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**Maintaining Technical  
Excellence Requires  
a National Plan**

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# MAINTAINING TECHNICAL EXCELLENCE REQUIRES A NATIONAL PLAN

by T. F. Davidson

*"Where there is no vision, the people perish." (Proverbs 29:18)*

Rocket propulsion is the cornerstone of every space transportation system. Since the late 1950s, the United States has been the undisputed world rocket propulsion leader. However, the technical excellence and technology base that earned us such a reputation have been eroding. Foreign competition now threatens to overtake this country early in the next century.

In the 21st century, rocket propulsion will become an increasingly important part of international trade. Without a change in national policy and a commitment to a strong, continuing, broad-based rocket propulsion technology program, the United States' position will continue to erode, possibly to a point of no return. Without a commitment to technical excellence we will fail!

### The Global Picture

- National position eroding
- Foreign competition increasing
- National technology imperative needed
- National commitment needed
- Commitment to technical excellence needed
- National plan needed

This was the picture visualized by the Aerospace Industries Association (AIA) in 1987, and this is why it selected rocket propulsion as one of their 10 key technologies for the year 2000 (Figure 1).

<b>ROCKET PROPULSION SYSTEMS</b>
<b>Advanced composites</b>
<b>Advanced sensors</b>
<b>Air-breathing propulsion systems</b>
<b>Artificial intelligence</b>
<b>Computational science</b>
<b>Optical information processing</b>
<b>Software development</b>
<b>Superconductivity</b>
<b>Ultrareliable electronic systems</b>

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Figure 1. AIA Key Technologies for the 1990s

To meet the challenge, AIA established a rocket propulsion committee (which I had the privilege of chairing until my retirement earlier this year) to develop the *National Rocket Propulsion Strategic Plan*. Developing such a plan required a broad spectrum of experience and disciplines. The *Strategic Plan* team needed the participation of industry, Government and academia. The list below tends to understate the number of participating organizations, since in many cases multiple divisions and centers participated.

### **The Strategic Plan Team**

<b>Industry</b>	<b>Government</b>
Aerojet	Department of Defense
The Aerospace Corporation	Department of Energy
Aerospace Industries Association	NASA
Atlantic Research	U.S. Air Force
Boeing Company	U.S. Army
General Dynamics Corporation	U.S. Navy
Hercules Inc.	
LTV Corporation	<b>Academia</b>
The Marquardt Company	Brigham Young University
Martin Marietta Corporation	California Institute of Technology
Rockwell International Corporation	Georgia Institute of Technology
Science Applications International Corp.	Pennsylvania State University
Sverdrup Technology	Purdue University
Thiokol Corporation	University of Akron
TRW, Inc.	University of Alabama
United Technologies Corporation	University of Delaware
Wyle Laboratories	University of Illinois
	University of Texas

Six NASA organizations participated in developing and commenting on *Strategic Plan* drafts:

- NASA Headquarters
- Langley Research Center
- Lewis Research Center
- Marshall Space Flight Center
- Stennis Space Center
- Jet Propulsion Laboratory

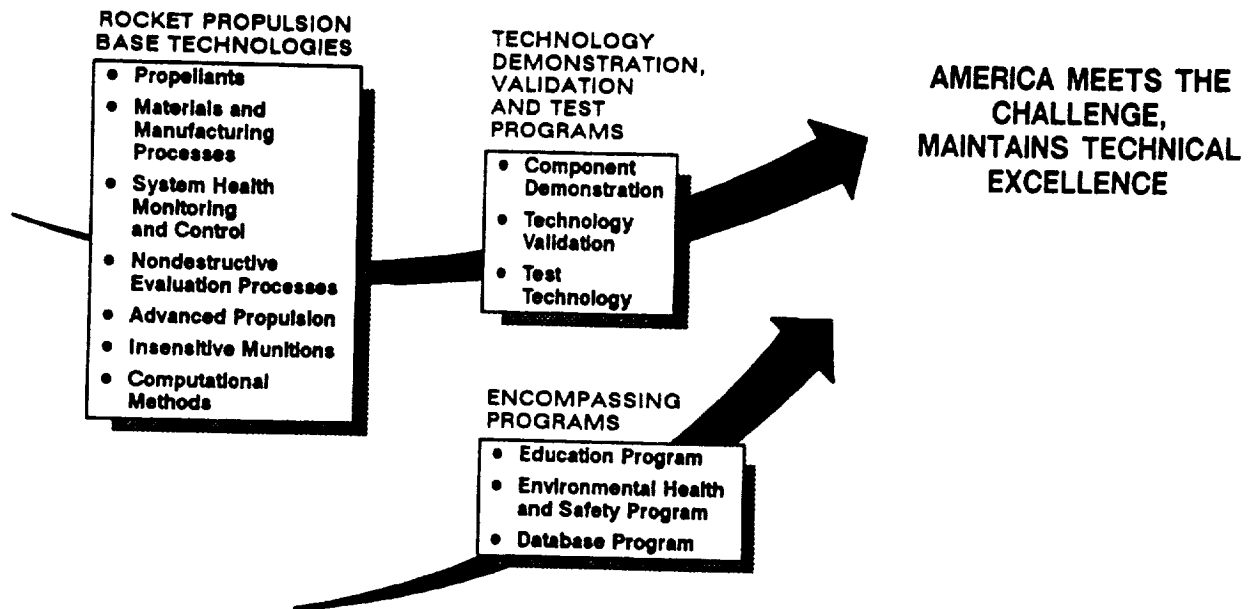
All told, from March 1988 to the present, over 50 organizations and 200 people have participated in developing the *Strategic Plan*. Such participation was necessary to ensure a national consensus. It took basically two years, 10 meetings and a great deal of dedicated, hard work to reach a plan draft that was ready for comprehensive, detailed independent review. The review was accomplished in two phases. In the first phase (October 1989), draft copies of the plan were sent to 137 organizations for review and comment. These included industry, Government and university organizations, as well as selected AIA and American Institute of Aeronautics and Astronautics (AIAA) technical committees. The October review yielded some 250 pages of comments. In the second phase, a symposium was held in Washington on 15 February to brief the plan. The symposium was sponsored by the National Center for Advanced Technologies (NCAT), a nonprofit educational foundation established by AIA to coordinate and integrate its Key Technologies effort. Two hundred attendees participated in the symposium. They were briefed, given copies of a revised plan draft and invited to submit their comments to NCAT for incorporation into the final plan. At the symposium, 60 questions were raised, recorded and answered in writing.

