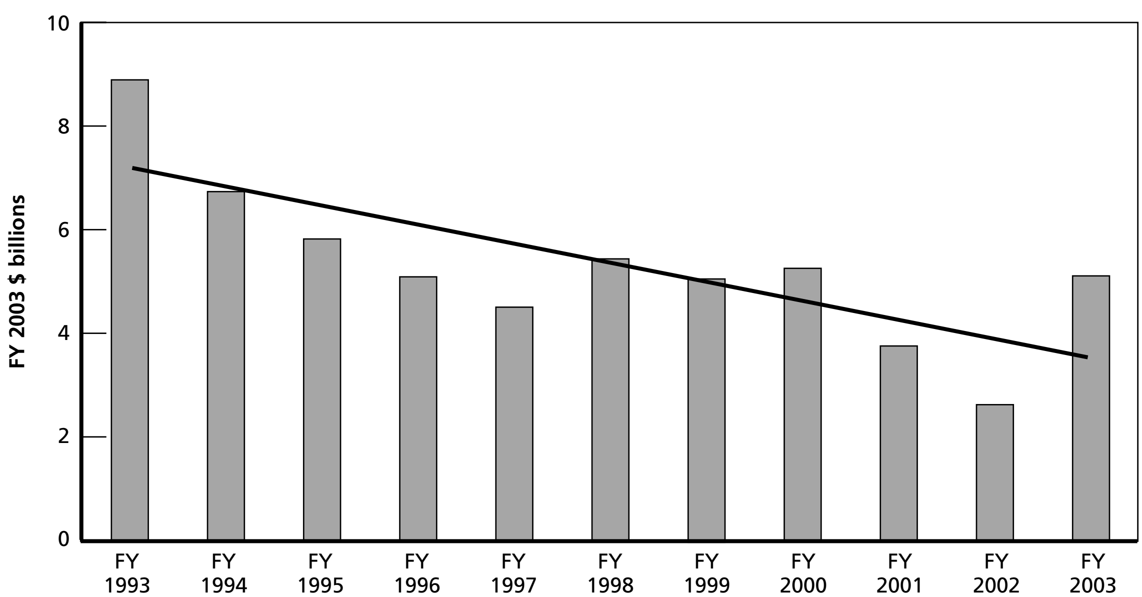
The trends discussed above carry over to all DoD aerospace spending. While the discussion in the previous paragraph was limited to airframe purchases, overall air system, missile system, and R&D expenditures tell a similar story (see Figures 2.9, 2.10, and 2.11).

Figure 2.9
Trend of DoD Air System Procurements, Including Infrastructure



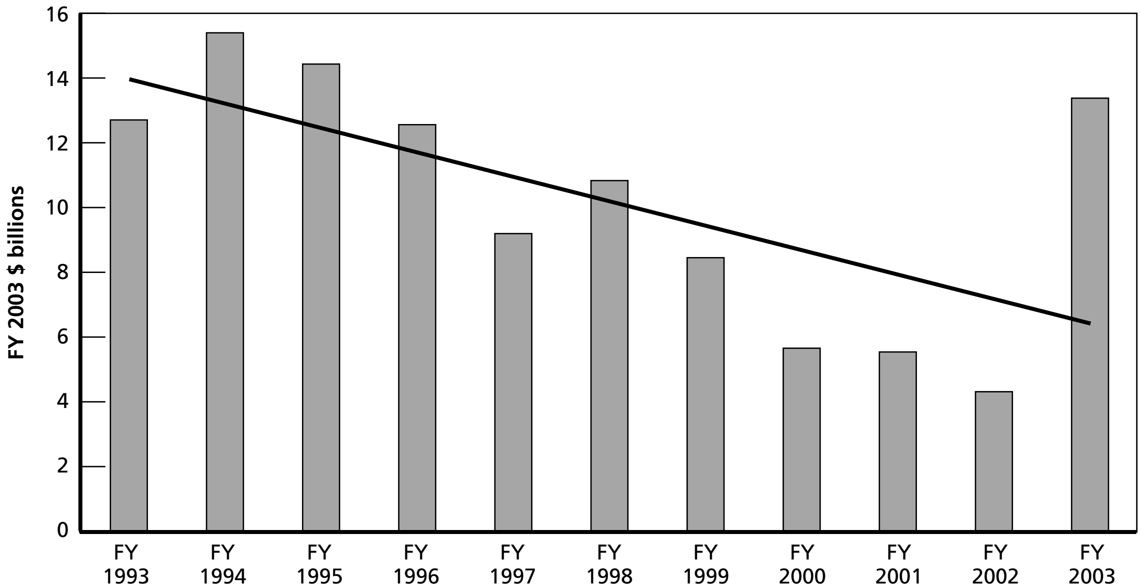
SOURCE: RaDiUS database.

Figure 2.10
Trend of DoD Missile System Procurements, Including Infrastructure



SOURCE: RaDiUS database.

Figure 2.11
Trend in DoD Aerospace R&D Expenditures



SOURCE: RaDiUS database.

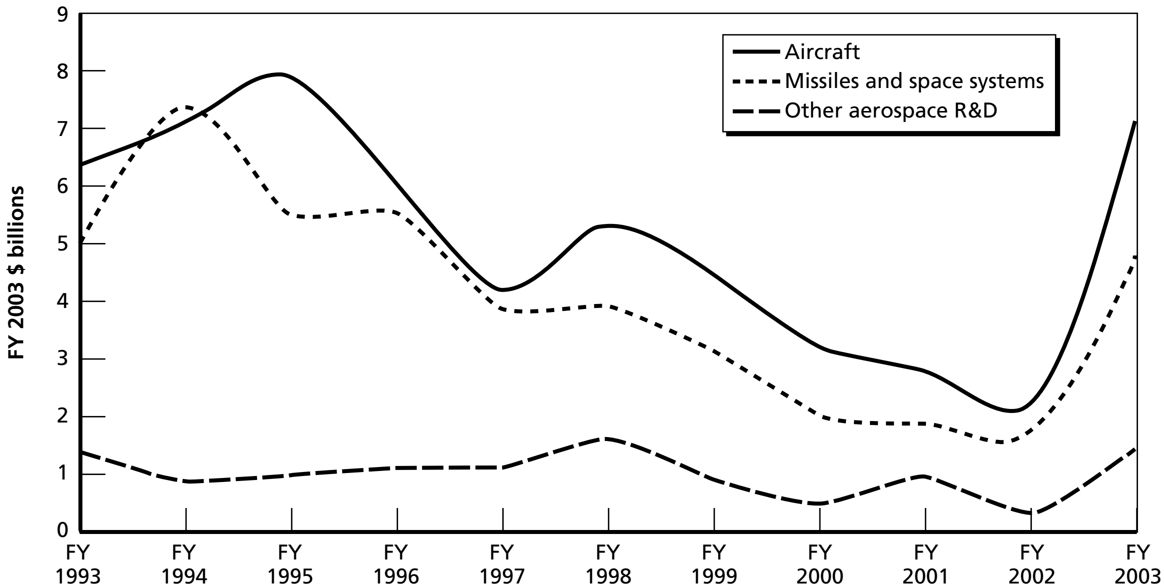
Over the course of the past decade, air system procurements decreased by approximately 33 percent—which takes into account expenditures more then doubling in 2003. Similar results can be seen when looking at missile system procurements, which declined by approximately 50 percent.

The same trend continues in aerospace R&D expenditures, where spending fell by more then 50 percent in a decade. Drilling deeper into these R&D figures, it appears that this decline applies to all types of aerospace systems—air, missile, and space (see Figure 2.12). Taken as a whole, this analysis reveals an across-the-board drop in DoD spending within the aerospace sector from 1993 to 2002, with a dramatic reversal in 2003.

Considering the breadth of the DoD mission, aerospace-related procurements account for a significant percentage of total military spending. During the period studied, aerospace expenditures represented 30 percent of all military acquisition spending. An examination of Figure 2.13, however, clearly shows that this share was declining before the spike in 2003. In 1994, the aerospace portion of the military's external expenditures stood at 35 percent of total spending, but by 2002 it was only 24 percent (a considerable decline in such a short period of time). As discussed above, this spending decrease may partially be explained as an artifact of regular procurement cycles—particularly with relation to the purchase of new airframes. Nonetheless, these data reveal a clear downward trend in the share of military spending being directed to aerospace procurements.

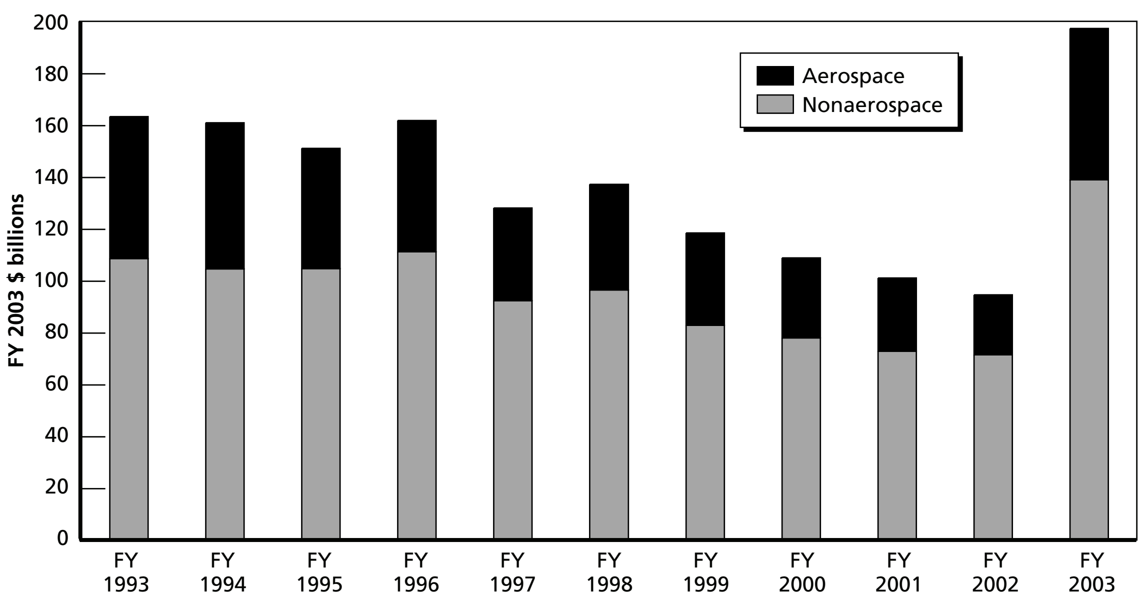
Our analysis found that the vast majority of DoD aerospace spending is directed to large businesses (see Figure 2.14). From 1993 to 2003, large companies received 89 percent of all external military spending in the aerospace arena. Small businesses, foreign contractors, non-profit hospitals, educational institutions, and small disadvantaged businesses

Figure 2.12
Trend in DoD Aerospace R&D by Type



SOURCE: RaDiUS database.

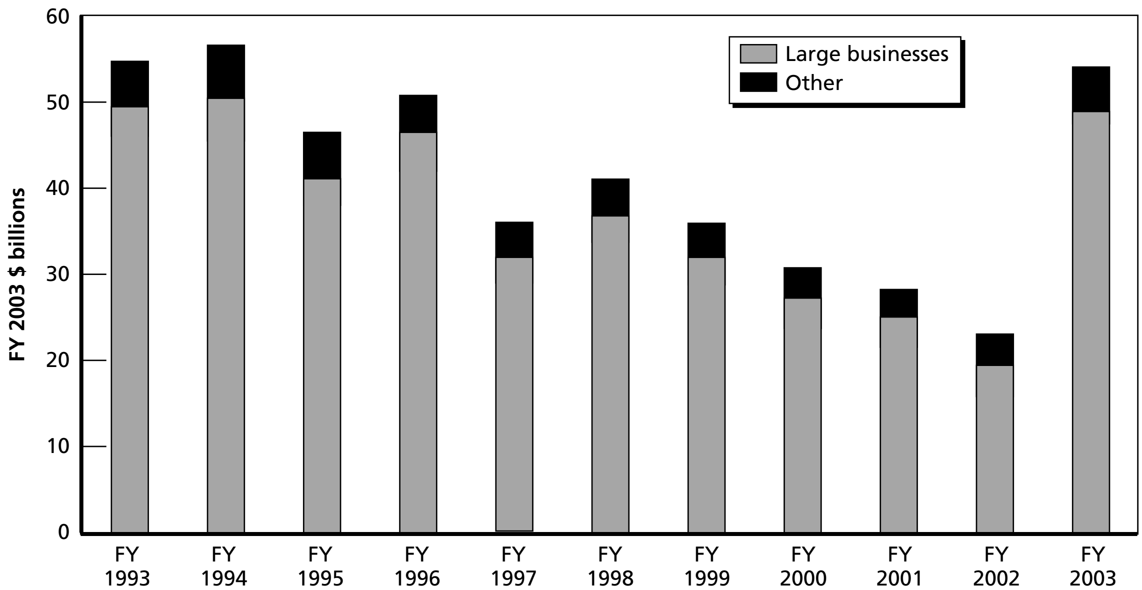
Figure 2.13
DoD Aerospace Spending Versus Nonaerospace Spending



SOURCE: RaDiUS database.

