Chapter 6

Technology Development Options

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TECHNOLOGY DEVELOPMENT is the U.S. Government's "Best Buy" if. . . it is concerned about the state of the Nation's space transportation technology base and it is optimistic about the space program's long-term prospects, but expects little near-term funding available for developing new vehicles. This option aggressively supports technology development programs across a broad range of disciplines. Greater funding for space transportation research and technology develops both technology and human capital – the next generation of aerospace engineers and technicians.

THE SPACE TRANSPORTATION TECHNOLOGY BASE TODAY

Many observers consider our existing space technology base to be inadequate. For example, since the U.S. commitment to the Space Shuttle in the 1970s, propulsion technology development has shifted from broad-based research to a very narrow focus on Space Shuttle main engine development. No other significantly advanced propulsion technologies have been developed in the United States for 20 years.[1] When the Saturn V program ended, much of the technology base was lost. Not only were the documentation of the technologies left incomplete and decentralized, but much of the "art" of certain disciplines was lost when scientists, metallurgists, and engineers left the industry or retired. In addition, many of the facilities that would be required today for developing the advanced engine technology have been closed down, mothballed, or converted to other purposes.

DEVELOPMENT OPTIONS

To reverse this deterioration, the National Research Council, for example, recommends that NASA improve engine design and develop:

- a range of advanced (low-cost, highly reliable) Earth-to-orbit engines to accommodate the potential future launch vehicle fleet mix;
- a reusable cryogenic orbital transfer vehicle (OTV) engine;
- a high-thrust, high-performance out-of-orbit propulsion system for manned Mars and similar missions; and
- a high-performance, low-thrust primary propulsion system for solar-system exploration spacecraft (nuclear-electric).

The National Research Council and other groups have also made a strong case for increasing research funding for materials and structures, automation, life support systems, and other disciplines that could contribute to a stronger technology base. Officials at NASA and DoD have recognized the need for additional attention to space transportation research and have instituted programs to help meet it.

1 National Research Council, Aeronautics and Space Engineering Board, Space Technology to Meet Future Needs (Washington, DC: National Academy Press, December 1987).

Box 6-1. – Experts are Concerned . . .

"Rebuilding the Nation's technology base is essential for the successful achievement of any long-term space goal. It is widely agreed that we are living off the interest of the Apollo investment, and that it is time to replenish our technology reservoir in order to enhance our range of technical options." – Sally K. Ride, *Leadership and Americans Future in Space* (Washington, DC: National Aeronautics and Space Administration, August 1987).

"Many technologies critical to the future of space transportation are poised for major advances . . . Current funding levels severely inhibit the timely development of a majority of necessary key technologies . . . Facilities in the areas of propulsion, structures, and aerothermodynamics are demonstrably inadequate to cope with development testing requirements." –Joint DoD/NASA Steering Group, *National Space Transportation and Support Study,* Summary Report, May 14,1986.

"Over the past 15 years . . . [NASA'S office of Aeronautics and Space Technology] has been severely restricted . . , NASA's preoccupation with short-term goals has left the agency with a technology base inadequate to support advanced space missions . . . IV]irtually . . . [no money]. . . has been spent on technology development for missions more than five years in the future. . . [T]he committee reviewed the state of advanced space R&T from the perspective of future missions. . . The result was depressing." — National Research Council, Aeronautics and Space Engineering Board, *Space Technology to Meet Future Needs* (Washington DC: National Academy Press, December 1987).

"Our current space technology program is deficient in two regards: first, the scope and intensity of the basic research and technology program is inadequate to provide the range of technical options we need for both the near and distant future; second, there are opportunities, now clearly identified, which we have not developed to the stage where they can be selected for application." –*Pioneering the Space Frontier,* Report of the National Commission on Space, New York: Bantam Books, May 1986.

"Space technology advancement underlies any comprehensive future space activity. The present course is a status-quo caretaker path with no potential growth. New commitments are called for in key technologies . . . We support . . . a threefold increase in this relatively low-budget but extremely important area of space technology advancement, especially in view of strong foreign commitments to such technology development." — *U.S. Civil Space Program: An AIAA Assessment, 1987.*

FUNDING

OTA did not carry out an independent assessment of the adequacy of current funding levels for advanced technology research and development. However, several recent studies have reached the following conclusions:

National Research Council

A recent National Research Council report drew a connection between low R&D funding for space, the trade imbalance between the United States and other countries and the loss of U.S. leadership in space.[2] Over the last 15 years, only about 2 to 3 percent of the total NASA budget has been dedicated to space research and technology, as shown in figure 6-1. The actual space R&T funding trend is given in figure 6-2. The NRC pointed out that even a comparatively mature industry like aeronautics spends about 3 percent of sales on research, while space research is running at about 1 percent of the industry's $20 billion annual space-related revenues. Because technology development for the exploration and exploitation of space is less mature than aeronautics, the report ar-

2 Ibid., pp. 153-156.

Figure 6-1.
NASA Space Research and Technology Budget as Percentage of Total NASA Budget

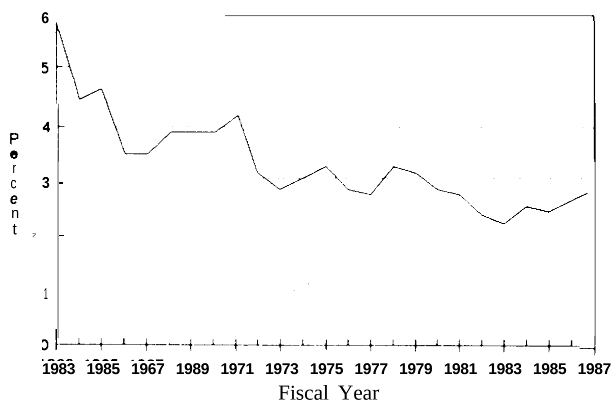


Figure 6-2.
NASA Space Research and Technology Funding

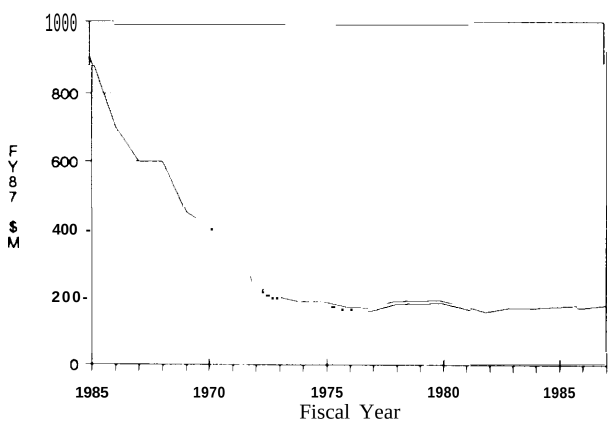
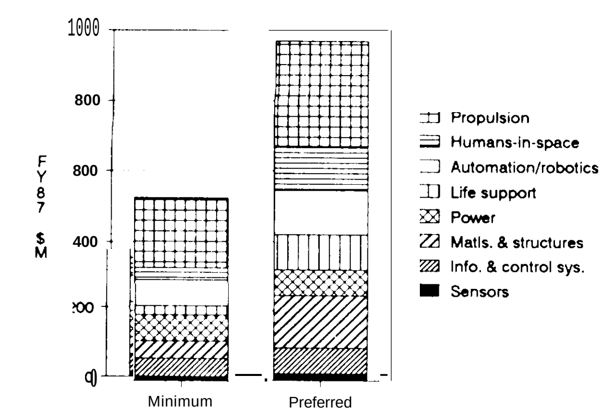


Figure 6-3.
Annual Space Research and Technology Funding Augmentation Recommended by the NRC



SOURCE: NRC, 1987 (corrected by OTA).

gues that space industry should have "a correspondingly greater ability to absorb usefully the technology investment." It recommends that for the next decade the NASA research and technology effort not be allowed to fall below 7 percent of the total NASA budget and that these resources should be protected from short-term requirements of major operational programs.

The NRC report cited rocket propulsion development as the most serious area of deficiency in the space technology base, followed by technologies supporting piloted space flight. Power, materials, and structures are next in priority with information systems, followed close behind by sensors. The report argues that the minimum funding to help improve the level of space technology would require a $530 million annual increase over the $171 million 1987 research and technology budget. The NRC's preferred program would call for a total annual increase of $970 million per year.[3] This recommended funding, which does not include NASA personne! costs, is shown in figure 6-3.