### Plan Chronology

- Team generates plan 1988-1989
- First independent review October 1989
- NCAT symposium February 1990
- Second independent review March 1990
- Issue plan July 1990

The plan was redrafted in May and will be distributed in July. The plan provides, if followed, a means for the U.S. to maintain technical excellence and world leadership in rocket propulsion. To implement the *National Rocket Propulsion Strategic Plan* is to invest in the social, economic and technological futures of America. It is the way to maintain **TECHNICAL EXCELLENCE** in rocket propulsion (Figure 2).

The *National Rocket Propulsion Strategic Plan* is a roadmap of technologies and strategies designed to maintain America's technical excellence and global competitive posture.



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Figure 2. The Plan

I encourage you to read the plan.\* In my opinion, this plan represents a national consensus of what needs to be done to maintain technical excellence in the 21st century. I would like to take this opportunity to express my appreciation to the over 200 people who helped prepare the plan and the approximately 600 people who reviewed it.

\* Distribution is authorized only to U.S. Government agencies and their contractors. Attendees at the February 1990 symposium will automatically receive copies. Additional copies (\$100 each/\$50 for universities and libraries) may be obtained by contacting Mr. R. H. Hartke, National Center for Advanced Technologies, 1250 Eye Street N.W., Washington, D.C. 20005

The following is a synopsis of the *Strategic Plan's* major parts:

- The challenge
- Base technology programs
- Technology demonstration, validation and test programs
- Encompassing programs
- Implementation

The executive summary presents the basic challenge and explains why maintaining rocket propulsion leadership must be a national technology imperative, the theme of the February NCAT symposium. The *Strategic Plan* lays the basis for upgrading existing propulsion systems and a firm base for future full-scale development, production and operation of rocket propulsion systems for space, defense and commercial applications.

The challenge simply stated is: National supremacy is fading, foreign competition is real and increasing, current full-scale development cycles take too long and cost too much and technology support has been declining.

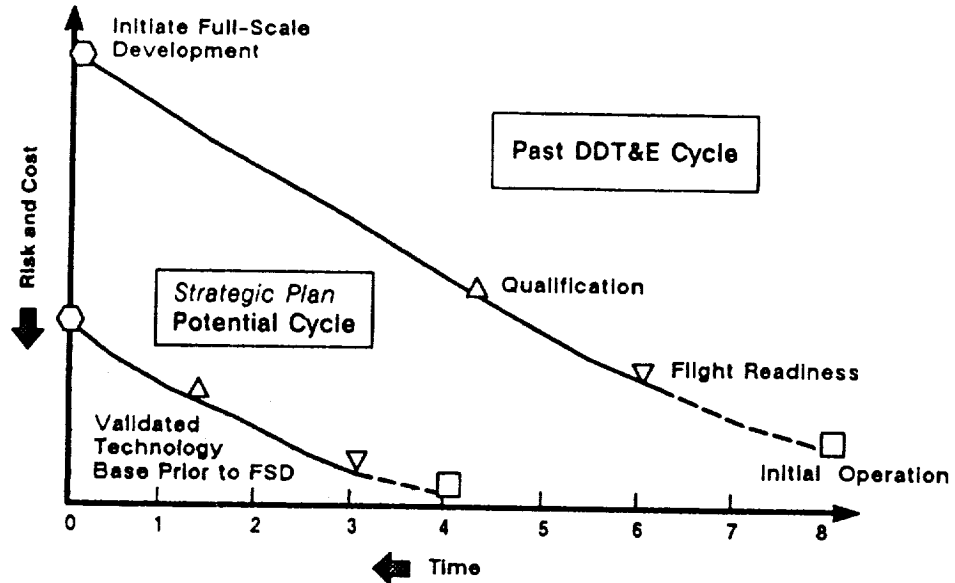
Table 1 shows the growth of foreign competition and capability since 1968. In many areas of both liquid and solid rocket propulsion technology, foreign competition has already overtaken the United States. Four examples come to mind: 1) the French are ahead of us in carbon/carbon composites and a basic understanding of electrostatic discharge, 2) the British are ahead on plume tailoring fundamentals and 3) the Japanese are ahead in the use of ceramic bearings. The National Science Foundation's (NSF) evaluation of Japanese liquid rocket technology and plans last fall left little doubt that Japan intends to have a completely autonomous rocket and launch capability by the end of this decade.