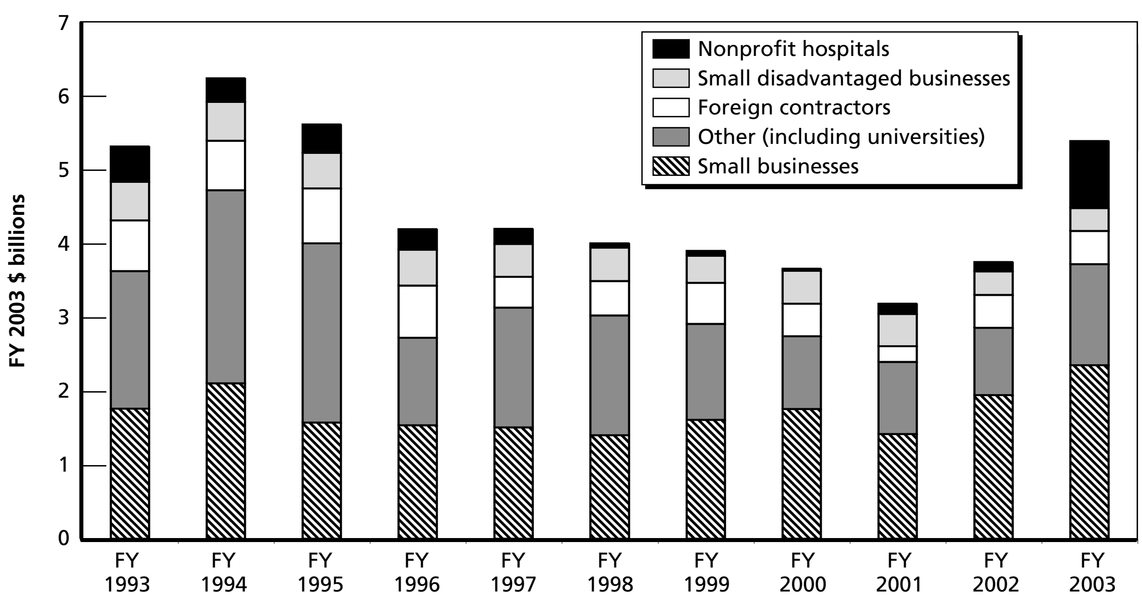
shared the remainder (see Figure 2.15). These data clearly display the dominance of large contractors within the military aerospace sector (although some of this gap may be closed when large prime contractors turn to smaller subcontractors to carry out specific activities). Similarly, the vast majority of DoD aerospace spending is directed to a very small number of

Figure 2.14
DoD Aerospace Spending by Performer Type



SOURCE: RaDiUS database.

Figure 2.15
DoD Aerospace Spending by Performer Type, Excluding Large Businesses



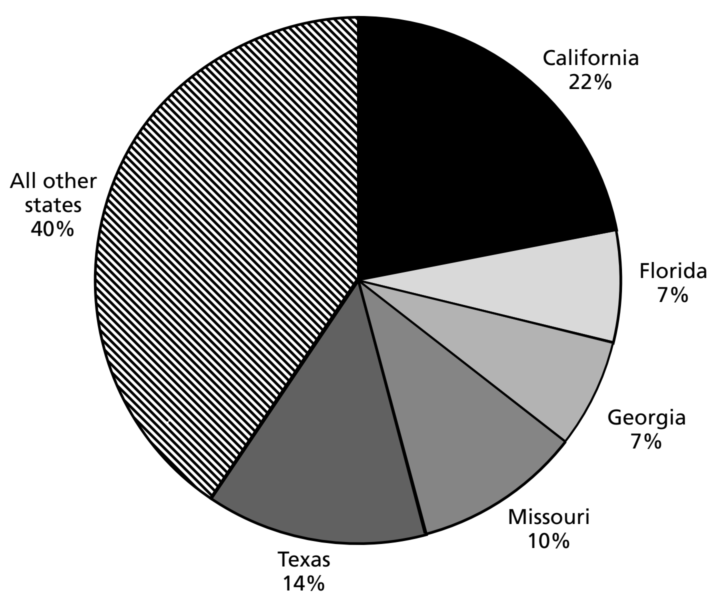
SOURCE: RaDiUS database.

states. In fact, five states account for 60 percent of all military-related aerospace spending by the federal government: California, Texas, Missouri, Florida, and Georgia (see Figure 2.16). Overall, these figures reveal a military aerospace establishment that is extremely consolidated in large companies based in a few states.

Another interesting finding based on our analysis is that military aerospace R&D money is disbursed almost entirely through contracts. Looking specifically at the United States Air Force (USAF),[2] contracts represent 97 percent of all spending. The small amount of remaining funds was split between project grants and cooperative agreements (see Figure 2.17). Overall, these data display a deep-rooted preference for contractual interactions with the aerospace industry, which is likely related to the amount of money going to large companies (which are most used to working through contracts).

A final finding worth noting is the predominance of development in overall military aerospace R&D spending. Over the period studied, development (budget activities 6.3 to 6.7, in military parlance) accounted for 93 percent of all aerospace expenditures; basic research (6.1) and applied research (6.2) amounted to just 4 percent and 3 percent respectively (see Figure 2.18).

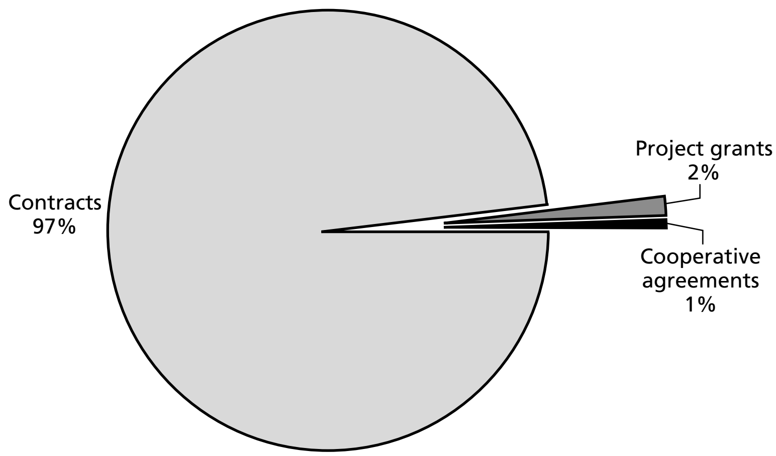
Figure 2.16
DoD Aerospace Spending by State, 1993–2003



SOURCE: RaDiUS database.

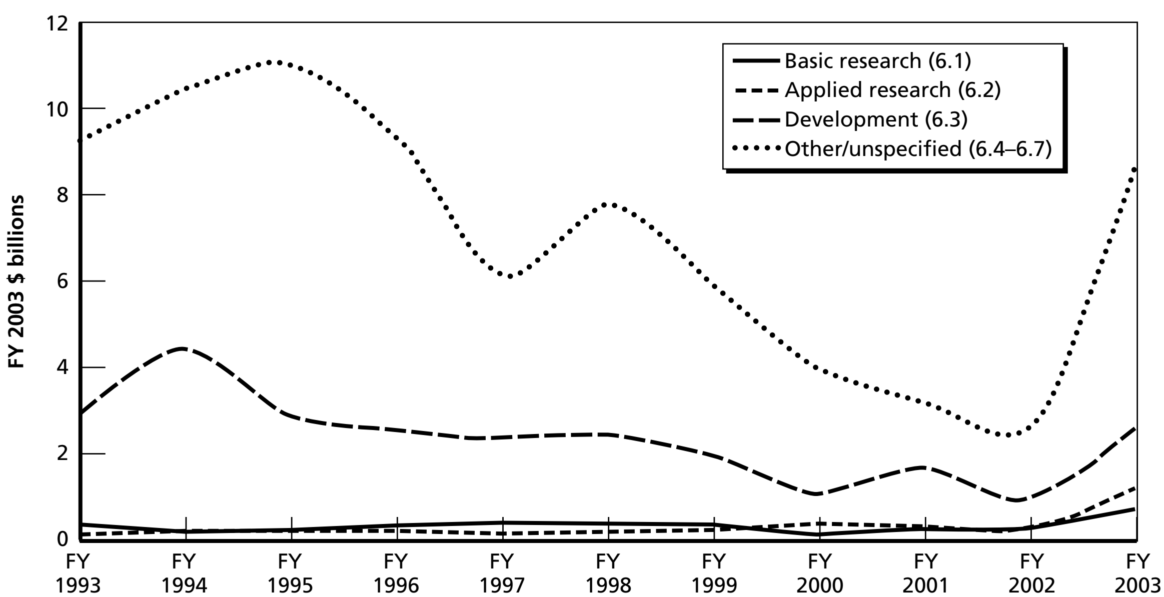
[2] Through the RaDiUS system, we only have good aerospace-related R&D data for the USAF because of inconsistent reporting by other parts of DoD.

Figure 2.17
USAF R&D by Funding Mechanism, 1993–2003



SOURCE: RaDiUS database.

Figure 2.18
DoD Aerospace R&D by Type



SOURCE: RaDiUS database.

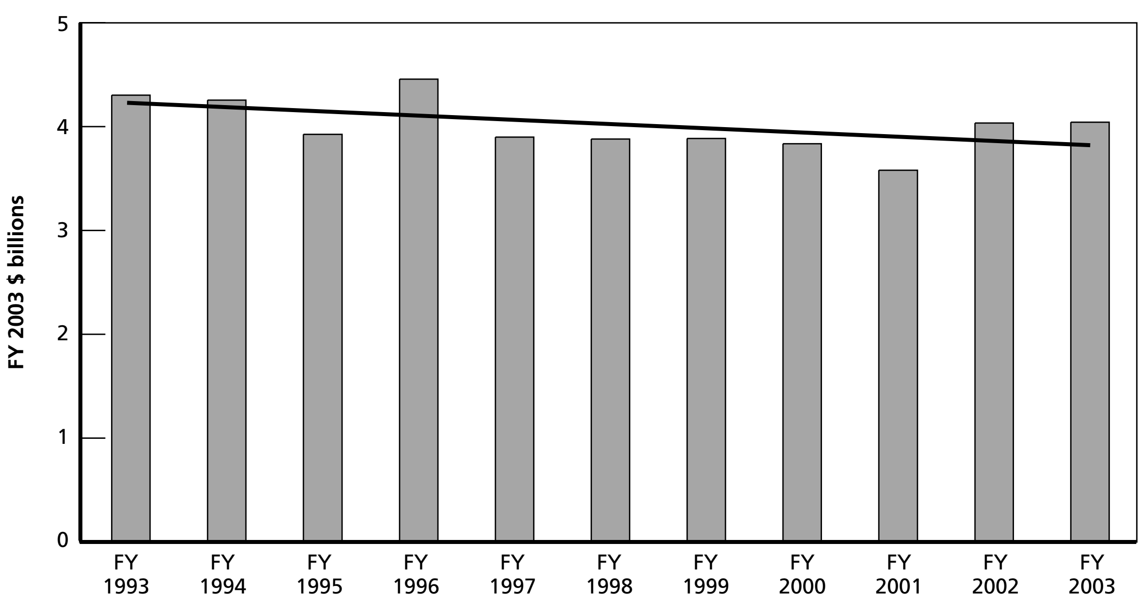
NASA Aerospace Spending Overview: 1993–2003

Unlike the military, which spends the majority of its unclassified aerospace budget on air systems, NASA does not make major procurements in this arena. While the space agency operates a fleet of T-38s (as training vehicles for the astronaut corps) and a number of test flight vehicles, most of its air system expenditures are dedicated to keeping those aircraft flying. Based on our data, it does not appear that the organization has made any large airframe purchases within the past decade. A large amount of the air system related spending within the agency is for new engines and infrastructure maintenance. Similarly, NASA does not make major missile system procurements—as indicated earlier, the agency is almost entirely absent from this area. The agency primarily turns to the aerospace industry for space system procurements and the conduct of aerospace-related R&D. Taking inflation into account, NASA has received remarkably stable funding during the past decade in the space systems arena (see Figure 2.19). Procurements in this area dropped approximately 10 percent (in FY 2003 dollars) during the period studied.

NASA concentrates most of its funding on the procurement of space vehicles (e.g., satellites, launchers, propulsion systems) and professional engineering and technical services. Combined, these areas received 83 percent of the agency's overall space systems budget from 1993 to 2003. The remainder of NASA's funds are dedicated to infrastructure development and maintenance, which accounts for 17 percent of space system spending. This part of the budget, however, has fallen severely in recent years (see Figure 2.20). There are two probable explanations for this precipitous drop in infrastructure spending starting in the late 1990s. First, it was during this period that NASA began shifting some responsibility for operating major space systems (e.g., the Space Shuttle) to private companies such as the United Space Alliance (USA). This transition of operational authority also resulted in shifting some responsibility for infrastructure development outside the government. Evidence for this transfer of responsibility can be seen when looking at the massive increase in spending for professional engineering and technical services that occurred the same year that infrastructure procurements dropped (see Figure 2.21).

