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Overview of the Space Propulsion Synergy Group (SPSG) Strategic Planning Support Efforts for Earth to Orbit Transportation

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OVERVIEW OF THE SPACE PROPULSION SYNERGY GROUP (SPSG) STRATEGIC PLANNING SUPPORT EFFORTS FOR EARTH TO ORBIT TRANSPORTATION

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Abstract

Although the current national space transportation infrastructure, including the Space Shuttle and expendable launch vehicles may meet most of the requirements for total mass to orbit for the remainder of this decade, and possibly somewhat beyond; it does not provide the safe, affordable, routine access to space that is absolutely essential to a successful space program. Also, the current transportation infrastructure falls far short of the heavy lift capability that will be required in any future (next two to three decades) national space exploration mission and possibly other national mission requirements. Therefore, it is imperative that a high national priority be assigned for planning a strategy for the evolutionary, and if need be, the revolutionary development of a space transportation infrastructure to satisfy all of these capabilities and attributes. A nationally accepted strategic plan for space transportation and propulsion would also enable a focused research and development program to meet the international challenge, and to remain competitive with limited national resources.

In view of this National need situation, the focus of a unique national organization known as the Space Propulsion Synergy Group (SPSG) has been directed for the past two years toward supporting strategic planning for earth to orbit space transportation and propulsion systems. The SPSG involves personnel from NASA Centers as well as other government agencies (DOD and DOE), industry and academia. From the beginning, it was recognized that a nationally represented organization was required because most of the space propulsion needs and challenges existed on a national level.

This paper presents a general description and highlights the approach the SPSG followed in their space transportation and propulsion systems strategic planning support activities. The process used in this study and analysis was a classic "top down" approach which attempted to be fully responsive to the stated national space transportation policies and space missions. It also attempted to make maximum use of the results of past studies and analyses.

A critical new element introduced into the process utilized was an emphasis on the identification of the transportation systems users/customers and the characteristics or attributes most valued by them in earth to LEO payload transportation services. After some false starts, the SPSG team decided that a process known as Quality Function Deployment (QFD) was needed to ensure that the customer/user real requirements and needs were properly addressed, and that the transportation system concepts advocated, including vehicles and propulsion systems, had the greatest probability of satisfying the customer's requirements and desired attributes. This was a fortunate decision as an innovative application of the QFD process has proven to be very effective in meeting the objectives of these SPSG activities. However, it is beyond the scope of this paper to describe how the QFD process was successfully applied and the results achieved with the process *.

A National Need and Challenge

For several years there has existed within the aerospace community a widely recognized need for vastly improved national space launch (earth to orbit) transportation system(s). The ability of this nation to fulfill its stated roles and initiatives in space is directly coupled to the availability of an operational transportation infrastructure that provides safe, affordable, and routine access to and from space. Underlying this need is an even more basic need, although probably not as well recognized, for a national strategy and plan for defining, and developing a space launch system which will provide the required capabilities and attributes.

Although the current national space transportation infrastructure, including the Space Shuttle and expendable launch vehicles may meet most of the requirements for total mass to orbit for the remainder of this decade, and possibly somewhat beyond; it does not provide the safe, affordable, routine access to space that is absolutely essential to a successful space program. Also, the current transportation infrastructure falls far short of the heavy lift capability that will be required in any future (next two to three decades) national space exploration mission and possibly for other national mission requirements. Therefore, it is imperative that a high national priority be assigned for planning a strategy for the evolutionary, and if need be, the revolutionary development of a space transportation infrastructure to satisfy all of these capabilities and at-

* The reader is referred to AIAA-93-1852, "Payoffs of Applying QFD Techniques to the SPSG Strategic Planning Support Effort for ETO Transportation and Propulsion Systems" by Jim Bray of Martin Marietta Corporation

tributes. A nationally accepted strategic plan for space transportation would also enable a focused research and development program to meet the international challenge and remain competitive with limited national resources.

It is also widely understood that space vehicles with the capabilities required by the space transportation infrastructure are completely dependent on the availability of propulsion systems which are able to satisfy all of the space vehicle performance requirements and desired attributes. Therefore, it is equally imperative that the propulsion systems capabilities and characteristics required by the space vehicles be thoroughly researched and understood; and a strategic plan outlined for their development and acquisition.

While the imperative need for a greatly improved transportation system, including the propulsion system, has been expressed and studied by both government and industrial organizations, as well as several national committees, the potential general solutions that evolved have not achieved national consensus nor have they endured. Notable among the national studies were the following:

Initiated By:	Documented In:
Request by US Congress to The National Research Council	"From Earth to Orbit" (An assessment of Transportation Options)
Request of The National Space Council	"Future of the US Space Program" - 1991
Request of The National Space Council	"America at the Threshold" - 1991

In addition there has been a considerable amount of time and monies expended in search of the specific best solution, i.e.,vehicle and propulsion system concepts, to meet the need for a substantially improved national space transportation infrastructure. Some of the principle efforts that have been undertaken by NASA, DOD or both to identify a specific best solution in the past few years are:

- The Space Transportation Architectures Study (STAS)
- The National Launch System (NLS) program
- The Manned Transportation Study

These studies/programs and many other activities by the aerospace community have materially contributed to the base of knowledge regarding ETO space transportation systems. However, they have not identified a concept(s), which has generated a national consensus on the best way to proceed to assure the timely availability of a national space transportation infrastructure with the capabilities and attributes required to support all of the national space endeavors; civil, defense and commercial. Indeed it appears that these studies did not produce clear discriminators that could be confidently utilized in selecting the best transportation system architecture from competing concepts. There appears to be a least two reasons for this shortcoming. First, the real users/customers were not generally represented in these studies and hence their real requirements and prioritized needs were not adequately addressed up front. And secondly, it appears that in many cases the solutions had been predetermined prior to the initiation of the study, analysis and selection process.