**Table 1. The Reality of Foreign Competition**

	1968		1990	
	Liquid	Solid	Liquid	Solid
1. Argentina				X
2. Australia				X
3. Brazil				X
4. Canada		X		X
5. China			X	X
6. Egypt				X
7. France	X	X	X	X
8. Great Britain	X	X	X	X
9. Greece				X
10. India			X	X
11. Israel				X
12. Italy			X	X
13. Japan	X	X	X	X
14. Norway				X
15. South Africa				X
16. South Korea				X
17. Sweden				X
18. Switzerland				X
19. Taiwan				X
20. Turkey				X
21. U.S.S.R.	X	X	X	X
22. West Germany	X		X	X
23. Yugoslavia				X
<b>Total</b>	<b>5</b>	<b>5</b>	<b>8</b>	<b>23</b>

X—Viable foreign competition

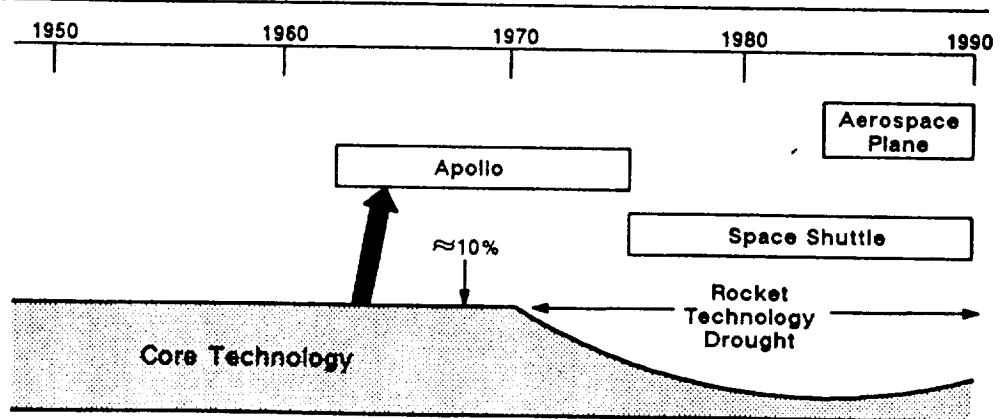
Figure 3 shows a typical development schedule for a new propulsion system over the last 20 years and what the key goals of the plan are: increased reliability, lower risk, shorter time and less costly development.



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Figure 3. A Strong Technology Base Will Reduce Risk, Cost and Schedule

During the 1950s and 1960s, technology support, as a percent of total rocket propulsion expenditures, averaged approximately 10 percent. The results of such technology investment were applied to many propulsion systems, e.g., Scout, Apollo and Space Transportation System (STS). In the early 1970s, technology support declined rapidly and has never regained the position it enjoyed earlier. We have coined this era the Rocket Technology Drought (Figure 4). The drought, which applies equally to all Department of Defense (DoD) systems, was a contributor to several space propulsion failures.



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Figure 4. The Technology Drought

In the 1990s and beyond, reliability, safety (which includes health and environmental concerns) and cost reduction must be accepted as technical goals on the same basis as performance goals have been in the past. Rocket propulsion must be a national technology imperative. Figure 5 sums up the problem, the challenge and the solution.

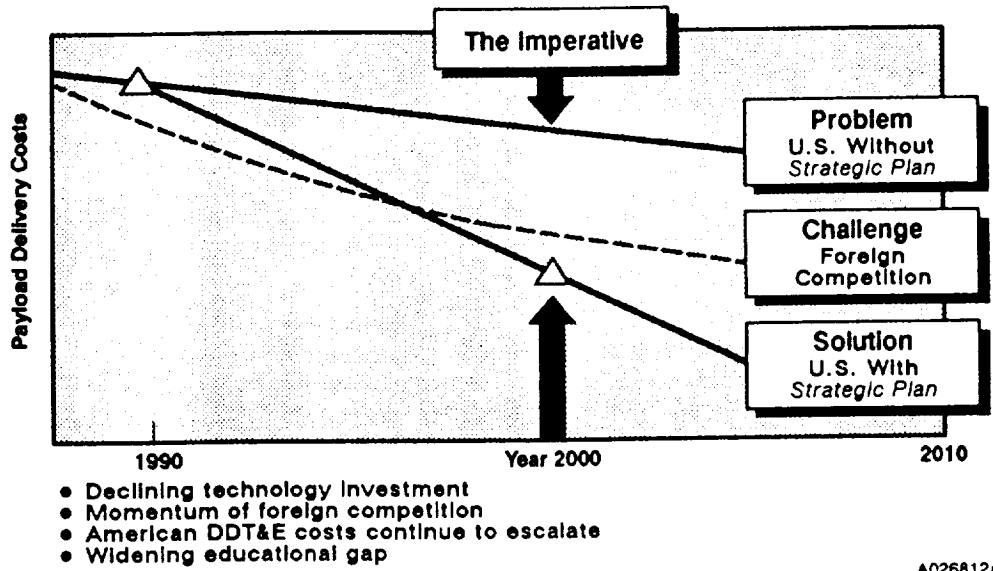
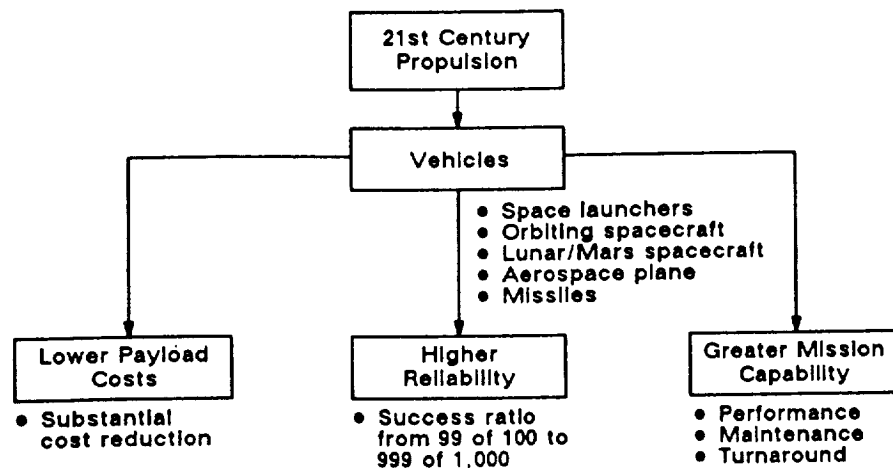