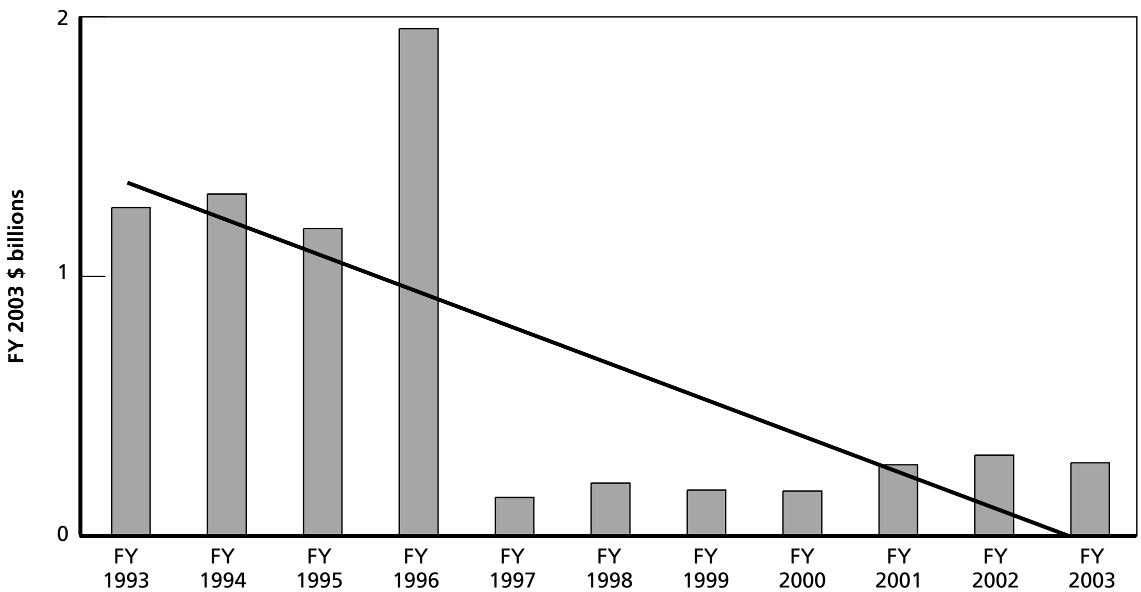
Second, and perhaps more important, was a decision by top NASA officials to reduce spending to support key infrastructure, a move that allowed needed funds to be spent to sustain ongoing spaceflight missions during a period of shrinking budgets. This helps explain

Figure 2.19
Trend of NASA Space System Procurements, Including Infrastructure



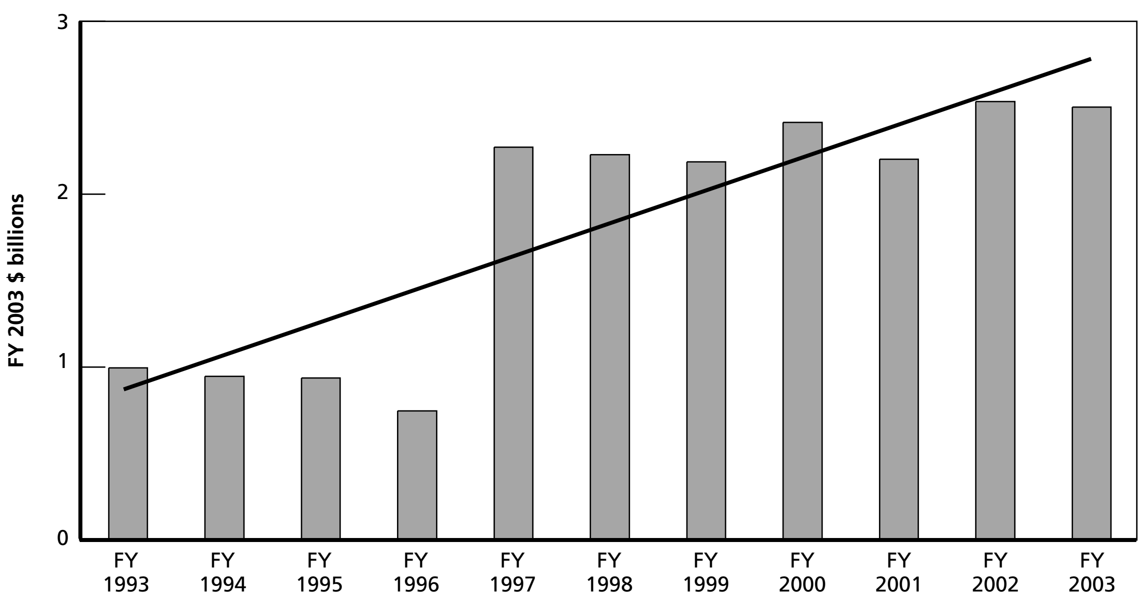
SOURCE: RaDiUS database.

Figure 2.20
Trend of NASA Infrastructure Spending



SOURCE: RaDiUS database.

Figure 2.21
Trend in Engineering and Technical Service Procurements

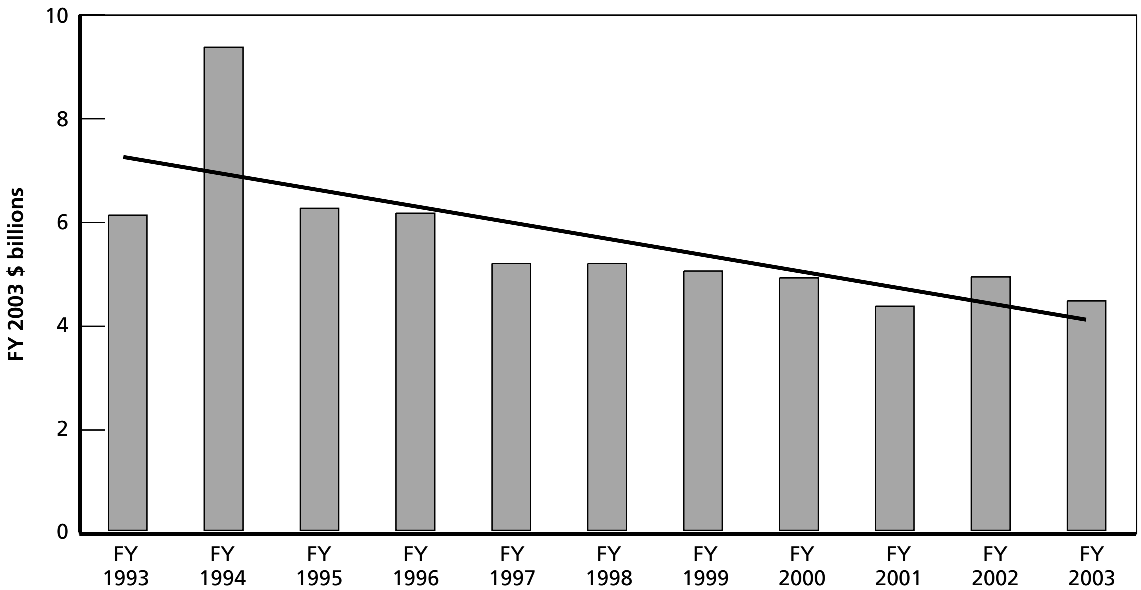


SOURCE: RaDiUS database.

the relatively small decreases in overall spending on space vehicles during this period: Monies that were traditionally spent on infrastructure were either shifted to private companies or transferred to fulfill programmatic needs.

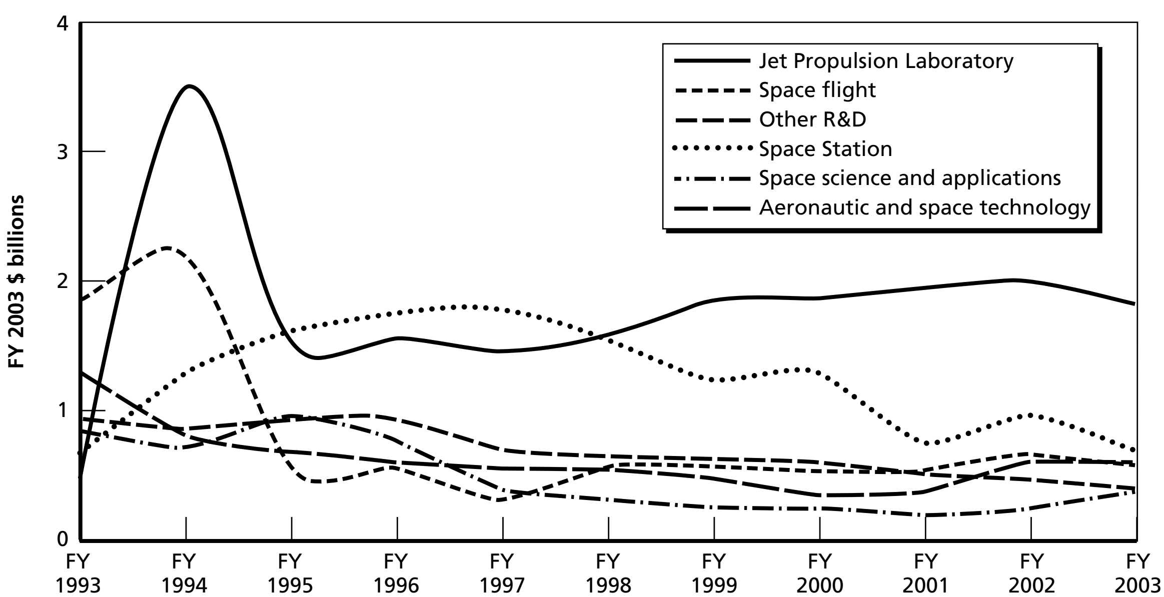
Unlike space systems, which experienced a relatively small drop in spending from 1993 to 2003, R&D expenditures dropped by over 40 percent during this same period (see Figure 2.22). The biggest declines were seen in aeronautic and space technology, space flight, and the space station (see Figure 2.23). Aeronautic and space technology spending fell nearly

Figure 2.22
Trend of NASA R&D



SOURCE: RaDiUS database.

Figure 2.23
NASA Aerospace R&D by Type



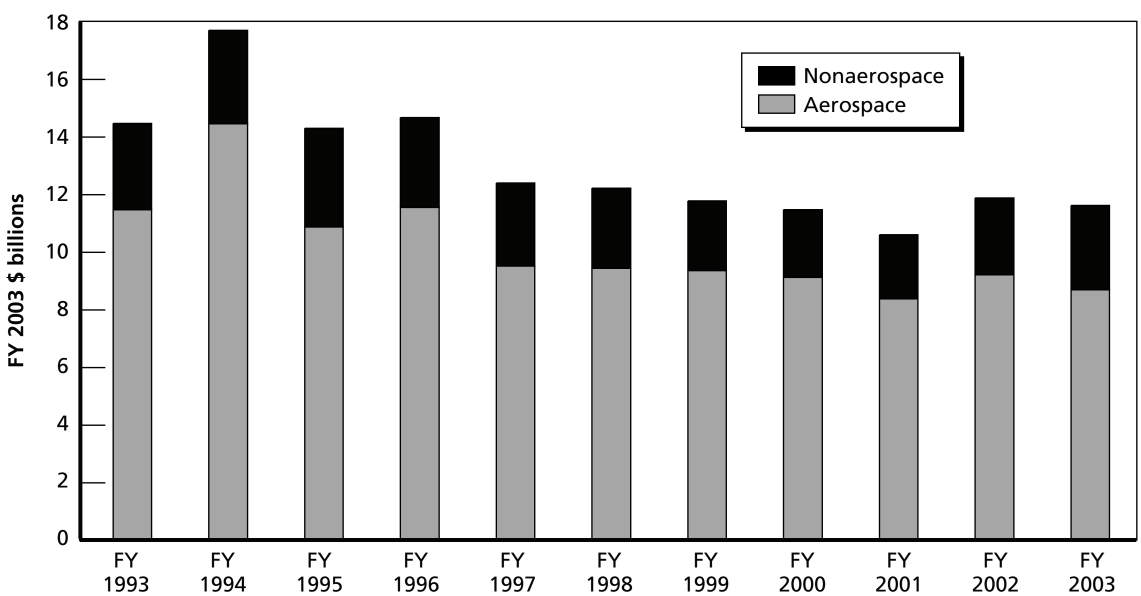
SOURCE: RaDiUS database.

60 percent, space flight fell over 80 percent (this reduction can be partially accounted for by the transition of some Space Shuttle operations from NASA to the United Space Alliance [USA]), and space station spending fell over 30 percent.