The lack of a recognized National Strategic Plan for Space Transportation to satisfy this national need is very troublesome and gives rise to serious concerns that the status and direction of the propulsion system development and technology programs in progress and in planning may not be adequate to meet the real requirements of the space transportation systems capable of supporting the objectives of the nation's future space missions. In view of this undesirable situation, the focus of a unique national organization known as the Space Propulsion Synergy Group (SPSG) has been directed for the past two years toward supporting strategic planning for earth to orbit space transportation and propulsion systems. The emphasis on <u>support</u> should be noted since this group (SPSG) was not chartered to develop a national space transportation and propulsion system strategic plan. Rather its purpose is to provide support to those individuals and organizations who are responsible for planning and timely development of the required national space transportation and propulsion system capabilities.

This strategic planning support could take on several forms, but there are two distinct forms that emerged from the SPSG planning activities. One is the strategic planning <u>processes</u> that evolved which is believed to contain several key "breakthroughs", and could be called a "pathfinder" process. There is a high degree of confidence that the utilization of this process and the "know how" built up by the SPSG activities will prove to be a valuable tool and asset to those responsible for planning and developing transportation and propulsion system.

The second form of support becomes clearer when it is understood that, as the process(s) were evolving in the SPSG strategic planning activities, they were also getting a thorough validation of their effectiveness in strategic planning. Further, this validation of the process took place at the system (transportation), the sub-system ((propulsion), and the technology level. Although the primary focus of the SPSG was on propulsion it was necessary to develop a representative, and acceptable, transportation system strategy including vehicle concepts, before the propulsion systems and technologies could be addressed. Hence the results or product of these SPSG activities are very broad and include tangible findings that should be of value to, and supportive of, those responsible for planning and decision making at the system, subsystem and technology level.

What is the SPSG and where did it come from? The origins, purpose, organization and activities of the SPSG are addressed in the next section.

Space Propulsion Synergy Group (SPSG)

The formation of the Space Propulsion Synergy Group (SPSG) had its roots in the Space Transportation Propulsion Technology Symposium that was held at Penn State University in June 1990. The participants of this symposium included representatives from NASA, DoD, the space propulsion industry, and universities with a focus on space propulsion. These participants produced a strong mandate for the creation of a follow-through/sustaining organization to pursue the nation's space propulsion needs and provide a positive force toward the fulfillment of these needs. The major observations concerning the national propulsion systems and technology needs resulting from this symposium were as follows:

- Space propulsion system long range strategic plans are sorely needed at the national level.
- The space propulsion community should not only change its culture, but also adopt a uniform culture within itself.
- There is a very large gap between technology developers and users which needs "bridging".
- Foreign launcher systems are advancing rapidly.
- Propulsion system test facilities and engineering staff are aging and diminishing.

Accordingly, the NASA Headquarters Office of Aeronautics, Exploration and Technology (Code R) and the office of Space Flight (Code M) **, which organized the Penn State Symposium, initiated the Space Propulsion Synergy Group (SPSG) in 1991 as an ongoing activity to respond to these challenges. The SPSG involves personnel from NASA Centers as well as other government agencies (DOD and DOE), industry and academia. From the beginning, it was recognized that a nationally represented organization was required because most of the space propulsion needs and challenges existed on a national level.

The organization of the SPSG is shown in Figure 1. The Executive Committee which consists of senior representatives of the Government agencies involved, is co-chaired by Mr. William Escher, NASA Headquarters' Office of Advanced Concepts and Technology and Mr. Robert Brodowski, NASA Headquarters' Office of Advanced Systems Development †. The Industry Support Team which is lead by Mr. Tom Mobley, Martin Marietta, has played a vital role in the achievement of the SPSG to date. In fact the communication and interplay between the aerospace industry and the government space agencies is considered to be one of the major strengths of this organization.

The SPSG Charter includes the following three primary objectives:

- To provide active support to management in the development of space propulsion strategic plans responding to the propulsion requirements of a robust affordable national space transportation infrastructure.
- To provide special assessment team capabilities with the necessary technical expertise and space program experience to assess and evaluate competing advanced space propulsion options, new innovative design approaches, technology issues, etc.
- To provide a forum for, and act as a catalyst in increasing and improving communication within the space propulsion community and between it and the broader space transportation community.

Although the SPSG worked toward all three objectives the focus of the past two years has been on space propulsion and transportation system strategic planning support.

** As part of a subsequent reorganization of NASA Headquarters, shared responsibility for the Space Propulsion Synergy Group has been transferred from Code M to the Office of Space Systems (Code D), and from Code R to the Office of Advanced Concepts and Technology.