NASA

NASA has recognized the need to revitalize its technology base, and in 1987 began a $773.1 million, five-year civilian Space Technology initiative (CSTI) which has the goals of "revitalizing the Nation's civil space technology capabilities and enabling more efficient, reliable, and less costly space transportation and Earth orbit operations."[4] The CSTI consists of 10 categories of hardware development, leading to demonstrations of actual hardware. CSTI is organized into six programs within NASA'S Office of Aeronautics and Space Technology. This effort is meant to reverse NASA's traditional process of using specific projects to

3 Ibid.
4 NASA Office of Aeronautics and Space Technology, "CSTI Overview," April 1988.

Table 6-1.–NASA's FY89 Funding Request for the Civilian Space Technology Initiative

Propulsion	$46.7M
. Earth to orbit	
. Booster technology	
Vehicle Development	$28.OM
● Aeroassist flight experiment	
Automation and Robotics	$25.9M
. Robotics	
. Autonomous systems	
Large Structures and Control	$25.lM
. Control of flexible structures	
. Precision segmented reflectors	
Information Technology	$17.1M
. Science sensor technology	
● Data: high rate/capacity	
Power	$14.0M
. High capacity power	
Total:	$156.8M (FY88$)

SOURCE: NASA

generate new technology. Instead of using individual high-risk projects to develop the technology needed to support specific missions, NASA now wants to first develop new generic technologies from which it can pursue rejects having lower cost and technical risk[5]

About $115 million was approved in fiscal year 1988 for this effort. An additional $156.8 million has been requested for fiscal year 1989, broken down into the six major areas (table 6-l). This requested CSTI funding would increase the share of the NASA budget going to research and technology from two percent to 2.6 percent.

Table 6-2.–**NASA's FY89 Funding Request for the Pathfinder Program**

Operations Technology	**$41M**
. Rendezvous and docking	
. Resource processing pilot plant	
. In-space assembly and construction	
● Cryogenic fluid depot	
● Space nuclear power	
Exploration Technology	$17M
. Planetary rover	
● Surface power	
● Optical communications	
● Sample acquisition, analysis, and preservation	
Mission Studies	$15M
Transfer Vehicle Technology	$14M
. Chemical transfer propulsion	
● Cargo vehicle propulsion	
● High energy aerobraking	
● Autonomous lander	
. Fault-tolerant systems	
Humans-in-space Technology	$13M
. Extravehicular activity/suit	
. Human performance	
. Closed-loop life support	
Total:	$100M (FY88$)

SOURCE: NASA

NASA's technology development generally emphasizes human flight. In the fiscal year 1989 budget, NASA is also requesting $100 million to begin the new Pathfinder program,[6] which will develop technology for possible future piloted lunar and Mars missions (table 6-2). When CSTI and Pathfinder funding are combined, NASA's budget request represents $256.8 million in new technology funding, or 2.25 percent of a greatly increased NASA budget request.[7]

5 "NASA Will Begin $1.7 Billion Program to Revitalize Space Technology Base," Aviation Week and Space Technology, Nov. 9, 1987, p. 28.

6 National Aeronautics and Space Administration, Office of Aeronautics and Space Technology, "Project Pathfinder, Technology Benefits Assessment," (Washington, DC: National Aeronautics and Space Administration, November 1987).

7 NASA's proposed $11.48 billion in the fiscal year 1989 budget is a $2.46 billion increase over 1987. However, NASA's actual FY 1989 budget is anticipated to be on the order of $10.7 billion. This would probably cause concomitant budget reductions in the technology base programs.

Table 6-3.– ALS-Focused Technology Development Projects

Project[a]	Task	Applicability	Annual Cost (FY88$)
1 LOX/LH2 Engine	Complete Test/Validation Program	ELVs & STS	$17.6M
2 Propulsion Facilities	Modify Existing Test Facilities	ELVs & STS	$24.0M
3 Expendable Cryogenic Tank	Test Demonstration Tank	ELVs	$12.0M
4 Adaptive Guidance, Navigation & Control	Demonstrate Hardware/Software Integration	ELVs	$ 6.1M
5 ManTech (mfg. technology)	Full-Scale Demonstration	ELVs	$4.5M
6 Engine Definition	Preliminary Design of STME and STBE	ELVs & STS	$12.0M
7 Health Monitoring Demo	Demonstrate Integrated Technology	STS	$4.0M
8 Electromechanical Actuators	Prototype Definition	ELVs & STS	$5.5M
9 Ground Ops	Demonstrate Technologies	ELVs & STS	$15.1M
10 Solid Rocket Booster	Complete Test/Validation Program	ELVs & STS	$ 7.0M
11 NDE for SRB	Technology Demonstration	ELVs & STS	$ 1.0M
12 Precision Recovery	Advanced Controls Demonstration	ELVs	$ 2.5M
13 LOX/LHC Engine	Complete Test/Validation Program	ELVs	$32.9M
14 Booster Structures	Fabricate Demo Article	ELVs	$ 3.0M
15 Propulsion Subsystems	Test Prototypes	ELVs	$ 0.5M
16 Reusable Cryogenic Tank	Reflight Certification Program	ELVs & STS	$ 2.0M
17 Structural Certification	Complete Static and Dynamic Tests	ELVs	$ 8.0M
18 Flight Simulation Lab	Proof-of-Concept Demonstration	STS	$ 2.0M
19 Multi-Path Redund. Avionics	Test and Evaluation Definition	ELVs	$10.3M
20 Expert Systems	Ground Based Laboratory Demonstration	ELVs	$ 3.5M
21 Multi-Body Ascent CFD	Adaptive-Grid Code	STS	$ 0.5M
22 Aero Data Base	Advanced Code	STS	$ 0.5M
23 Base Heating Codes	Flowfield Models	ELVs	$ 0.5M
		Total:	$175.0M