There was also a clear decline in space science spending (it dropped from $850 million in 1993 to $375 million in 2003), but at least some portion of this reduction can be accounted for by increased spending for space science missions conducted at the Jet Propulsion Laboratory (JPL), where funding increased from $1.5 billion in 1995 to $1.8 billion in 2003.[3] Looking at combined spending for space science R&D and JPL during the period studied, it appears that overall space science spending decreased by approximately 20 percent. Taking into account NASA's entire R&D portfolio, the agency experienced significant reductions in overall spending during this period.

Unlike DoD, NASA's spending is heavily weighted in favor of aerospace versus nonaerospace expenditures—a logical result of the agency's mission (see Figure 2.24). Looking at the period examined for this study, aerospace procurements and R&D expenditures represented 78 percent of all NASA spending—with the remaining 22 percent directed toward nonaerospace activities. The largest segments of NASA's nonaerospace spending were equipment and supplies, telecommunication services, equipment maintenance, administrative and management support services, utilities, facilities construction, and real property maintenance. In contrast with DoD, the aerospace portion of NASA's spending has been relatively stable during the past decade. That fact that it remained between 76 percent and 82 percent from 1993 to 2003 would seem to indicate that agency operations have not grown at the expense of actual programmatic spending.

Figure 2.24
NASA Aerospace Versus Nonaerospace Spending



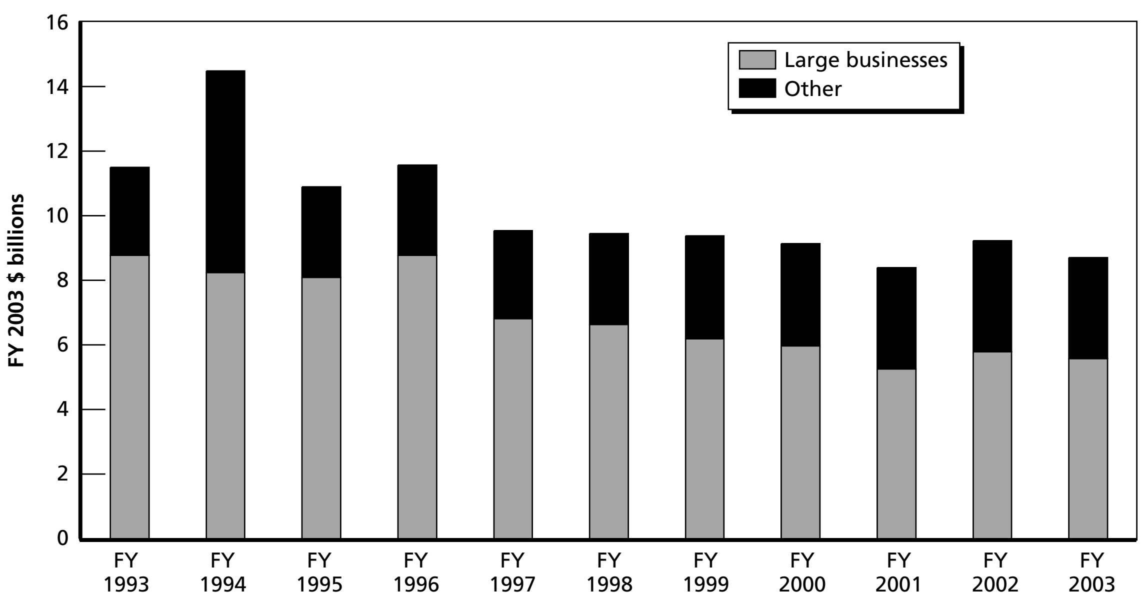
SOURCE: RaDiUS database.

[3] The large spike in JPL-related procurements is likely an artifact of some 1993 spending being accounted for in 1994. This can be seen in actual money transfers rather then budget authority.

As with the military, the majority of NASA's aerospace spending is directed to large businesses (see Figure 2.25). The space agency, however, does not rely on big companies to quite the same degree as DoD does. From 1993 to 2003, large companies received 68 percent of all NASA spending within the aerospace arena (compared with 89 percent for DoD). Small businesses, foreign contractors, nonprofit hospitals, educational institutions, and small disadvantaged businesses shared the remainder (see Figure 2.26). This percentage dropped somewhat from 1993 to 2003—declining from three-fourths to two-thirds of all spending. Based on our analysis, we found that NASA clearly has closer relationships with American universities—the civilian aerospace program sends more then 20 percent of its external funds to educational institutions, while military aerospace spending in this area is less than 1 percent (the classified budget may increase this figure).

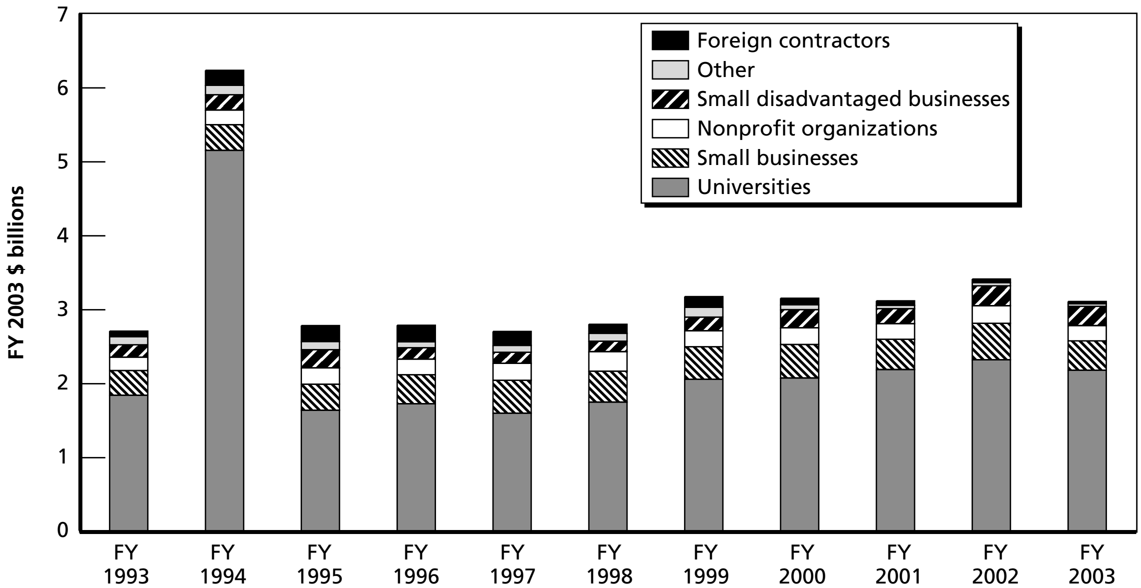
NASA spending is allocated within a small number of states to an even larger degree than DoD expenditures are. Eighty-two percent of NASA's aerospace procurements are concentrated in five states—California, Texas, Florida, Maryland, and Utah (Figure 2.27)—compared with a 60-percent concentration of all military-related aerospace spending in five states (see Figure 2.16). These data show a civilian aerospace establishment that is slightly less consolidated in large companies (although they still account for two-thirds of expenditures) but that is centered in a few key states to an even larger degree. The figures also reveal that three states are true aerospace giants—California, Texas, and Florida. Not surprisingly, these are also large states with a great deal of political power (influence that dates back at least to the beginning of the space age).

Figure 2.25
NASA Aerospace Spending by Performer Type



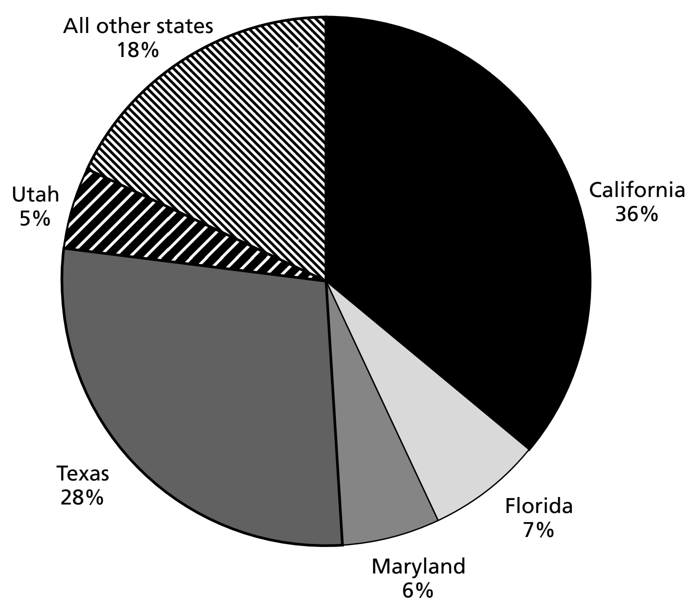
SOURCE: RaDiUS database.

Figure 2.26
NASA Aerospace Spending by Performer Type, Excluding Large Businesses



SOURCE: RaDiUS database.

Figure 2.27
NASA Aerospace Spending by State, 1993–2003

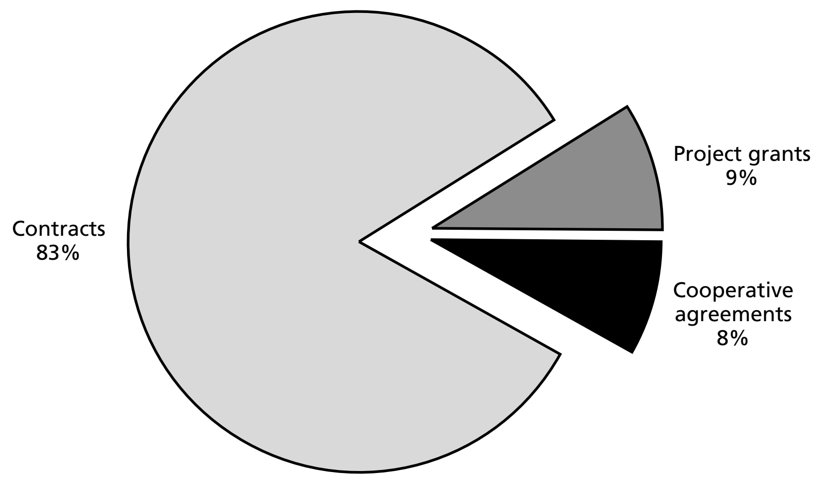


SOURCE: RaDiUS database.

Our data indicate that NASA also has a preference for allocating extramural funds via contracts, although to a lesser degree then the military. Contracts represent 83 percent of NASA's aerospace R&D spending, compared with 97 percent for DoD. Because of its stronger relationships with academia, NASA uses project grants and cooperative agreements to a great degree (see Figure 2.28). While these figures bolster the argument that there is a deep-rooted preference for contractual interactions with the aerospace industry, they also provide further evidence of NASA's greater reliance on educational researchers to carry out its projects.

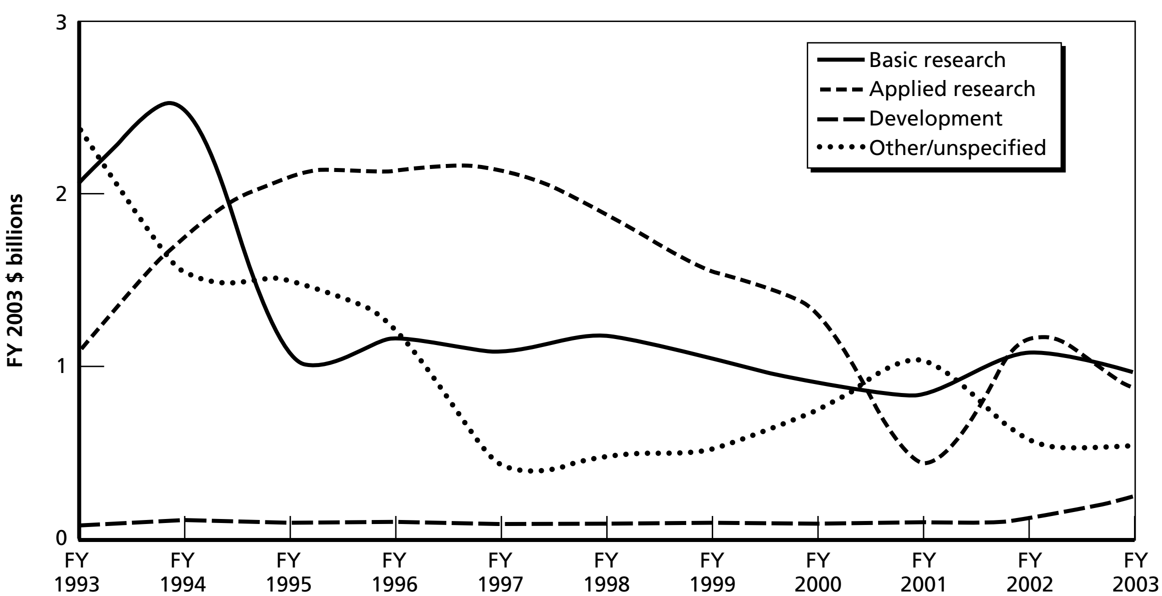
Finally, it appears that NASA is involved in a greater amount of aerospace-related research than the military, which focuses most of its R&D efforts on development (see Figure 2.29). During the period studied, 72 percent of all NASA's R&D expenditures were directed

Figure 2.28
NASA Aerospace Spending by Funding Mechanism, 1993–2003



SOURCE: RaDiUS database.