† Mr. Paul Herr of the NASA Headquarters Office of Advanced Systems Development served as Co-chairman from the initiation of the SPSG until December 1992 when he retired.

SPACE PROPULSION SYNERGY GROUP (SPSG)

Co-Chairman: Mr. William Escher (OAST)
Co-Chairman: Mr. Robert Brodowski (OSSD)
Executive Secretary: Mr. Walter Dankhoff
Technical Support: Mr. William Hope

VOLUNTARY INDUSTRY SUPPORT TEAM KEY INTERFACES

Coordinator: Tom Mobley, Martin Marietta Corporation

Propulsion Systems

Aerojet Propulsion Division
Ron Hankins

Atlantic Research Corporation
TBD

Hercules Aerospace
Bob Keller

The Marquardt Corporation
Carl Stechman

Pratt & Whitney
Randy Presley

Rocketdyne
Murv Sears

Thiokol Corp., Space Operations
Don Sauvageau

United Technologies Corp. Chemical Systems Division
Chris Kalivas

Space Systems

Boeing Defense & Space Group
Hal Di Ramio

General Dynamics
Dan Heald

Lockheed Missile & Space Company
Frank Borgardt

Lockheed Engineering & Sciences Co.
Walt Karakulko

Martin Marietta Manned Space Systems
Tom Mobley

McDonnell Douglas Space Systems
Edward Cady

Rockwell International
James Berry

TRW Space & Technology Group
Robert Sackheim

EXECUTIVE COMMITTEE

Organization	Name	Area *
NASA Headquarters (OACT)	Mr. David Stone	T
NASA Headquarters (OSF)	Mr. John Mulcahy	S
NASA Headquarters (OSSD)	TBD	S
NASA Headquarters (OAT)	TBD	T
Johnson Space Flight Center	Mr. Ralph Taeuber	S
	(Mr. William Boyd)	S
Johnson Space Flight Center	Mr. Don Nelson	T
Jet Propulsion Laboratory	Mr. James Kelley	T
Kennedy Space Center	Mr. Russell Rhodes	O
Langley Research Center	Mr. Charles Eldred	T
	(Mr. Doug Stanley)	T
Lewis Research Center	Mr. Larry Diehl	T
	(Mr. Joseph Hemminger)	T
Marshall Space Flight Center	Mr. John McCarty	S
	(Mr. Eric Hyde)	T
Marshall Space Flight Center	Mr. James Thompson	S
	(Mr. Steve Richards)	S
Stennis Space Center	Mr. Glade Woods	O
	(Mr. Steve Dick)	O
Strategic Defense Initiative Org.	Maj. Jess Sponable	S
Air Force (SAF/AOSS)	Col. Charles Banta	S
ANSER / Air Force (SAF/AQT)	Mr. Raymond Chase	S
Air Force Space & Missile Center	Maj. Jeff Fitzsimmons	S
Air Force Space Command	Lt. Col. Randy Joslin	O
Air Force Phillips Laboratory	Mr. Lee Meyer	T
Aerospace Corporation	Mr. Tony Zachary	T
AEDC	Mr. Mike Russom	O
Department of Energy	Dr. John Bertin	T
Pennsylvania State University	Dr. Charles Merkle	T

* = Area of Current Primary Responsibility and General Expertise
T = Technology
S = System
O = Operations/Test

Figure 1

General Approach

In retrospect, it may have been presumptuous on the part of the SPSG to assume or hope they could succeed in developing an approach (process) which could produce the results and inputs needed to develop a national strategic plan for an improved space transportation and propulsion system which incorporated the capabilities and attributes needed and demanded by the users (customers). And more than that, a process that would produce space transportation strategies that were a valuable asset in generating national consensus and support; particularly in view of the considerable amount of energies and moneys that have been expended on the same objectives is the past several years without noticeable success.

However, there were several factors that favored the SPSG that should be considered:

- The SPSG is an ad hoc broad based organization that includes constituents from both government and industry, and with both launch vehicle and propulsion system experience and a diversity of backgrounds and expertise from technology through development, production and operations.

- The SPSG activities were not schedule driven. The SPSG was not directed to complete the studies assessments and findings by a set date. Therefore, they were able to take the time that was needed to do the job right.

- Also, the SPSG was oriented toward "better and smarter ways of doing business, through cultural changes", starting at the Penn State Symposium: and were able to learn as they proceeded; including lessons learned from past studies and activities which had similar objectives.

In summary, when the SPSG did run into problems in carrying out the assessments of candidate launch vehicle and propulsion system concepts, they were able to stop, take the time to address the problem, and develop innovative ways to accomplish their objectives. This occurrence will be addressed further in a later portion of this paper.

What follows is a general description which highlights the approach the SPSG followed in their space transportation and propulsion systems strategic planning support activities. It was recognized that the National Space Council issued a National Space Launch Strategy Directive in July 1991 which is responsive to the National Space Policy, with respect to access to space (see Figure 2). This directive, along with preceding directives, provided authoritative inputs to defining a representative baseline space transportation strategy with options which was then used as a basis for developing space propulsion strategies with options which are outlined in this report.