Figure 5. Why an Imperative?

The basic technology improvement areas are shown in Figure 6. The *Strategic Plan* was developed to support perceived military and space objectives and schedules. Space objectives through the year 2020 are shown in Figure 7. Rocket propulsion technology must be developed and validated during the 1990s to support future needs because of the severe environments that are unique to propulsion technology.

**Why Propulsion Technologies Must Be Developed Early**

- Propulsion systems have the most severe:
  - Forces
  - Pressures
  - Temperatures
  - Heat fluxes
  - Material environments
  - Energy densities
  - Vibration levels
- 21st century improvements, therefore, must start in the 1990s



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Figure 6. Improvements Are Needed for U.S. Aerospace Competitiveness

National Objectives		1990	1995	2000	2005	2010	2015	2020
Chemical Propulsion as Primary System	Space Station Freedom			▲				
	Advanced Launch System				▲			
	Advanced Orbit Transfer Propulsion (LEO to GEO)				▲			
	Robotic Mars Mission						▲	
	Manned Lunar Station						▲	
	Manned Mars Mission (chemical and nuclear rocket propulsion)							▲
Chemical Propulsion as Supporting System	NASP (air-breathing and rocket propulsion)				▲			
	Hypersonic Transport (air-breathing and rocket propulsion)						▲	

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Figure 7. The Plan Supports Future National Space Objectives

Figure 8 charts the technical sections and basic phases of the plan. Under Base Technologies, objectives, overall approach, schedule and costs have been defined for chemical rocket propulsion (solid rocket, liquid rocket, hybrid rocket and advanced concepts) in the following areas, which encompass 258 individual programs:

- Propellants
- Materials and manufacturing processes
- Health monitoring and control
- Nondestructive evaluation
- Computational methods
- Insensitive munitions
- Advanced propulsion concepts