Figure 2.29
Breakdown of NASA Aerospace R&D by Type



SOURCE: RaDiUS database.

toward research projects (33 percent for basic research, 39 percent for applied research). Although in real dollar terms DoD still outspends NASA with regard to basic and applied aerospace research ($2.1 to $1.9 billion in 2003), our data reveal that the space agency is much more focused on research activities.

Conclusion

The clearest trend that emerges from our analysis of aerospace spending is that overall government expenditures in this area have been steadily declining during the past decade. Although we have examined only a relatively small period of time, our data suggest that this general decline has been felt in each of the three identified aerospace sectors—air systems, missile systems, and space systems. Air system and missile system expenditures dropped significantly during the period studied, while space system spending fell at a somewhat slower rate. There is some evidence that this trend may be reversing itself, but at this point it is unclear whether this turnaround represents the beginning of a new upward trend. It is obvious, however, that aerospace procurements have been dramatically falling since the end of the Cold War (and even before that for military air system procurements).

One notable trend is the 50 percent decrease in new airframe procurements for military aircraft. Although some of this drop may be explained by regular procurement cycles, such a sharp decline indicates that military expenditures may remain far below Cold War–era levels. Full air system procurements have also dropped, although not as steeply as for airframe spending alone. One potential explanation for this slower decline is that the military has had to maintain some spending for engines and major air system components (as well as maintenance) as it attempts to field a smaller number of operational airframes. If airframe procurements do not recover, however, these other expenditures may eventually decrease as the military transitions to a smaller suite of air assets. Missile system spending declined even more then air system expenditures, but experienced a large spike in 1993 that can be accounted for by increased missile utilization during the Afghanistan and Iraq wars. Overall DoD aerospace R&D spending (for air, missile, and space systems) also declined quickly after the Cold War: Expenditures were cut in half during the period studied. In the end, however, the most substantial trend that emerges from this study is a 40 percent overall decline in military aerospace–related spending during the past decade (even when taking into account the 2003 spike in spending).

The outlook for NASA is only slightly better. Over the past decade, NASA's spending fell by 35 percent (for air systems, space systems, and R&D). The agency has been able to avoid major declines in space system expenditures (these declined by only 10 percent), but it appears that NASA has had to adopt risky measures to achieve this end. First, the agency has drastically reduced infrastructure expenditures, indicating that NASA is probably not spending what is necessary to keep all of its facilities in good condition (a reality forced on it by tighter budgets). Second, the agency has increased its dependence on technical service providers, such as USA, which have taken on some of the operational responsibility for major programs like the Space Shuttle. Finally, the agency cut R&D spending by over 40 percent during the past decade. These data show that NASA leaders have had to make hard decisions to maintain a relatively aggressive slate of mission priorities while the agency's real buying power has been falling. The question that emerges, however, is whether the strategies NASA has selected to achieve this objective can be maintained indefinitely.

APPENDIX A

The Evolution of the Aerospace Industry

Development of the Aviation Industry[1]

By the end of the first century of flight, the United States possessed the world's largest aerospace industrial complex, with Russia and Western Europe trailing not far behind. The industry had evolved steadily in the years since the flight of the Wright brothers' *Flyer* in 1903. The initial government foray into the arena of powered flight had actually occurred seven years earlier, when the War Department awarded a $50,000 grant to Samuel Langley for aviation research. It was the Wright brothers, however, working largely in isolation from the larger scientific community, who built the first aircraft capable of sustained powered flight. Although the initial reaction to the achievement was somewhat muted in the United States, the Europeans rapidly pursued the new technology for military purposes. In 1906, France came the first government to purchase the rights to utilize the Wright brothers' wing-warping technology, although the U.S. Army began buying Wright A flyers two years later (this represented the first government aircraft procurement). The early years of the aviation industry's development within the United States was largely characterized by a nasty patent battle between the Wright Company and the Herring-Curtiss Company. In 1904, Glenn Curtiss had entered the aviation arena when he was awarded a contract to build a dirigible engine. Within a few years (backed by Augustus Herring and Alexander Graham Bell), Curtiss began competing with the Wright brothers. In 1909, this competition led to a Wright lawsuit claiming that Herring-Curtiss had violated its wing-warping technology patent, and this legal battle dragged on during the subsequent decade. Although American companies (and many individuals working in private workshops) continued to advance aviation technology during this period, their European counterparts progressed much faster, due in large part to government sponsorship of aviation-related R&D and the lack of conflict within the industry.

By the outbreak of World War I, the great European powers had a significant lead over the United States in air power: By the start of the war, France had built two thousand aircraft and Germany had built a thousand. In 1915, in an effort to begin the long process of catching up with the Europeans, Congress created the National Advisory Committee for Aeronautics (NACA). One of the most important early activities of this new agency, which

[1] The section of the report discussing the historical development of the aviation industry is drawn from a general examination of the following sources: Bilstein (1996), pp. 1–20; Weiss and Amir (2004); Bilstein (2001), pp. 3–40; Crouch (1989); Howard (1998), pp. 15–446; and Rout and Rout (2002).

had an annual operating budget of only $5,000 (one-tenth the amount the War Department had given to Samuel Langley twenty years earlier), was to negotiate a cross-licensing agreement between the Wright-Martin Company and Curtiss Aeroplane. This agreement ended the extended fight within the American industry and paved the way for increased production of aircraft to support the war effort.[2] Over the coming years, the NACA became heavily involved in advancing cutting-edge aeronautical technologies, eventually opening the Langley Field research facility in 1920. Even before the war, however, the military was the driving force behind growth in American aviation. Although the U.S. Navy focused on applied research and built most of its own planes during the war years (primarily at the Naval Aircraft Factory in Philadelphia), the U.S. Army engaged in the full range of aviation activities and worked with industry partners to produce the thousands of planes necessary for the war effort. After the war, the NACA and the Army Air Service (AAS), which worked primarily at McCook Field in Ohio, were the primary government agencies sponsoring aeronautical R&D in a continued effort to attain military parity with foreign governments and to foster the development of a commercial aviation industry.

While the NACA and AAS strove to advance aeronautical capabilities, other entities within the federal government were taking steps to foster the development of commercial airlines. Starting in the early 1920s, government policymakers played an important role in the economic development of the aviation industry. During this period, the Post Office Department's airmail service initiated long-distance routes and began constructing a cross-country navigational system. In 1925, Congress passed the Contract Air Mail Act, which required that the air mail service turn over its routes to private air carriers, thus allowing commercial airlines (United, Eastern, TWA, and American) to take over airmail operations. The following year, the Air Commerce Act led to the creation of the Aeronautics Branch within the Department of Commerce (the Aeronautics Branch became the Bureau of Air Commerce in 1934). This new organization was given authority to certify aircraft, license pilots, establish airways, and investigate accidents. The act also resulted in the adoption of the Air Commerce Regulations (ACRs), which were promulgated to codify the safety rules decreed by the statute. By the early 1930s, the Aeronautics Branch introduced radio navigational systems and formalized protocols for the air traffic control network, began monitoring airfield operations, and evolved regulations to certify both aircraft and pilots. These policies and activities greatly enhanced investor confidence in the rapidly developing industry and made passenger and cargo service economically realistic. During this period of rapid growth, air operations were dominated by high-wing monoplanes with all-metal construction, such as the Ford Trimotor ("Tin Goose") and Lockheed Vega.

Aircraft became increasingly advanced during the 1930s, as the industry introduced technologies and aeronautical designs that had been developed by civilian and military researchers. These included low-drag engine cowling, new airfoil shapes, efficient propellers, retractable landing gear, and low-winged monoplanes with engines mounted on the wings' leading edge. Throughout this period, commercial airframe and engine manufacturers (Douglas, Boeing, Martin, Curtiss-Wright, Chance Vought, Grumman, and Pratt & Whitney) relied heavily on military procurements to push the industry forward. In fact, the mili-

[2] Such cross-licensing agreements (i.e., sharing information between aviation companies) were vitally important to building U.S. superiority in this sector—these agreements have not been used as much in the space sector.

tary accounted for 68 percent of total sales (78 percent of sales for airframes alone) (Bilstein, 1996, p. 31).

The first modern airliners (set apart from earlier designs by their all-metal, twin-engine, low-wing monoplane construction) were introduced during the mid-thirties: the Boeing 247 in 1933 and the Douglas DC-3 in 1935. The DC-3, which became the most popular airline worldwide, made continental passenger air travel commercially viable for the first time. At the same time, flying boats like the Sikorsky S-42 and the Boeing 314 began establishing the first transcontinental air routes, making Pan American Airlines a major force within the aviation industry.

In 1934, new antitrust regulations took effect that required the separation of airline operators and aircraft manufacturers, leading to the breakup of such companies as United Aircraft and Transport Corporation, which owned both the Boeing Company and United Airlines. This was the first in a series of legislative and administrative activities intended to maintain some level of government control over the rapidly expanding aviation industry. Passage of the Civil Aeronautics Act of 1938 represented a watershed event in the development of the aviation industry. Unlike earlier legislation, which had primarily been concerned with economic regulation, this act addressed the need for safety regulations and set the organizational foundations for comprehensive government oversight of the aviation industry. The act was precipitated by a growing number of passenger deaths, culminating in the crash of a TWA DC-2 three years earlier that claimed the life of Senator Bronson Cutting of New Mexico. The act created the independent Civil Aeronautics Authority (CAA, the precursor of the Federal Aviation Administration), which was responsible for performing the quasi-legislative and quasi-judicial functions of safety and economic regulation. Two years later, the Civil Aeronautics Board (CAB) was created to take over economic oversight of the commercial airline industry and conduct aviation accident investigations.[3] During the next two decades, the federal government continued to play an active role in fostering the commercial industry by providing funding for the training of civilian pilots, the construction of air traffic control towers, the development of civil airports, and development of advanced air traffic control systems.

While the aviation industry had clearly made great strides during the interwar period, World War Two (WWII) completely changed the growth trend within the sector—it went from steady growth over several decades to a massive explosion of activity within a short period of time. Although the military had been gradually increasing its dependence on aircraft during the interwar era, there were still fewer than 300 commercial transport aircraft operating in the United States before WWII. The approach of war not only transformed aviation technology, it also led to a massive increase in the number of aircraft procured by the government annually, with clearly positive effects on manufacturers and, equally important, on the whole airline industry. The most significant early rationale for these changes was events taking place on the global stage, specifically Germany's rapid rearmament (with a focus on advanced aircraft) during the mid-1930s. As a result of its large annual investments in aeronautical technologies, Germany by 1936 had developed the most highly advanced aviation industry in the world. This led the United States (as well as Great Britain and France) to

[3] The CAA was ultimately replaced by the Federal Aviation Administration. The CAB's responsibility for accident investigations was eventually transitioned to the National Transportation Safety Board. The CAB maintained its economic oversight role until airline deregulation.

begin ramping up its aircraft production capabilities. By 1941, American manufacturers were building approximately 6,000 airplanes annually. With the nation's entry into WWII, President Franklin Roosevelt ordered government procurements alone to increase to 20,000 planes within one year—with that number doubling every year thereafter. This led to an extraordinarily increased production capacity among aircraft manufacturers and continually advancing technologies on the planes they were building. From 1940 to 1945, the aviation industry produced more than 300,000 military aircraft and employed over two million workers (including thousands of women)(Weiss and Amir, 2004). These developments resulted in important changes within the industry. Instead of constructing one aircraft at a time, manufacturers built factories with assembly lines capable of producing thousands of planes ranging from combat fighters to strategic bombers to transports.

Not only did WWII have obvious dramatic impacts on military aircraft, it also led to swift changes for commercial airlines. During the war, the major airlines had more business then they could handle, including ferrying soldiers and transporting cargo. The immediate postwar period was marked by the introduction of large four-engine transports, such as the Boeing 377 Stratoliner, Douglas DC-4 Skymaster, and Lockheed L-049 Constellation. Many of these airliners incorporated technologies that had been developed for military aircraft during the war.

The Stratoliner was the world's first aircraft with a pressurized cabin, which allowed it to fly at 20,000 feet and cruise at 200 miles per hour. Technical advances like this were important evolutionary steps for transport aviation and set the stage for a major expansion in the industry. Throughout the early period of aviation development, the airline industry faced continued competition from other transportation modes—buses, trains, and ocean liners represented the primary methods of long distance travel. In 1951, however, with the explosion in airline travel after the war, air passenger-miles exceeded passenger-miles traveled on trains, and by the end of the decade, more transatlantic travelers were flying then were traveling by sea. As the airlines slowly overtook trains and ocean liners, they began to change their operations. One of the most important changes was the introduction of coach seating, which Capital Airlines began offering during the late 1940s (until that time, all passenger travel had been first class). This was a huge success and was quickly adopted by other carriers. Marketing also began to play a crucial role as competition between the major domestic carriers (United, American, Eastern, and TWA) heated up. Innovations like Continental Airlines' Gold Carpet Service, Texas International's "Peanut Fares," and American Airlines frequent flyer program accelerated the non-price competition among the domestic air carriers—ticket prices at the time were heavily regulated by the CAB. Finally, the introduction of computerized reservation services (which were jointly financed by competing airlines) during the early 1960s dramatically increased the efficiency of airline operations and allowed for reduced prices. The average time to make a reservation decreased from 45 minutes to 3 minutes with these new systems.