Objectives of Future Space Transportation and Propulsion Systems Strategic Planning

- **Goal:** Satisfy National Space Policy for Earth to Orbit (LEO) Transportation

- **Specific Objectives:**

  - Improve the operational capabilities of propulsion systems in the existing transportation infrastructure to more efficiently support near term national space program needs.

  - Assure the availability of advanced propulsion systems with those capabilities and attributes required by a new transportation infrastructure for the national medium payload (both personnel and cargo) missions of the next two to three decades.

  - Assure the timely availability of propulsion systems with greatly enhanced capabilities for launching large payloads that will be required future national space exploration missions.

  - Enhance the domestic commercial space launch industry's propulsion capability to ensure success in international competition.

The process used in this study and analysis of national strategies for space propulsion systems and technologies required for future space transportation systems is illustrated in Figure 3. As may be seen it was a classic "top down" approach which attempted to be fully responsive to the stated national space transportation policies and space missions. It also attempted to make maximum use of the results of past studies and analyses which provide an extensive technical database relative to space transfer propulsion systems.

The inputs used to initiate the process were of three types:

1. National policies and strategies:
   - National space policy with respect to access to and from space.
   - National Space Launch Strategy issued by the National Space Council
2. National Space Missions, both current and planned:
   - Civil missions (NASA Civil Needs Data Base, CNDB FY93)
   - National security missions
   - Commercial missions

NATIONAL SPACE POLICY WITH RESPECT TO ACCESS TO AND FROM SPACE
• Assured Access to Space Is A Key Element • Objectives Of U.S. National Space Launch Infrastructure – Provide Safe, Reliable Transportation To And Return From Space – Reduce Cost Of Transportation And Hence Encourage Expanded Space Activities – Exploit Unique Attributes Of Manned And Unmanned Launch And Recovery Systems – Encourage Development Of U.S. Private Sector Space Transportation Capabilities

NATIONAL SPACE LAUNCH STRATEGY
• Ensuring That Existing Launch Capabilities Are: – Sufficient To Meet Government Needs To Transport People And Cargo To And From Space Through The Current Decade – Provide A n Important Element Of The Nation's Launch Capability Into The First Decade Of The 21st Century • Developing A New Unmanned, But Man Rateable Space Launch System To Greatly Improve National Space Launch Capability By: – Reductions In Operations Cost – Increases In Reliability – Responsiveness – Mission Performance • Sustaining A Vigorous Space Technology Program (Both Broad Based And Focused) To: – Provide Cost Effective Improvements To Current Launch Systems – Support Development Of Advanced Launch Systems Concepts, e.g., Single Stage To Orbit, And Experimental Flight Vehicle Programs • Actively Considering Commercial Space Launch Needs And Factoring Them Into Decisions On Improvements In Launch Vehicles And Launch Facilities

Figure 2

3. Transportation architecture and infrastructure studes:
   - Government agencies (NASA and DoD)
   - Officially appointed special study groups

Using these inputs and the results of launch vehicle and propulsion system concept analyses conducted by government agencies and aerospace contractors, viable candidate launch vehicle systems for an ETO Transportation Infrastructure were identified and analyzed to determine the propulsion system performance requirements. An additional, and critical part of this step in the process was the identification of the transportation system user/customer and characteristics or attributes most valued by the user/customer in an earth to LEO payload transportation services.

In view of the broad scope and complexity of this undertaking, and the many elements and variables involved, a technique for visually displaying these elements and their