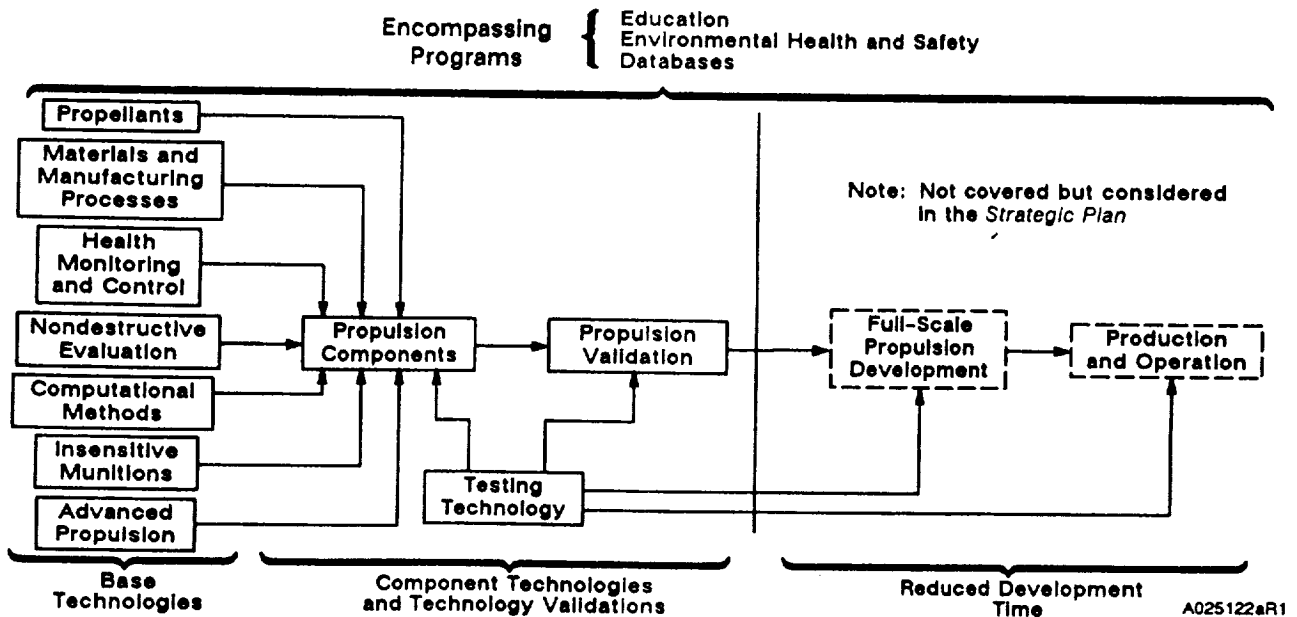
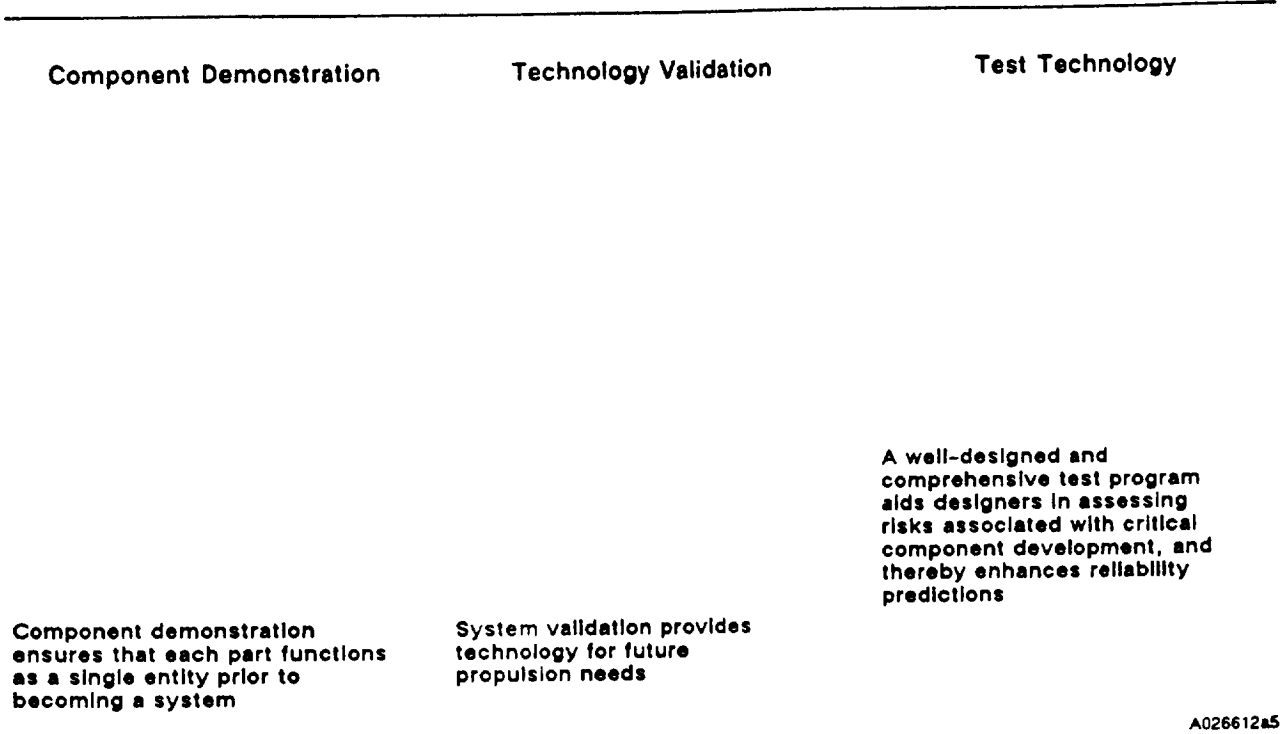


Figure 8. The Plan Addresses the Key Areas in Rocket Propulsion Technology



Base technology will flow into propulsion component development and demonstration, then into the prototype system validation phase, as illustrated in Figure 9. There is also a need to first develop, then validate new testing techniques, instrumentation, diagnostic approaches and automated expert test data analysis systems.



**Figure 9. Technology Validation Process**

The third area covered in the plan comprises Encompassing Programs. Encompassing programs are needed to ensure technical excellence. They fall into three categories:

- Databases
- Environmental health and safety
- Education

Only those programs needed to support rocket propulsion technology are presented, but in most cases these should fit into required larger, across-the-board national efforts.

Accurate storage, retrieval and rapid dispersion of data, as shown below, are essential for the future of rocket propulsion technology.

**Database Elements**

**Database Management**

Select and specify hardware and software for centralized data management and maintenance

**Materials Properties**

Provide standardized material properties for use in probabilistic design techniques

**Design/Processing**

Maintain documentation of analytical methods and lessons learned. Databases will affect the formulation of industry-wide standards