With all of these developments occurring during the postwar era, the commercial aviation industry continued to grow. During the first half-century of flight, government and industry researchers developed scores of incremental and evolutionary improvements in aviation technologies. Taken as a whole, these advances totally revolutionized the sector, allowing commercial airlines to become the predominant transportation mode for long-distance travel and enhancing national security capabilities. In the 1950s, a new technology emerged that represented a singular paradigm shift in commercial aviation capabilities—the jet engine.[4] The concept had been developed primarily in Great Britain and Germany before the war, with the British taking a lead during the postwar years. The United States began serious research in jet engines during WWII and by the outbreak of the Korean War had fielded two jet fighters—the Lockheed P-80 and the North American F-86. By the end of the 1950s, combat aircraft (and a growing number of bombers) around the world employed jet engines. By this time, American engine manufacturers like Pratt & Whitney and General Electric had succeeded in overtaking their European counterparts in the turbojet field. In 1958, Boeing introduced the 707, the first practical commercial jetliner. Four years earlier, the British had introduced the BOAC de Havilland Comet I jetliner, but two tragic accidents caused by the aircraft's vulnerability to metal fatigue allowed U.S. manufacturers to overtake Great Britain in the commercial jetliner race.

The 111-passenger, four-engine Boeing 707 could fly at 41,000 feet and cruise at nearly 600 miles per hour (the airliner's first flight from New York to Paris was accomplished in under 9 hours). The 707 vaulted Boeing into the lead among worldwide airframe manufacturers, a distinction it would maintain for the next three decades. The addition of the Douglas DC-8 and Lockheed Constellation jetliners cemented American leadership in this crucial economic sector. From a technological perspective, the remainder of the twentieth century was dedicated largely to improving the performance and safety of commercial jet transport. No revolutionary technology advances were made throughout this period, although evolutionary technologies such as digital-fly-by-wire and glass cockpits had significant impacts.

The federal government had been on the forefront of the technical effort aimed at introducing jet engines into military and commercial aircraft—funding the lion's share of the R&D and procuring a large number of combat fighters, bombers, and transports. While this work continued during the coming decades, particularly in the military sector, the most important developments during the subsequent period were largely legislative and administrative. One of the most significant effects of the swift expansion of airline operations during the postwar era was an increasingly congested national airspace. In June 1956, a TWA Constellation and a United DC-7 collided over the Grand Canyon, killing 128 passengers and crew. The accident dramatized the fact that, although U.S. air traffic had more than doubled during the previous decade, little had been done to expand the capacity of the air traffic control system. Two years later, this crash led to the passage of the Federal Aviation Act of 1958. The legislation created the Federal Aviation Agency (FAA) to centralize the federal government's role in fostering and regulating civil aeronautics and air commerce. The FAA was tasked with

- regulating air commerce
- promoting civil aeronautics
- developing and operating the air traffic control system
- creating standards for aviation safety.

[4] The concept of practical jet propulsion emerged in 1929 when Britain's Frank Whittle proposed a revolutionary alternative to the piston engine and laid the foundation for the successful creation of the jet engine. German airplane designer Dr. Hans von Ohain, working with substantially more developmental funding, fielded a combat-ready aircraft, the German Me-262, in 1944. Later that year, the British fielded the Gloster Meteor.

Eight years later, the FAA (renamed the Federal Aviation Administration) was folded into the newly created Department of Transportation, which brought 31 previously scattered federal elements into a single cabinet-level department. The legislation that created the new department also created the National Transportation Safety Board (NTSB), which took responsibility for probing transportation accidents. NTSB replaced the CAB as the primary investigatory agency for aviation accidents. During this period, as a result of a decline in military budgets and tightening commercial markets, the aviation industry experienced a wave of mergers in the manufacturing sector. The Martin Company and North American Aviation merged with nonaerospace companies to form Martin Marietta and North American Rockwell; McDonnell Aircraft merged with Douglas Aircraft to form McDonnell Douglas.

The sector experienced a bump, however, with the introduction of the Boeing 747 (the first wide-body jetliner, the 747 was the world's fastest commercial transport, traveling at Mach 0.85) and increased defense funding during the Vietnam War.

As early as the 1950s, the airline industry had begun questioning whether there was a continued need for the CAB and its control over ticket prices and air routes. Critics argued that the organization couldn't keep up with private sector events, such as the introduction of jet aircraft and rising fuel costs. By the early 1970s, economic regulation of the airline industry had led to artificially high fares and poor availability for customers in small regional markets. This led, in turn, to the passage of the landmark Airline Deregulation Act of 1978, which allowed airlines to fly to new regional destinations, provided increased scheduling flexibility, and abolished federal control over rates (seven years later, Congress abolished the CAB altogether). Over the next decade, deregulation produced a wave of mergers, expansions, and airline failures. Big winners included Allegheny Airlines (US Airways) and Delta Airlines—each was progressively transformed from a small regional carrier to a major national company. Big losers included Braniff Airlines, Eastern Airlines, and Pan American Airlines. These companies were irrevocably damaged by overextended operations, destructive internal battles between ownership and labor, and competition from rival airlines. By the early 1990s, United and Delta had not only consolidated their domestic operations but had also taken over most of Pan Am's international routes when the latter went out of business. At that time, the largest three airlines (American, Delta, and United) controlled over half of the domestic market and an even greater share of the international market. By the end of the first century of flight, however, these larger airlines were increasingly challenged by smaller carriers that could operate more efficiently by offering point-to-point travel options as opposed to the traditional hub-and-spoke systems that the larger companies relied upon.

The manufacturing sector also experienced some important changes during the period of deregulation. On the military side, with budgets increasing dramatically as part of the Reagan administration's overall defense buildup, government procurements were on the rise. Activities on the commercial side were not as dynamic, however, largely because of the conspicuous lack of any completely new airliner designs by American companies and the changing economic environment facing domestic carriers. Because of increased foreign competition from the European Airbus Consortium, there was a marked decrease in U.S. manufacturers' global market share. With the end of the Cold War and continued international competition, the aviation industry began a slow slide starting in the early 1990s. By the middle part of that decade, this had led to another series of mergers that greatly reduced the number of companies working in this sector. In 1995, Lockheed and Martin Marietta merged to form the Lockheed Martin Corporation, one of the largest aerospace companies in the world. Lockheed Martin abandoned transport aircraft manufacturing and engaged primarily in government contract work. In 1996–1997, Boeing acquired both Rockwell International and McDonnell Douglas. The augmented Boeing Company became the sole domestic producer of large commercial transport aircraft (Boeing also remained involved in building military aircraft).

Development of the Missile and Space Industry[5]

The beginnings of rocketry date back to around the thirteenth century, when the Chinese were reported to have used black powder rockets. During the eighteenth and nineteenth century, more advanced solid fuel rockets were employed for a variety of uses ranging from artillery barrages to propelling harpoons. It wasn't until the twentieth century that serious thought was given to using liquid fuel to produce much more powerful rockets. Early theoretical work in this area was done by Russian schoolteacher Konstantin Tsiolkovsky and German engineer Hermann Oberth. It was an American physics professor at Clark University in Massachusetts, however, who was the first to build a workable liquid fuel rocket—Robert Goddard. Working in isolation from the larger scientific community, which had earlier shunned his work, Goddard designed and tested hardware during the early 1920s. In March 1926, he conducted the first successful launch of a liquid propellant rocket on a farm in central Massachusetts—the vehicle reached a height of only 41 feet in 2.5 seconds. During the coming years Goddard continued his research, eventually building rockets that flew nearly two miles into the sky.

Although Goddard's work was largely ignored in the United States, rocket engineers in Germany were very interested and sought to incorporate his findings into their own research. Despite the creation of the American Interplanetary Society and rocket studies conducted at the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT), rocketry developments in the United States lagged far behind those in Germany. Although early work on barrage rockets and Jet Assisted Takeoff (JATO) instruments were conducted during WWII, it was the Germans who developed the first large rockets. Named V2s, these vehicles were used to deliver explosive payloads against enemies of the Third Reich (primarily Great Britain). After the end of the war, many of the German rocket scientists who developed the V2 either surrendered or were captured by American and Russian forces. The largest group, headed by Werner von Braun, was captured by the U.S. Army and brought to the United States in 1945. This group and the V2s captured by American forces represented the core of an Army effort to build ballistic missile systems, which eventually moved to Huntsville, Alabama, to form the Army Ballistic Missile Agency (ABMA). During the immediate postwar period, while much of the strategic focus of the armed forces was on the development of nuclear weapons and long-range bombers, research programs investigating potential development of technically feasible ballistic missiles evolved slowly.

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[5] This section of the report discussing the historical development of the space industry is drawn from a general examination of the following sources: Bilstein (1996), pp. 1–20; Weiss and Amir (2004); Pelton (1998), pp. 1–11; Mack and Williamson (1998), pp. 155–167; Naugle and Logsdon (2001), pp. 1–15; Snyder (2001), pp. 271–277; and Day (2004).

National Security Space Program

During WWII, many new companies led barrage rocketry and JATO research efforts in the United States, including Aerojet Engineering Corporation and Reaction Motors. By the early 1950s, however, these smaller operations began to be attractive acquisition targets for more established aviation companies. As a result, better-known corporations like Ryan, Northrop, Convair, Martin, North American, Lockheed, and Douglas purchased these smaller organizations and began pursuing a range of rocketry-related activities. During this period, there was a great deal of cross-fertilization between aviation and space efforts, with many engineers and scientists working on both sides of the house. Within a relatively short period of time, however, many of these companies had established separate divisions for their continuing missile development work. This began a slow but steady process whereby rocket (and eventually space) research evolved largely independent of the aviation research conducted by these same companies.

While there was little sustained interest in ballistic missile technology following WWII, the promise of smaller nuclear warheads during the 1950s provided a new opportunity for proponents to push research in this area. Combined with intelligence emerging from behind the Iron Curtain that the Soviets were making significant progress, this led to the creation of a crash intercontinental ballistic missile (ICBM) program within the Air Research and Development Command (ARDC) under Brigadier General Bernard Schreiver. The new program utilized "parallel development" with different prime contractors for every major system. Parallel development was intended to insure against one contractor failing to deliver and to allow program managers to use resultant technologies and systems interchangeably. The Atlas and Titan programs emerged from this program, eventually becoming the first two operational ICBMs—capable of hitting any target within the Soviet Union if launched from the United States (fielded in 1959 and 1962, respectively).

In the mid 1960s, these systems were eventually augmented by the Boeing Minuteman series, which integrated subsystems from Thiokol Chemical, Aerojet-General, Hercules Incorporated, North American Rockwell, Sylvania Electronics, Avco Corporation, and General Electric Company. Within the overall nuclear arsenal, these ICBMs were further supplemented by Polaris (and eventually Poseidon), submarine-launched missiles built by Lockheed Missiles and Space for the U.S. Navy.

While the early military focus was largely on ballistic missiles, by the late 1950s the center of attention had begun to shift toward launch vehicles and national security satellites. Most of the launch vehicles utilized during this period for national security missions were derivations of ICBM designs. The Delta, Atlas, and Titan families were incrementally advanced during the coming decades to fulfill military launch needs (as well as civilian expendable launch vehicle requirements). These launchers carried into orbit a wide variety of satellite systems that were progressively developed during the remainder of the century by existing aerospace companies (e.g., Boeing, Lockheed) and increasingly by specialized satellite producers (e.g., TRW, Hughes, Loral).

Reconnaissance and signal intelligence satellites were the most important early national security space systems. Starting in 1960, the military began operating a series of film-return satellite systems that used cameras to take relatively high-resolution images of the Earth's surface before returning the film in a small reentry vehicle that was snatched from the air by special aircraft (e.g., CORONA, HEXAGON, GAMBIT). During this period, several systems were developed to intercept Soviet radar transmissions (e.g., GRAB, DYNO, POPPY, PARCAE) and by the end of the decade new systems were in place that could intercept telephone transmissions (e.g., CANYON, VORTEX, MERCURY). The mid 1970s saw a major advance with the launch of the first real-time imaging satellites, starting with the KH-11 KENNAN, which could provide high-resolution photographs within minutes of a tasking order. The next major development in reconnaissance satellites was a platform, such as the LACROSSE and ONYX systems, capable of peering through cloud cover.