SPACE PROPULSION
SYNERGY GROUP

SPACE PROPULSION STRATEGIC PLANNING PROCESS

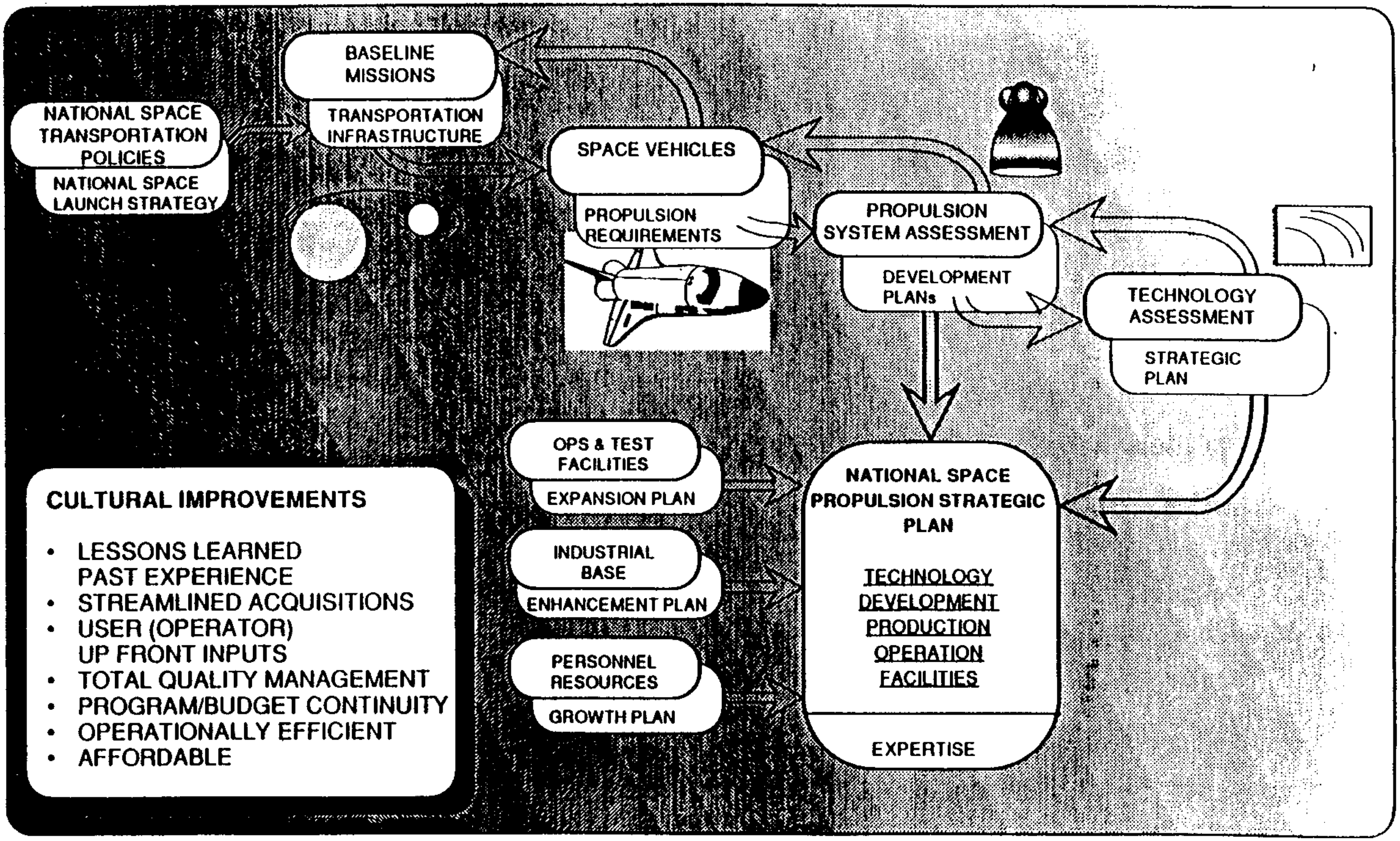


Figure 3

Table I. Achieving Strategic Planning Credibility

What Was Needed	How It Was Achieved
• Reflect The National Space Policy	• Based On National Space Transportation Policy And Strategy
• Support National Mission Requirements	• Searched Recognized Data Bases
• Encompass All Viable Candidates	• Researched Architecture Studies
• Develop The Right Set Of Verifiable Assessment Criteria	• Developed Using QFD Process
• Use A Structured Approach And A Balanced Assessment Team	• Used Team Of Technical Experts – Government – Industry
	• Involved Designers, Manufacturers Operators, Technologists Up Front – Each With Equal Voice – Achieve Consensus
• Embraced/Accepted By Customers/ Users	• Researched Customers And Users <u>Real</u> Needs And Desires Using QFD
• Show Evidence Of Credible Scope And Depth Of Supporting Research/Analysis	• Divided Total Planning Into Manageable, Definable "Pieces" And Documented Activities And Results In Technical Support Volumes

interaction was evolved early in the endeavor. This technique is a strategic planning "roadmap". It is literally that; a wall-sized planning roadmap which starts with the major inputs, continues through the steps involved in the process and ends with the several types of outputs. It is physically made up of the actual charts, figures, etc., that had to be developed and exercised in the process and presents them in the order, or flow, in which they occur. In this manner, the individuals involved in the process can understand the interaction of their specific input or analysis with the total process. The strategic planning roadmap has also proven to be a valuable tool in briefing others on the process and the results of the SPSG strategic planning support activities [††].

Also, it was recognized that in any strategic planning process it is vital that a basis for credibility be established. Therefore, an "up front" effort was directed to the question of what is needed to establish credibility and how can it best be achieved. The results relative to development of a credible strategic plan to attain a safe, reliable, affordable national space transportation system are shown in Table I.

In view of this, the first step in the strategic planning process was to establish a well balanced, diversified team of personnel to conduct the process using the principles of concurrent engineering. This team consisted of members from NASA, DoD, DoE, industry and academia, each having an equal voice in the process. Team members were carefully selected to provide representation for customers (needs and requirements), users/operators (needs and requirements, and lessons learned), developers (feasibility optimization of systems to requirements and lessons learned), manufacturers (manufacturing efficiency and lessons learned), and technologists (availability of enabling technology). This system of establishing up front involvement of the users/operators, manufacturers and technologists in a formal manner represents a major change to the process used for the definition and planning of transportation systems and propulsion systems in the past.

The attributes shown in Table II are an early consensual result of the space transportation strategic planning studies.

[††] It was impossable to include copies of a strategic planning "roadmap" in this paper, but a copy may be obtained by contacting the author, Walter F. Dankhoff at W.J. Schafer Associates, 525 School Street S.W., Suite 301, Washington, D.C. 20024.