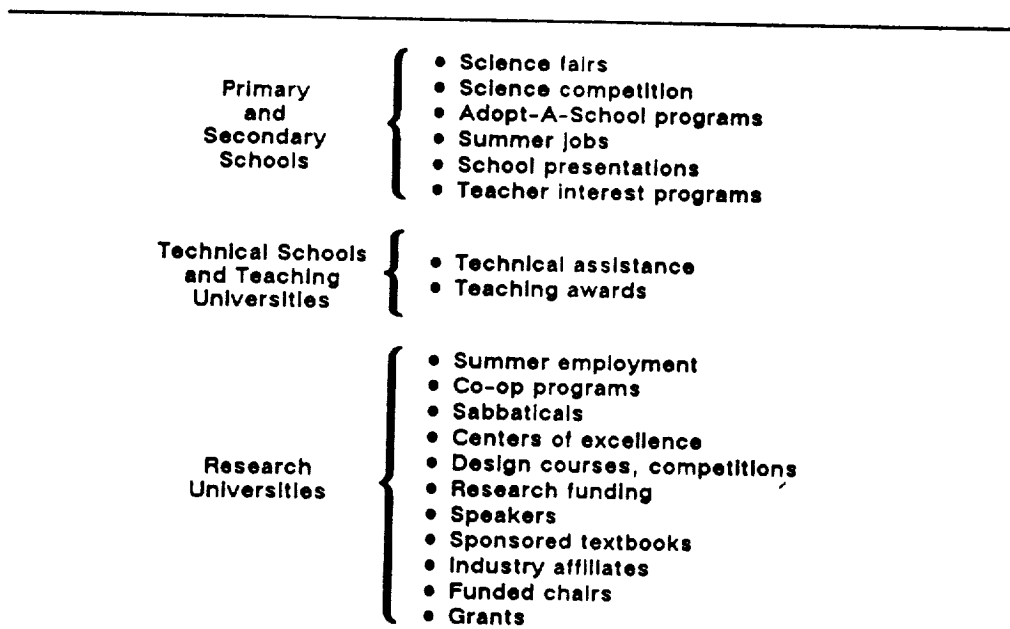
Environmental health and safety (EHS) impacts must be considered and minimized in all future propulsion efforts. Industry-wide standards for risk assessment and management of design and process characteristics that address human health and preservation of the environment must be developed.

- Establish aerospace safety and environmental center
- Create environmental working group
- Identify new hazards and failure prediction and detection technologies
- Improve computer simulation and modeling techniques

An area of increasing concern, education is a prerequisite for the U.S. to maintain technical excellence and global competitiveness. The problem is summarized below:

- Education
- Aerospace needs and industry will grow in 21st century
- U.S. rocket scientists and engineers retiring
- Must attract students to technical fields
- Must train students for technical fields
- Rocket community must do its share

Figure 10 illustrates the types of programs we think necessary. Efforts such as those currently being undertaken at the Penn State Space Propulsion Engineering Research Center are an excellent example of what needs to be done. These should be expanded whenever feasible.

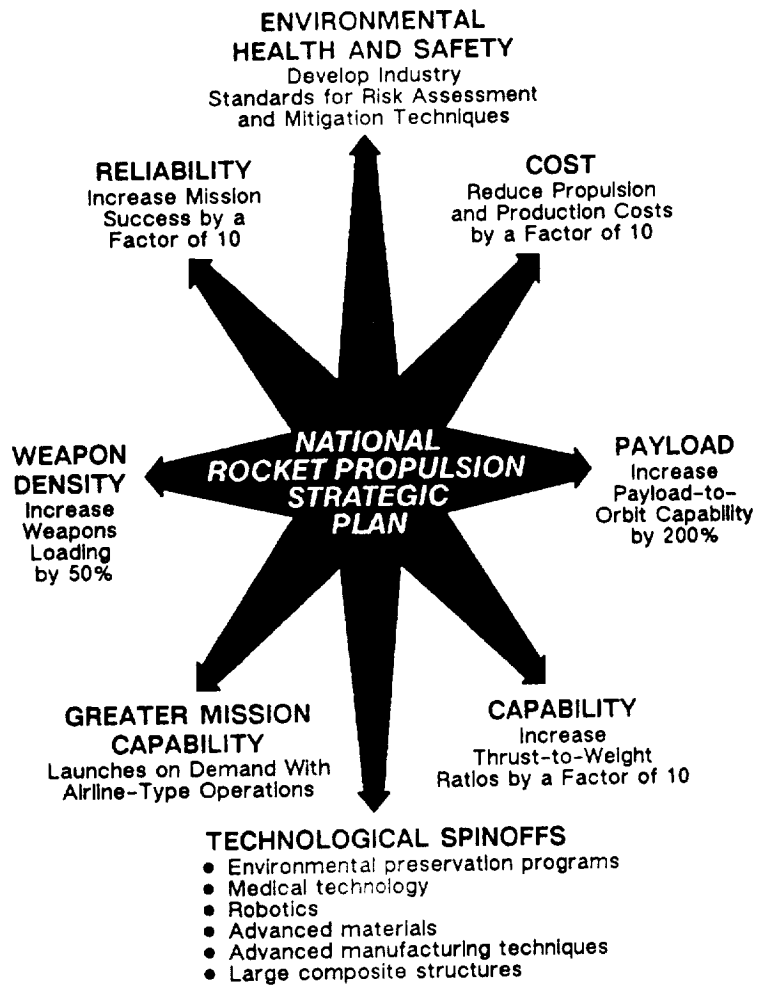


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**Figure 10. Education Programs**

If implemented, the plan will provide a host of technical payoffs to the country, some of which are shown in Figure 11.

The 303 programs detailed in the plan will cost approximately \$5.3 billion (a significant financial investment) over the next 10 years (Table 2).