[a]Ranked by ALS Program Office.
ELV: Expendable Launch Vehicle.
STS: Space Transportation System (Shuttle and support systems).

SOURCE: USAF and NASA, ALS Focused Technology Program, Revision A, Mar. 1, 1988.

Table 6-4. – ALS-Focused Technology Program Funding Requested

Year	Annual Funding
1989	$155 M
1990	$210 M
1991	$173 M
1992	$127 M

Air Force

The most significant Air Force attempt to improve the technology base is the Focused Technology Program which is an integrated DoD/NASA effort funded within the ALS program. The intent of the Focused Technology Program is to highlight the technologies most relevant to ALS development. Table 6-3 lists technology development projects now in progress, showing their application to

ELVs, the Shuttle, or both. They are ranked in order of their importance to the ALS program, as assessed by the ALS program office. Table 6-4 shows anticipated annual funding requests for the ALS Focused Technology Program. Funding for each technology element is split between the Air Force and NASA budgets, with the percentage varying.

Space Transportation Architecture Study (STAS)

Perhaps the most comprehensive data available on the state of the Nation's space transportation technology base is contained in the STAS documents. The STAS effort first identified technologies that might be available by the mid- 1990s and then matched the technologies with types of launch vehicles they would benefit. It developed a plan for investing in both generic and specific technologies designed "to achieve low operations cost, robustness, flexibility, and world leadership in space transportation."[8] The STAS technology plans contain recommended funding levels, milestones, system payoffs, and technology goals. The program would cost $5 to $6 billion over 10 years, with $3 to $4 billion required for the first 5 years.

National Commission on Space

The National Commission on Space stated that a space research and technology program should properly be conceived as generating future opportunities, not directed to specific applications. It did, however, emphasize some specific areas of space technology that would support the broad agenda of the National Commission on Space. These include technologies for:

- space science (e.g. sensors, propulsion);
- piloted spacecraft (e.g. life support, expert systems);
- nuclear space power (e.g. radioisotope thermoelectric generators, multi-megawatt reactors);
- space transportation (e.g. Earth-to-orbit and electric propulsion); and
- space industry (e.g. communications, remote sensing, space manufacturing).

The Commission also observed that NASA's annual funding of space research and technology fell from a high of about $900 million (constant 1986 dollars) in the mid-1960s to less than $200 million annually since the mid-1970s. The Commission recommended a tripling of NASA's technology budget from 2 percent to 6 percent of NASA's total budget, about where it was during the Apollo era.[9] Based on OMB projections of NASA's budget, over 10 years at about $10 billion per year, this amounts to a recommendation for tripling space technology funding from about $2 to $6 billion over the 10-year period.

SUMMARY

Many Government and aerospace industry officials have expressed dissatisfaction with the current space transportation technology base. Although OTA has not carried out an independent assessment of the Nation's technology requirements for space transportation, clearly many launch systems explored in this special report would require advances in

8 U.S. Department of Defense and National Aeronautics and Space Administration, Joint Steering Group, National Space Transportation and Support Study, Summary Report, May 1986, p. 22.

9 U.S. National Commission on Pioneering the Space Frontier, (New York: Bantam Books, May 1986), pp. 95-106.

several technical disciplines, including propulsion, materials, and automated manufacturing and checkout.

As the Nation's plans for advanced space transportation research mature, it will be extremely important to maintain a balance between focused technology efforts directed towards specific applications and more long range basic research and development. Although focused research may provide important near-term results, basic research and development can provide the broad technology base that allows the Nation to capitalize on future technological opportunities, some of which are likely to be unknown today.