The quantitative goals were developed by the SPSG Working Panel who are responsible for the content of this report. It should be emphasized here that these are attribute goals which were developed without any constraints of time, budget or other programmatic considerations. They are simply goals that in the consensual judgement of the SPSG Working Panel are achievable at some reasonable point in the future. The panel judgements did take into consideration the level of attributes that existing transportation systems are capable of delivering and, more important, the level that future transportation system customers/users will demand and should expect to receive. Of course, the expectations have to be tempered, and were by the SPSG panel, with a realistic picture of the technology base and foreseeable technology advancements. But, as emphasized in other sections of this report, there has to be a focus on technologies which will effectively impact the desired attribute goals. Another way of looking at it is that, unless the U.S. aerospace community recognizes that the customers/users need and will eventually demand better space transportation systems, and start responding to that demand, foreign competitors will fulfill the need by marketing better transportation systems.

Table II. Goals for Medium Payload ETO Transportation System Attributes

Attribute	Goal
Crew/Vehicle Safety	0.9995
Mission Reliability	0.999
Affordability	<$500/Lb
Operability*	0.90
Availability	0.95
Responsiveness	7 Days
Payload Capability 28.5° Inclination	20 Klbs to LEO
System Capacity	500 Klbs to LEO/Year

* In accordance with "Operability Index" methodology developed by Kennedy Space Center. Minimum value 0, Maximum value 1

Subsequently, the use of a process known as the Quality Function Deployment (QFD) resulted in the development and ranking of a more comprehensive list of major and subsidiary attributes for medium payload transportation systems. As will be noted later, the attributes developed by the QFD process were similar, but in greater depth than those shown in Table I, and provided the basis for the assessment of the candidate launch vehicle and propulsion systems.

Missions, Payloads and Space Transportation System Architectures

Based on currently identified national space missions, and initiatives (civil, national security, and commercial) there appears to be a requirement for two distinct classes of transportation systems. One system is to provide transportation of medium payloads (less than 20,000 pounds) for personnel and high tech, expensive equipment to low earth orbit. There also is a distinct future requirement for a heavy lift space transportation system for cargo and crew which will be primarily driven by future space exploration missions.

There is a clear need for both classes of space transportation systems, but the need for a new medium payload transportation infrastructure with the required capabilities and attributes is most urgent. There are several compelling reasons for this statement. First, the number of medium weight payloads (civil, national security, and commercial) that have been officially or otherwise identified for the next two decades is more than 90 percent of the total number of payloads +. Another very compelling reason is the desirability of having a transportation system capable of offloading the space shuttle, and of replacing it as soon as possible with a more operationally efficient, affordable system.

Because it will take time to define any national space exploration missions and programs, the requirements for heavy lift capabilities are somewhat in the evolutionary phase. This is not to imply that the nation can either defer the definition of a Heavy Lift Launch Vehicle (HLLV) concept, or defer the decision to pursue the required technology. It must be clearly recognized that our nation does not have a space launch capability even close to the 100,000, 300,000 or 600,000 pound capability required to successfully execute any national space exploration program.

However, in view of the ill defined nature of missions requiring heavy lift capability, and in the interest of brevity, the remaining portion of this paper will concentrate on ETO transportation systems and propulsion systems that will be required for medium payload missions in the next two or three decades. A more complete description of missions, payloads and space transportation architectures may be found in Reference 1.

A medium payload mission is defined as 20,000 lbs or less to LEO, 28.5° inclination. A critical first step in developing a strategic approach to meeting this objective is the establishment of a thorough understanding of the transporta-

+ Civil payloads from NASA Civil Needs Data Base (CNDB) tion system operators' and the ultimate customers' (payload providers) requirements and general needs. This was accomplished, in part, by compiling a baseline for all of the national space mission (civil and defense) payload requirements and the potential commercial space transportation industry's payload market. The baseline for the combination of the civil and Department of Defense (DoD) medium payloads for the next 30 years is presented in Figure 4. This includes payloads of both personnel and high value cargo to LEO, and return where appropriate.

This information was analyzed to determine what payloads, by mass categories, must be transported to LEO and when they must be delivered. The major finding of this analysis was that approximately 92 percent of the total earth to orbit (ETO) payloads (civil and DoD) have a mass of 20,000 pounds or less. Other pertinent findings from analysis of the national mission plan were that total mass to orbit per year is approximately 750,000 pounds; 25 percent of the total payloads require a man aboard the vehicle; and approximately 16 percent involve the return of a payload to earth. The transportation of these medium sized payloads in a manner commensurate with these needs is, therefore, of prime importance in the development of a strategic plan.

The commercial satellite market is dominated by payloads of less than 6,000 pounds (80 percent) which operate in a geosynchronous earth orbit (GEO). These satellites are generally transported to a GEO transfer, low earth orbit, and have a propulsion stage attached which powers them to GEO. Total payload mass (satellite and propulsion stage) to LEO is less than 18,000 lbs.

Figure 5 presents an estimated commercial satellite mass distribution for GEO and the LEO equivalent. The estimated 151 commercial payloads shown is a conservative (50 percent discounted) mission model for the years 1992 through 2010 ++ . Figure 6 presents the estimated commercial mission rate and averages approximately eight launches per year.