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**Figure 11. Technical Payoffs**

**Table 2. Program Summary**

	Cost of Programs (\$M)	Number of Programs
Propellants	538.20	60
Materials and Manufacturing Processes	561.20	63
Computational Methods	275.40	32
Health Monitoring and Control	125.00	14
Nondestructive Evaluation	144.00	10
Insensitive Munitions	159.10	17
Environmental Health and Safety	145.30	7
Liquid Rocket Components	325.00	27
Solid Rocket Components	273.70	18
Advanced Propulsion Concepts	457.50	10
Test Technology	333.50	11
Propulsion Validations	1,821.00	23
Databases	106.60	11
Total	5,265.90	303
Education		19

On an average annual basis (\$527 million/year), this represents an increase of 160 percent over FY89 levels (\$202 million estimated). Such an increase will require a national commitment and "ramp up" of approximately 18 percent per year from FY89 year levels through the mid-1990s. Of the total funding, approximately 30 percent should come from industry (IR&D, capital expenditures, etc.) and the remainder from the Government (DoD and NASA).

Figures 12, 13, and 14 present projected annual costs, benefit distribution by mission (including DoD) and benefit distribution by end item user, respectively.

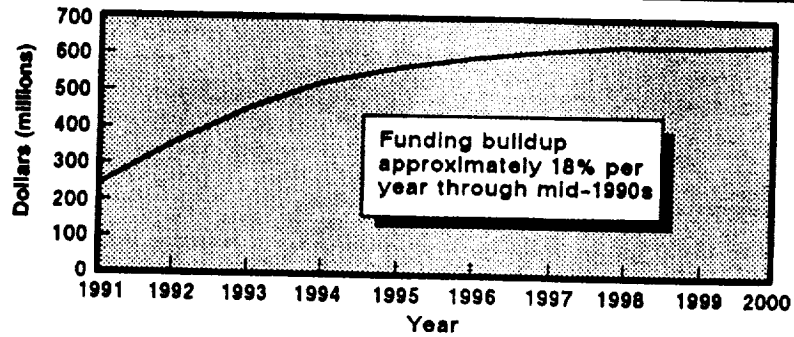
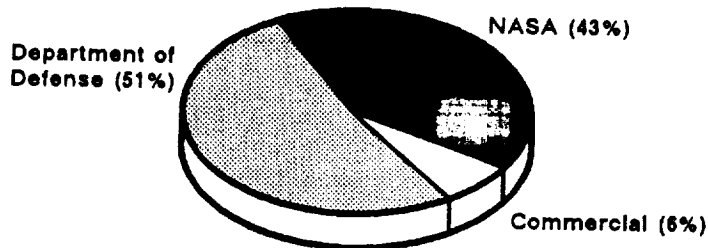
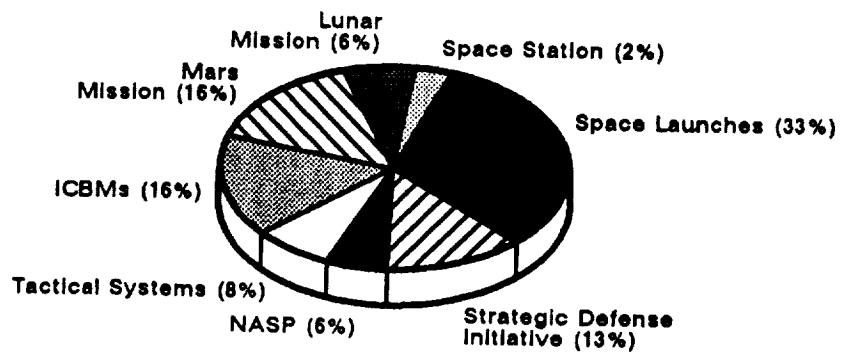


Figure 12. Projected Annual Costs



Each sector will benefit directly as the objectives of the Strategic Plan are met.

Figure 13. Benefit Distribution



Developed technologies will coincide with national goals.

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Figure 14. Benefits by Mission (Including Department of Defense)

Such a national financial commitment cannot be short term. It must be renewed and sustained into the next century to meet future space and defense rocket propulsion needs (Figure 15).