The military sector has been heavily involved in a number of space development projects that extend beyond missiles, launch vehicles, and intelligence gathering satellites. Starting in the 1960s, at the same time NASA was developing civilian weather satellites, the military was also embarking on development of the Defense Meteorological Support Program (DMSP). The platforms in this system were used early on to reconnoiter regions that reconnaissance satellites were scheduled to image—the rationale being that valuable film could be saved by not imaging an area covered with clouds. In the coming decades, more advanced systems were created that became a crucial tool for scheduling military operations and protecting land, sea, and air forces. Another military system that enjoyed continuously increasing importance was navigation satellites. Starting in the mid 1960s, the *Transit*, *Oscar*, and *Nova* constellations provided Doppler positioning technologies to give accurate locations for both land- and sea-based assets. These early systems eventually made way for the *Timation* system, which in the mid-1980s was replaced by the Global Positioning System (GPS). This constellation of 24 radio navigation satellites is able to provide highly accurate positioning information (in addition to its military uses, GPS has proven to have many commercial applications). A final important category of the national security space system is communications satellites—these systems meet requirements specific to the military, particularly the ability to safeguard against enemy jamming. Crude systems first took flight during the early 1960s (SCORE, Courier, Lincoln Experimental Satellites) but were soon replaced with the platforms that formed the Initial Defense Communication Satellite Program (IDCSP). Starting in the early 1970s, these systems were steadily phased out and replaced by more sophisticated platforms to form the Military Satellite Communications (Milsatcom) architecture. This system includes wideband, mobile and tactical (or narrowband), and protected (or nuclear-capable) satellites. Government contractors, working closely with military scientists and program managers, have developed all these national security space systems, ranging from reconnaissance satellites to GPS to communications satellites. This has proven to be a large, and very important, market segment within the broader aerospace industry.

Civilian Space Program

At the same time as developments were going on within military rocketry, another front within the Cold War was about to open in outer space. In 1955, the United States announced to the world its intention to launch a scientific satellite into Earth orbit during the International Geophysical Year (July 1957 to December 1958). Taking this declaration as a call to action, the Soviets redirected some of their ICBM work toward achieving the same goal—and did so before the Americans. Chief rocket designer Sergei Korolev set about redesigning the R-7 ICBM for orbital flight. In October 1957, the five-engine R-7 rocketed into the night sky and successfully placed the world's first artificial satellite, dubbed *Sputnik*, into an elliptical orbit around the Earth. This was, quite literally, an earth shaking event that had a tremendous effect on the world stage. Although the United States successfully launched the smaller *Explorer I* satellite aboard a Jupiter-C launch vehicle the following January, government leaders recognized that the nation needed to take the potential threat to national prestige posed by Soviet space successes more seriously. This led to the creation of NASA in 1958, which became the preeminent civilian agency for space exploration. The new agency subsumed the NACA and ABMA (as well as other federal entities) and took responsibility for federal interactions with the Jet Propulsion Laboratory (JPL).

Over the next few years, NASA worked to organize itself and initiate research programs, but still lagged behind ongoing space efforts in the Soviet Union. This became apparent in April 1961, when the Soviets launched Yuri Gagarin into Earth orbit—a feat the Americans would not match for nearly 10 months with John Glenn's orbital flight in February 1962 (although NASA did launch two successful suborbital flights during the interim period). Combined with the failed Bay of Pigs invasion, the resulting crisis environment led to President Kennedy's announcement that the United States would seek to land humans on the Moon before the end of the 1960s. Project Apollo transformed the civilian space program and NASA from a relatively small R&D agency to an organization responsible for implementing a presidential initiative requiring a nationwide production effort and construction of global communications and tracking facilities. From 1960 to 1966, NASA's budget increased from only $401 million ($1.9 billion in 2000 dollars) to $5.9 billion ($26 billion in 2000 dollars). At its peak, NASA's budget was over 4 percent of the entire federal budget. By the mid 1960s, more than 375,000 government, industry, and university personnel were involved in the civilian space program.

The first step in the lunar exploration program was Project Gemini, which was initiated in December 1961. That project was intended to test many of the technologies and operational maneuvers necessary for a human mission to the Moon. The Gemini spacecraft, built by McDonnell Aircraft Corporation, was a two-seat vehicle launched atop a Titan rocket. Between March 1965 and November 1966, ten Gemini missions were successfully carried out, meeting all the project's original objectives and setting the stage for Project Apollo. After President Kennedy established the lunar landing goal, NASA had set off to figure out how to accomplish that objective. The agency selected a mission approach called *lunar orbit rendezvous,* in which a modular spacecraft composed of a Command Service Module (CSM), which contained life support systems for the three-astronaut crew and the heat shield for Earth reentry, and a Lunar Module (LEM), which would separate from the CSM in lunar orbit, carry two astronauts to the lunar surface, and return them to the CSM in lunar orbit. The CSM and LEM would be launched on top of a massive Saturn V rocket, which was capable of placing 260,000 pounds into low earth orbit. To build these spacecraft and launch vehicles, NASA turned to several prime contractors and an extensive web of subcontractors. The primes included Boeing (Saturn V first stage), North American (Saturn V second stage, CSM), Douglas (Saturn V third stage), North American's Rocketdyne division (J-2 engine, F-1 engine), Grumman Aerospace (LEM), and IBM (Saturn V instrumentation). Although this government-industry partnership suffered a setback with the tragic *Apollo 1* fire,[6] the project achieved its primary goal when *Apollo 11* successfully landed astronauts Neil Armstrong and Buzz Aldrin on the lunar surface in July 1969. During the

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[6] On January 27, 1967, tragedy struck the Apollo program when a flash fire occurred in the *Apollo 1* command module during a launch pad test of the Apollo/Saturn space vehicle being prepared for the first piloted flight. Astronauts Gus Grissom, Ed White, and Roger Chafee were killed.

subsequent three years, five more Apollo spacecraft successfully landed humans on the lunar surface.

Although NASA budgets decreased after the success of Project Apollo, human spaceflight remained dominant within the space agency with the establishment of the Space Shuttle program, an effort to build a reusable space transportation system. Like Apollo before it, the Shuttle program involved industry partners from around the country—North American Rockwell (including its Rocketdyne division), McDonnell Douglas, Lockheed, Hamilton Standard, Thiokol, and Martin Marietta. Twenty-five years after it became operational in 1981, the Space Shuttle is still the only American human-rated launch vehicle. The Shuttle and International Space Station program (initiated in 1984 and initially called Space Station Freedom) formed the core of NASA's human spaceflight programs at the end of the first century of flight. These projects had a combined annual budget of approximately $6 billion, nearly half of NASA's entire appropriation. The programs continued to have close relationships with the space industry, which not only built most of the necessary hardware but during the mid-1990s also became increasingly involved in human spaceflight operations.

Although the human spaceflight program has historically garnered a large share of attention and funding within the civilian space program, NASA has also been involved in a wide variety of other activities. The space agency has been responsible for developing, launching, and operating satellites and probes that carry out a range of applications and science programs. As early as 1945, when a British Royal Air Force officer named Arthur C. Clarke wrote an article that described the use of crewed orbital satellites, the government and industry began investigating applications for such platforms. Telecommunications satellites were among the first uses that were examined, starting with research conducted at AT&T's Bell Laboratories (which eventually led to the launch of AT&T's Telstar experimental satellite in 1962). At the same time that AT&T was conducting its research, NASA launched a series of experimental communications satellites—including Echo (the first artificial satellite that actually relayed a real-time voice message from Earth to orbit and back), Relay, and Syncom. During the first century of flight, telecommunications represented the only true commercial space industry. Even before working on communications satellites, NASA had been conducting research relating to meteorological satellites. The initial program that emerged from this undertaking was the TIROS series of weather platforms (the first TIROS was launched in April 1960), which was followed by the Nimbus, ATS, POES, and GOES satellite families. NASA continues to be involved in the development of advanced meteorological systems, which are operated by the National Oceanographic and Atmospheric Administration (NOAA), the other civilian space agency within the federal government.[7] A final significant civilian applications program was the development of Earth resource satellites. NASA's Landsat program was the agency's initial foray into the study of Earth's land features. Landsat-1 was launched in 1972 and was followed by four more operational vehicles (Landsat-5, launched in 1985, was still in service at the end of the first century of flight). Remote sensing data provided by Landsat systems were being used by a wide variety of customers, including NASA's Earth Sciences Enterprise, geologists, hydrologists, agriculture scientists, urban and regional planners, and geographers. Although some of these projects were conducted completely in-house, most NASA application programs have been carried out in close cooperation with the key contractors within the aerospace industry. Space science

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[7] NASA is responsible for meteorology satellite R&D; NOAA is responsible for operations.

efforts began in the United States shortly after the end of WWII with high-altitude balloons and sounding rockets used to perform investigations of the upper atmosphere. *Explorer 1*, the first American satellite, was equipped with instrumentation that led to the discovery of the Van Allen radiation belts. During the Apollo years, the majority of NASA's space science activities revolved around lunar exploration and sending planetary probes to explore the inner planets. In 1964–1965, a series of Ranger spacecraft conducted important lunar research for Project Apollo. This effort produced more than 17,000 photographs of the lunar surface. In May 1966, the Ranger achievements were followed by the successful soft landing of *Surveyor 1* on the lunar surface (in addition to conducting chemical analyses of the lunar soil, the Surveyor series took nearly 90,000 photographs of the lunar surface). During this same period, the Lunar Orbiter program conducted five missions around the Moon that produced lunar maps and photographed 20 potential Apollo landing sites. From 1962 to 1975, seven Mariner probes conducted initial investigations of Earth's three neighbors within the inner solar system; these missions made significant discoveries during this 13-year period (see Table A.1).

Starting in 1976, the *Viking 1* and *Viking 2* missions followed initial planetary explorations with a highly successful Mars lander program that returned incredible photographs of the Martian surface and performed biology experiments designed to look for possible signs of life (these experiments were inconclusive). During the same period, the *Voyager 1* and *Voyager 2* spacecraft set off on an extended exploration of the gas giant planets of the outer solar system. These spacecraft remained operational into the 21st century, returning invaluable data regarding the region of space where the Sun's influence ends and deep space begins.

By the 1980s, increasingly tight budgets had led NASA to reduce its commitment to planetary exploration. It was not until 1990 that the *Magellan* spacecraft arrived at Venus and began providing Earthbound researchers with radar maps of the Venusian surface. This was followed five years later by the *Galileo* spacecraft's arrival at Jupiter to begin an extensive exploration of the Jovian system. By the late 1990s, NASA had adopted a leaner approach to planetary exploration, although it was still able to undertake significant studies with the *Near Earth Asteroid Rendezvous*, *Mars Pathfinder*, *Lunar Prospector*, *Stardust*, *Mars Global Surveyor*, *Mars Odyssey*, and *Deep Space 1* spacecraft. During the past two decades, in addition to

Table A.1
Mariner Program Accomplishments

Mission	Accomplishments
Mariner 2	First spacecraft to fly by another planet, studying Venus' atmosphere and surface. During its journey to Earth's neighbor, the craft made the first-ever measurements of the solar wind
Mariner 4	Collected the first close-up photos of another planet when it flew by Mars, revealing lunar-type impact craters. Also conducted long-term studies of the solar wind environment
Mariner 5	Flew within about 2,500 miles of Venus and had the closest encounter with the Sun up to that time
Mariner 6 and 7	Completed the first dual mission to Mars, flying past the equator and south polar regions and analyzing the Martian atmosphere and surface with remote sensors
Mariner 9	First artificial Mars satellite, orbiting the planet for nearly a year. Revealed a very different planet than expected—one boasting gigantic volcanoes and an immense canyon stretching 3,000 miles across its surface
Mariner 10	Pioneered the use of a "gravity assist" swing by Venus to bend its flight path on its mission to the small, airless, cratered globe of Mercury (where a fortuitous gravity assist enabled the spacecraft to return at six-month intervals for close mapping passes covering half of Mercury)

planetary exploration, NASA has embarked on an aggressive program utilizing orbital observatories to conduct astronomy and astrophysics research. These "Great Observatories"—the Hubble Space Telescope, Compton Gamma Ray Observatory, and Chandra X-Ray Observatory—have revolutionized those areas of study. As with the civilian space applications discussed above, in-house researchers led many of these programs, but government contractors played a critical role in hardware development.

APPENDIX B
Data Tables

As discussed in Chapter One, the approach taken by RAND to scope government aerospace activities was to use procurement data systematically collected on all contracts awarded by federal departments and agencies. Specifically, the study team used the Federal Procurement Data System (FPDS) to identify all air system, missile system, and space system expenditures, including extramural R&D spending. RAND has full access to this system through its RaDiUS database program, which was used to assemble the data tables below. These data tables were the foundation of the analysis found in this report.