Medium Payload Strategic Approach

Currently Available Space Transportation Systems

The currently available space transportation systems will undoubtedly be the mainstay, if not the only systems available through the remainder of this decade. Therefore, they are an important element of the strategic approach for medium payload class transportation. The capabilities of the currently available transportation systems were assessed and compared to the requirements defined in the baseline national mission plan. This comparison showed that the total mass to orbit of approximately 750,000 pounds maximum per year can be transported by the current U.S. fleet of Space Shuttle (Orbiters) and expendable launch vehicles (ELVs), providing that:

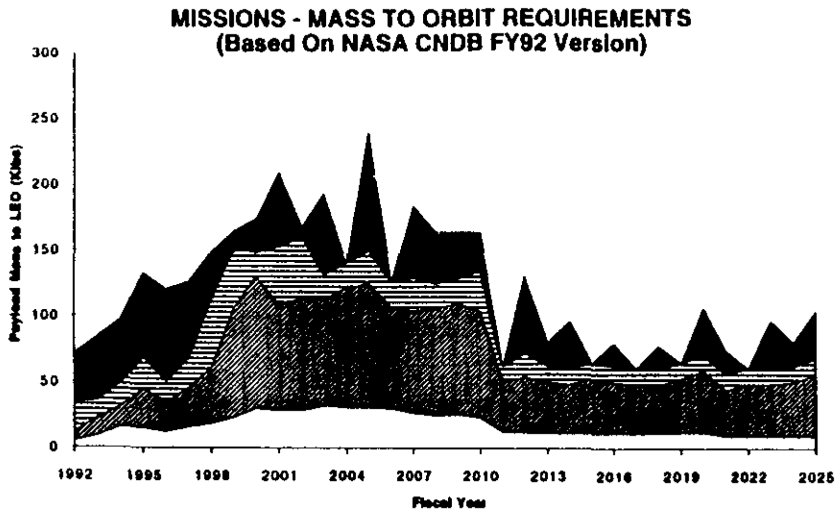
- There is continued availability of the maximum projected capability
- No significant schedule problems are encountered
- There are 12 ELV and 8 Space Shuttle flights per year
- Payloads are redistributed during the Space Station Freedom (SSF) deployment

Figure 7 presents the U.S. Launch Vehicle options for ETO transportation of commercial payloads. Considering the commercial payload requirements discussed earlier, an obvious capability gap exists for 15,000 to 30,000 pounds payloads. Although the Titan 34D could be used, only multiple payload manifests would be economically feasible. Some other potential approaches to to filling the 15,000 to 30,000 pound capability gap are shown in Figure 8. The projected Shuttle manifest overload also limits the availability of that option for the heavier commercial payloads.

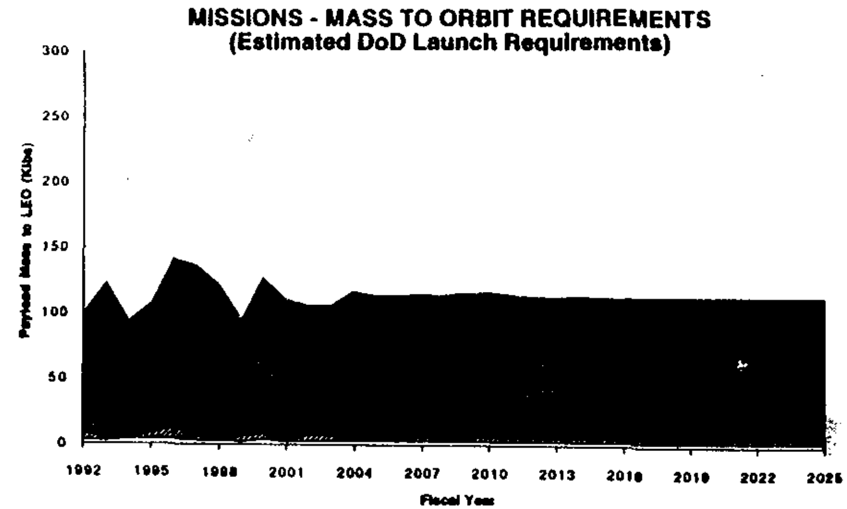
Having established that the current ETO transportation infrastructure (Space Shuttle and expendable launch vehicles) will satisfy most of the anticipated medium payload civil, DoD, and with some limitations, commercial missions; why is there a compelling need to develop and put into operation another medium payload transportation system? The answer is that, although the current fleet appears to meet the requirement for total mass to orbit, it can not meet the National Space Transportation Policy requirement to provide affordable, routine access to space; nor can it satisfy the desired attributes/goals for the user/operator needs.

A comparison of the estimated status of the attributes of the current fleet to the anticipated future user/operator requirements for these attributes is shown in Table IV. The large disparity between the cost per pound delivered to orbit goal and the actual cost per pound delivered by the current transportation system (Space Shuttle plus expendable launch vehicles) as shown in Table II is widely recognized as the crucial problem in ETO space transportation. This lack of affordability is a major impediment to progress in this and other nation's space endeavors. There is a national consensus that this problem must be energetically and effectively addressed if the U.S. is to truly become a space fairing nation and is to be commercially competitive in the international market. Actually, there are several other very desirable attributes of a world class ETO transportation system that are very lacking in our current national systems. These include the attributes of dependability,

++ COMSTAC Innovation and Technology, 30 October 1991



Category 1	0 Lbs.	73 Payloads	14%
Category 2	1 to 1000 Lbs.	253 Payloads	48%
Category 3	1001 to 5000 Lbs.	89 Payloads	17%
Category 4	5001 to 10000 Lbs.	30 Payloads	06%
Category 5	10001 to 20000 Lbs.	29 Payloads	06%