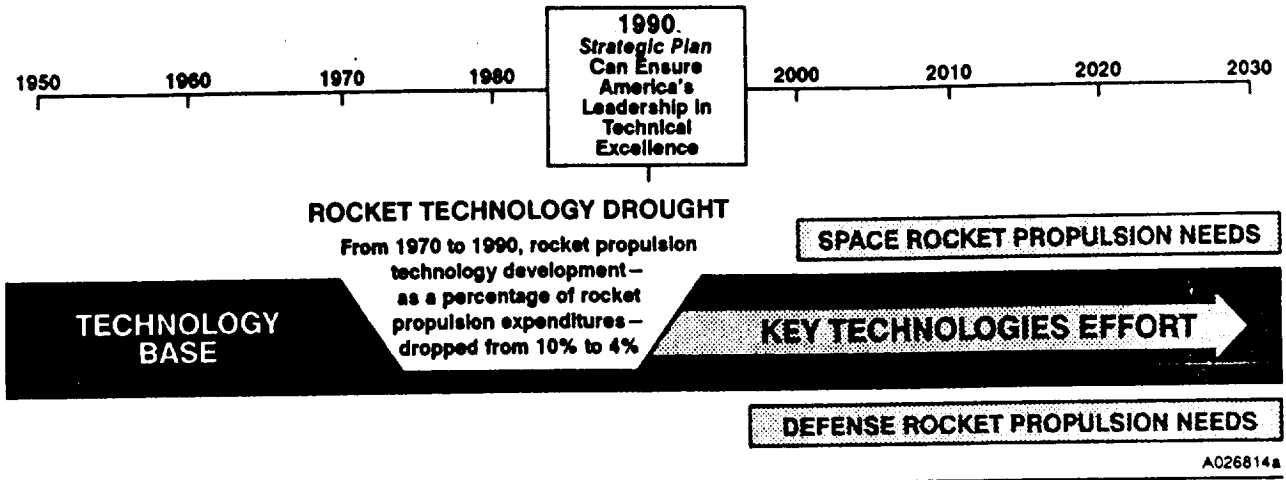


Figure 15. The Technology Drought

The *Strategic Plan* has a great deal of national leverage. When implemented it will power America into the future, as illustrated in Figure 16. To maintain technical excellence and global competitiveness, we must adopt the conclusion of the AIA Rocket Propulsion Committee and the planning team—PROPULSION TECHNOLOGY ISN'T EXPENSIVE: IT'S PRICELESS.

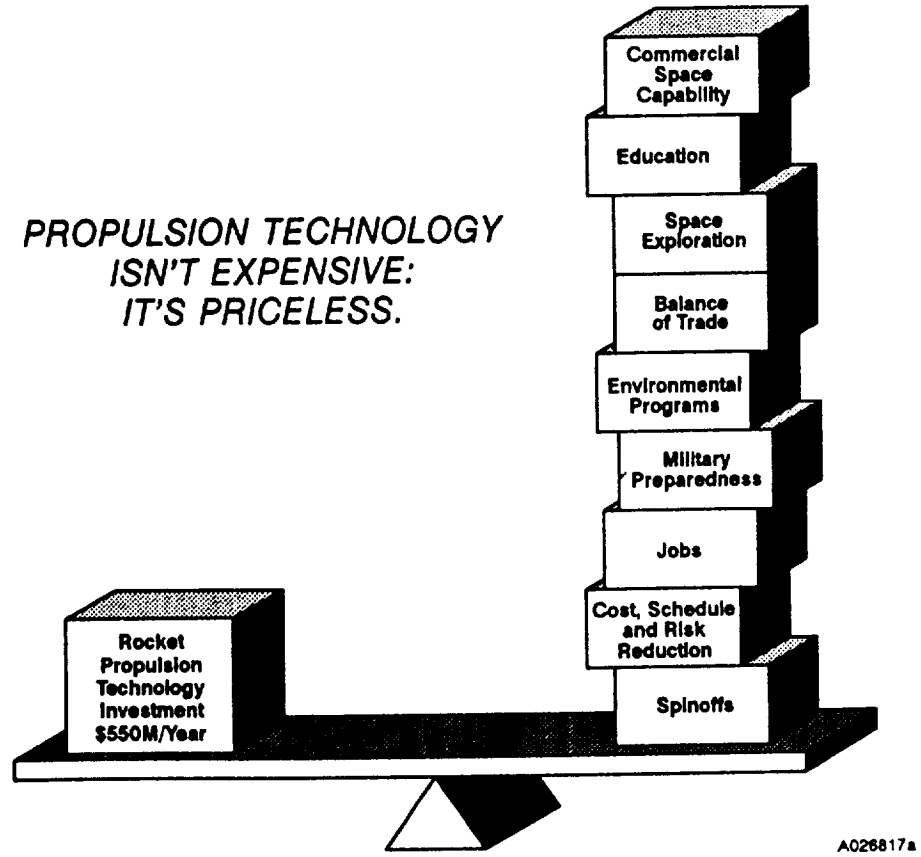


Figure 16. National Benefits

How can the plan be implemented? First, it will take unprecedented cooperation within the rocket community. Generating the plan has shown that it can be done. Second, the plan must be sold to decision makers in Congress, Government and industry. Starting last month and continuing through the summer, AIA has been briefing the *Strategic Plan* to Congressional and Government decision makers. Third, Government, industry and academia organizations must use the *Strategic Plan* as a basis, as applicable, for their own plans. Fourth, a mechanism must be established to coordinate industry, Government and university plans with the AIA *Strategic Plan*. A possible approach could be to use the JANNAF Executive Committee with industry participation.

Today rocket propulsion and technical excellence are at a crossroads. The comparison of our current position with that of the steel industry in the 1960s is frightening (Table 3). Rocket propulsion must not suffer the same fate as the steel industry.

**Table 3. The Nation Is at a Rocket Propulsion Crossroads**

	1960 Steel Industry	1990 Rocket Industry
Aging Work Force	X	X
Aging Facilities	X	X
Declining Technological Base	X	X

The implementation of the *Strategic Plan* will require:

- Rocket community cooperation
- Decision maker participation
- Inclusion in organization plans
- National coordination mechanism

Rocket propulsion must be a NATIONAL TECHNOLOGY IMPERATIVE. The time to act is now. The choice is decline or progress! For the first time, we now have a national rocket propulsion strategy. It needs your support and commitment. I am reminded of a quotation from C. J. Grayson's *Productivity, A New Scenario* that applies to rocket propulsion, technical excellence and global competitiveness:

*"The crisis is real. For any leader, the time to worry is when your speed is slower than the horses coming up behind. The time to worry is not after but before they pass you by."*

**OPERATIONAL EFFICIENCY -  
NEW APPROACHES TO FUTURE  
PROPULSION SYSTEMS**