FEDERAL AIR & SPACE SPENDING IN FY2003 BILLIONS	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
AIR SYSTEMS	34,282	35,566	27,417	34,247	22,539	24,826	22,859	20,522	19,686	16,966	35,502
Aircraft and airframe structural components	18,998	19,891	12,892	20,248	10,641	13,038	11,593	8,307	9,280	5,515	17,640
Aircraft components and accessories (non-structural)	2,021	1,596	1,909	1,848	1,295	1,661	1,612	2,138	1,804	2,065	3,188
Aircraft launching, landing, and ground handling equipment	122	65	83	71	87	135	67	102	83	150	218
Aircraft tires and tubes/pneumatic	31	29	41	46	42	44	61	48	42	35	35
Communication, detection and coherent radiation equipment	1,037	1,553	1,480	898	1,163	976	622	614	399	864	1,044
Engines, turbines, and components	4,388	4,487	3,509	3,505	2,563	2,736	3,193	3,191	2,818	2,734	4,755
Engine accessories	147	136	137	120	107	195	250	249	144	221	413
Fire control equipment	292	201	446	128	156	146	93	188	80	135	354
Instruments	107	137	175	148	110	77	117	121	96	150	197
Rockets, rocket ammunition, and rocket components	128	7	180	91	139	190	268	353	227	72	348
Weapons	43	26	10	79	106	25	59	132	182	13	81
Other (including federal personnel)	1,146	1,374	1,185	1,403	1,006	1,101	1,164	1,259	1,151	1,742	2,917
Infrastructure	5,820	6,065	5,371	5,663	5,124	4,502	3,758	3,818	3,379	3,272	4,312
MISSILE SYSTEMS (including Ballistic Missiles)	8,911	6,748	5,831	5,101	4,509	5,427	5,067	5,260	3,795	2,622	5,158
Guided missiles (excluding warheads and explosive components)	6,808	5,405	5,030	4,164	3,826	4,579	3,802	3,845	2,875	1,980	3,437
Guided missile warheads and explosive components	127	33	113	67	1	20	14	12	6	30	58
Nuclear warheads and warhead sections	2	1	-	-	0	-	-	0	0	2	-
Guided missile explosive propulsion units and components/solid fuel	-	-	-	0	-	-	-	-	-	-	-
Guided missile inert propulsion units and components/solid fuel	11	13	1	126	28	2	-	(0)	-	-	-
Nuclear rockets (including ballistic missiles)	-	-	-	-	0	-	-	-	-	-	-
Infrastructure	1,963	1,295	688	745	654	825	1,251	1,404	913	610	1,663
SPACE SYSTEMS	4,844	4,673	4,416	5,068	4,624	4,714	4,220	4,292	3,990	4,279	4,889
Space vehicles (including satellites)	2,095	1,920	1,729	1,717	1,538	1,566	1,336	1,128	1,328	1,279	1,971
Space vehicle explosive propulsion units and components/solid fuel	9	22	9	39	40	35	11	10	8	20	-
Space vehicle inert propulsion units and components/solid fuel	325	313	411	520	566	603	428	505	29	94	75
Professional services (re-categorization of NASA engineering and technical services)	994	947	937	748	2,266	2,222	2,181	2,409	2,196	2,529	2,497
Infrastructure	1,421	1,472	1,329	2,045	214	287	264	240	430	359	346
RESEARCH AND DEVELOPMENT	18,908	24,794	20,692	18,699	14,416	16,084	13,555	10,662	9,996	9,548	17,868
Aeronautic and space technology	1,326	815	708	611	556	583	488	374	398	630	626
Aerospace navigation and navigational aids	11	5	2	4	3	2	2	2	1	0	0
Air transportation	4	5	14	18	37	16	4	3	4	273	2
Aircraft (defense)	6,301	7,116	7,904	5,907	4,190	5,312	4,412	3,213	2,804	2,272	7,178
General science and technology R&D	203	222	201	186	163	179	169	133	130	104	92
Missiles and space systems (defense)	5,056	7,370	5,527	5,509	3,889	3,917	3,184	2,007	1,866	1,740	4,772
Space flight	2,482	2,437	902	759	675	1,311	857	534	624	781	1,181
Space operations (tracking and data acquisition)	380	292	261	178	101	97	106	108	90	70	74
Space science and applications	1,104	878	1,175	1,153	604	643	407	309	626	239	439
Space and terrestrial	-	-	-	-	-	-	0	-	7	66	418
Space Station	666	1,315	1,620	1,767	1,784	1,562	1,256	1,311	782	963	700
Commercial space programs	23	18	39	17	14	8	18	41	30	11	153
Other space R&D	809	809	822	1,025	944	881	790	758	676	391	401
Operation of Government-Owned Facility (Jet Propulsion Laboratory)	541	3,513	1,517	1,564	1,457	1,573	1,862	1,868	1,959	2,007	1,832

DOD AIR & SPACE PROCUREMENTS IN FY2003 BILLIONS	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
AIR SYSTEMS	32,496	33,971	25,773	32,505	21,483	21,669	21,931	19,442	18,372	15,865	34,702
Aircraft and airframe structural components	18,970	19,880	12,827	20,222	10,521	11,811	11,560	8,290	9,142	5,391	17,615
Aircraft components and accessories (non-structural)	2,000	1,536	1,870	1,816	1,269	1,477	1,586	2,067	1,736	2,022	3,163
Aircraft launching, landing, and ground handling equipment	94	61	82	71	81	117	61	86	76	145	209
Aircraft tires and tubes/pneumatic	31	29	40	46	41	39	61	48	42	35	35
Communication, detection and coherent radiation equipment	1,010	1,522	1,434	862	1,142	859	614	577	389	853	1,030
Engines, turbines, and components	3,439	3,809	2,937	3,042	2,458	2,414	3,095	3,131	2,778	2,680	4,725
Engine accessories	147	135	137	119	104	175	246	246	142	220	411
Fire control equipment	292	201	446	128	156	133	93	188	80	135	354
Instruments	104	136	173	146	108	70	115	119	93	146	195
Rockets, rocket ammunition, and rocket components	123	6	180	91	138	172	268	353	227	71	348
Weapons	42	26	9	79	106	23	59	132	182	13	81
Other (including federal personnel)	909	1,122	889	949	860	831	956	955	738	1,398	2,637
Infrastructure	5,333	5,507	4,747	4,936	4,499	3,549	3,218	3,251	2,748	2,758	3,899
MISSILE SYSTEMS (including Ballistic Missiles)	8,902	6,731	5,829	5,097	4,504	4,930	5,066	5,260	3,795	2,621	5,157
Guided missiles (excluding warheads and explosive components)	6,802	5,399	5,030	4,163	3,826	4,163	3,802	3,845	2,875	1,980	3,437
Guided missile warheads and explosive components	127	33	113	67	1	19	14	12	6	30	58
Nuclear warheads and warhead sections	2	1	-	-	0	-	-	0	0	2	-
Guided missile explosive propulsion units and components/solid fuel	-	-	-	0	-	-	-	-	-	-	-
Guided missile inert propulsion units and components/solid fuel	11	13	1	126	28	2	-	(0)	-	-	-
Nuclear rockets (including ballistic missiles)	-	-	-	-	-	-	-	-	-	-	-
Infrastructure	1,960	1,285	686	741	649	747	1,250	1,404	913	610	1,662
SPACE SYSTEMS	543	418	484	599	720	757	333	459	412	249	851
Space vehicles (including satellites)	378	242	324	341	415	412	173	178	230	127	715
Space vehicle explosive propulsion units and components/solid fuel	8	21	7	26	38	30	8	10	8	20	-
Space vehicle inert propulsion units and components/solid fuel	0	0	7	139	204	241	67	207	22	57	74
Infrastructure	157	155	145	93	62	73	85	63	152	45	62
RESEARCH AND DEVELOPMENT	12,744	15,348	14,386	12,498	9,192	9,834	8,448	5,705	5,592	4,322	13,377
Aeronautic and space technology	19	11	17	8	1	1	1	0	0	10	18
Aerospace navigation and navigational aids	9	1	1	1	-	1	2	2	1	0	0
Air transportation	1	0	10	10	31	2	-	2	3	13	1
Aircraft (defense)	6,301	7,116	7,904	5,905	4,186	4,828	4,410	3,211	2,796	2,263	7,172
General science and technology R&D	194	202	183	172	142	144	136	94	91	72	63
Missiles and space systems (defense)	5,053	7,367	5,519	5,509	3,888	3,549	3,160	1,998	1,858	1,733	4,763
Space flight	624	240	340	211	354	673	264	(9)	78	120	606
Space operations (tracking and data acquisition)	50	55	46	22	6	8	12	10	9	2	15
Space science and applications	254	165	221	389	219	297	146	56	426	3	62
Space and terrestrial	-	-	-	-	-	-	0	-	7	66	418
Space Station	7	4	2	1	6	4	6	11	15	5	3
Commercial space programs	-	-	-	1	-	-	-	24	21	-	138
Other space R&D	231	188	144	271	360	329	310	307	289	34	118

NASA AIR & SPACE PROCUREMENTS IN FY2003 BILLIONS	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
AIR SYSTEMS	1,044	797	688	925	440	367	430	387	446	259	202
Aircraft and airframe structural components	1	2	2	4	1	1	2	1	15	0	0
Aircraft components and accessories (non-structural)	1	9	5	3	5	5	9	7	3	4	2
Aircraft launching, landing, and ground handling equipment	0	1	-	0	7	6	6	17	7	5	9
Aircraft tires and tubes/pneumatic	-	-	-	-	-	-	-	-	-	-	-
Communication, detection and coherent radiation equipment	0	1	1	3	4	4	2	3	3	0	0
Engines, turbines, and components	929	664	556	449	84	63	64	42	24	43	21
Engine accessories	0	-	0	1	2	0	0	0	-	-	0
Fire control equipment	-	-	-	-	-	-	-	-	-	-	-
Instruments	0	-	1	1	1	0	2	1	0	1	1
Rockets, rocket ammunition, and rocket components	4	1	-	0	1	-	-	-	-	0	-
Weapons	0	-	-	-	-	-	-	-	-	-	-
Other (including federal personnel)	13	11	19	15	14	12	14	25	69	82	85
Infrastructure	95	108	104	449	322	277	331	292	324	122	84
MISSILE SYSTEMS (including Ballistic Missiles)	11	16	4	18	6	5	3	(0)	(0)	0	0
Guided missiles (excluding warheads and explosive components)	6	6	-	1	-	-	-	-	(0)	0	-
Guided missile warheads and explosive components	-	-	-	-	-	-	-	-	-	-	-
Nuclear warheads and warhead sections	-	-	-	-	-	-	-	-	-	-	-
Guided missile explosive propulsion units and components/solid fuel	1	0	2	13	1	2	3	(0)	-	-	-
Guided missile inert propulsion units and components/solid fuel	-	-	-	-	-	-	-	-	-	-	-
Nuclear rockets (including ballistic missiles)	-	-	-	-	-	-	-	-	-	-	-
Infrastructure	4	10	2	4	5	3	0	(0)	-	0	0
SPACE SYSTEMS	4,297	4,250	3,922	4,451	3,896	3,877	3,883	3,833	3,578	4,030	4,038
Space vehicles (including satellites)	1,714	1,674	1,397	1,370	1,116	1,110	1,162	949	1,097	1,151	1,256
Space vehicle explosive propulsion units and components/solid fuel	-	-	-	-	-	-	-	-	-	-	-
Space vehicle inert propulsion units and components/solid fuel	324	313	404	381	362	338	360	298	7	37	1
Professional services (re-categorization of NASA engineering and technical services)	994	947	937	748	2,266	2,222	2,181	2,409	2,196	2,529	2,497
Infrastructure	1,264	1,317	1,183	1,952	152	207	180	177	277	314	284
RESEARCH AND DEVELOPMENT	6,150	9,425	6,284	6,184	5,204	5,204	5,057	4,922	4,375	4,942	4,473
Aeronautic and space technology	1,307	804	691	604	553	553	470	354	387	607	601
Aerospace navigation and navigational aids	1	2	1	2	0	(0)	-	-	-	-	-
Air transportation	-	0	1	2	1	2	2	1	0	1	2
Aircraft (defense)	-	-	0	2	4	2	1	2	7	9	6
General science and technology R&D	10	16	15	13	18	20	33	40	39	33	29
Missiles and space systems (defense)	-	-	-	-	-	7	17	5	2	2	1
Space flight	1,857	2,198	562	548	321	571	594	544	546	661	576
Space operations (tracking and data acquisition)	324	230	209	150	89	82	89	96	74	63	57
Space science and applications	851	713	953	764	385	315	259	250	197	234	375
Space and terrestrial	-	-	-	-	-	-	-	-	-	-	-
Space Station	659	1,311	1,618	1,765	1,778	1,558	1,250	1,300	768	958	696
Commercial space programs	23	18	39	17	14	8	18	17	9	11	15
Other space R&D	578	620	678	754	584	520	479	452	388	357	284
Operation of Government-Owned Facility (Jet Propulsion Laboratory)	541	3,513	1,517	1,564	1,457	1,573	1,862	1,868	1,959	2,007	1,832

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