Category 1	0 Lbs.	TBD	TBD%
Category 2	1 to 1000 Lbs.	40 Payloads	17%
Category 3	1001 to 5000 Lbs.	11 Payloads	05%
Category 4	5001 to 10000 Lbs.	69 Payloads	29%
Category 5	10001 to 20000 Lbs.	53 Payloads	23%

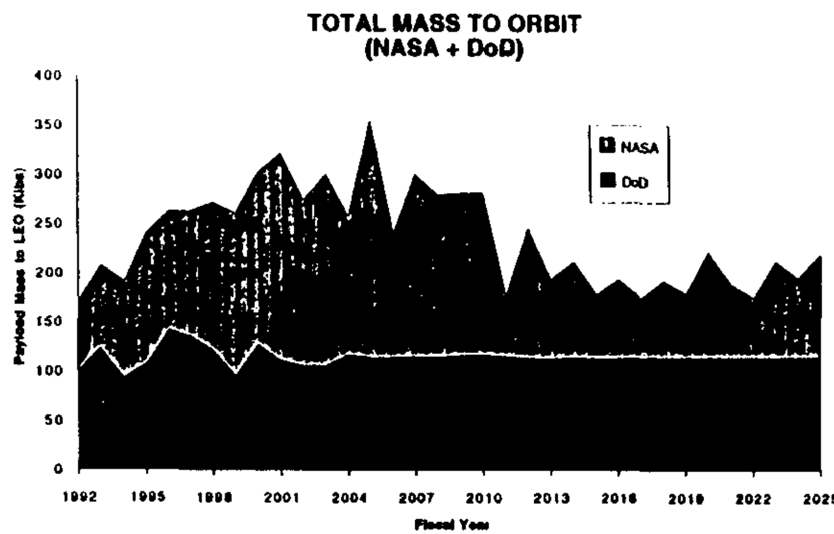


Figure 4

operability and responsiveness which all have a major impact on affordability. These attributes must be addressed with equal vigor in defining and developing a new and better transportation system to replace the current system. The bottom line, however, is affordability.

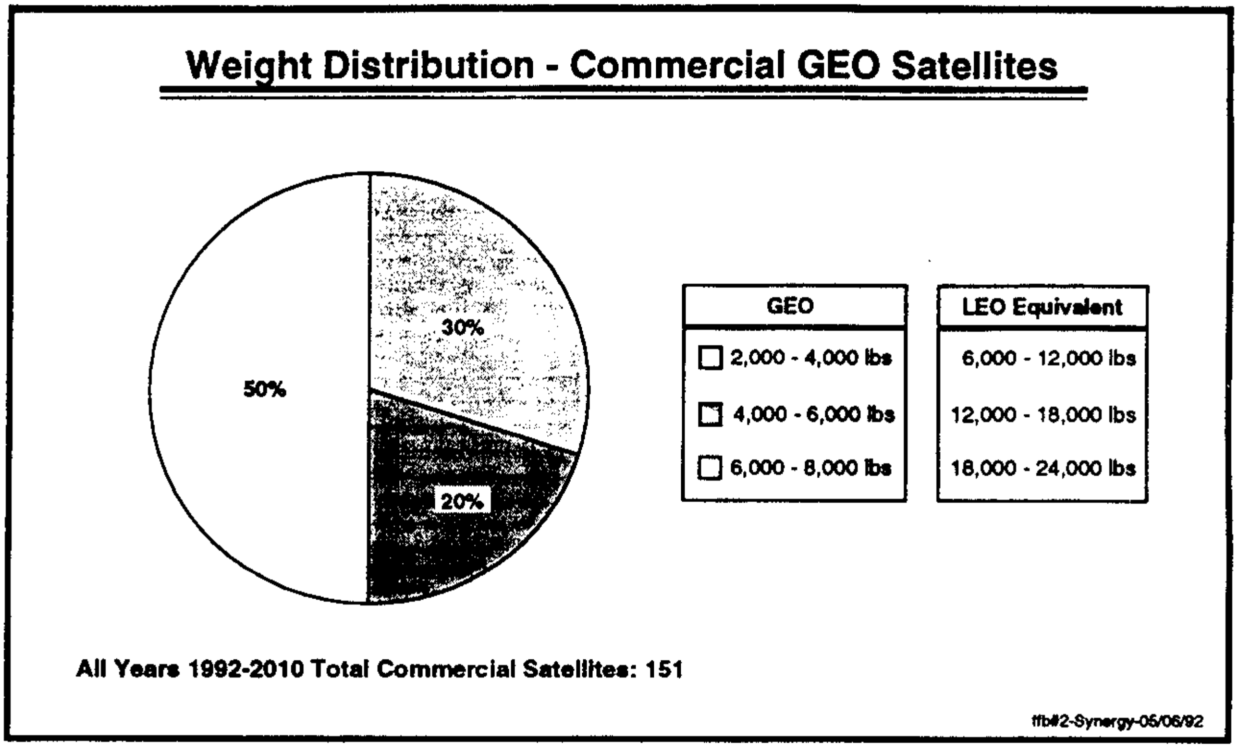


Figure 5

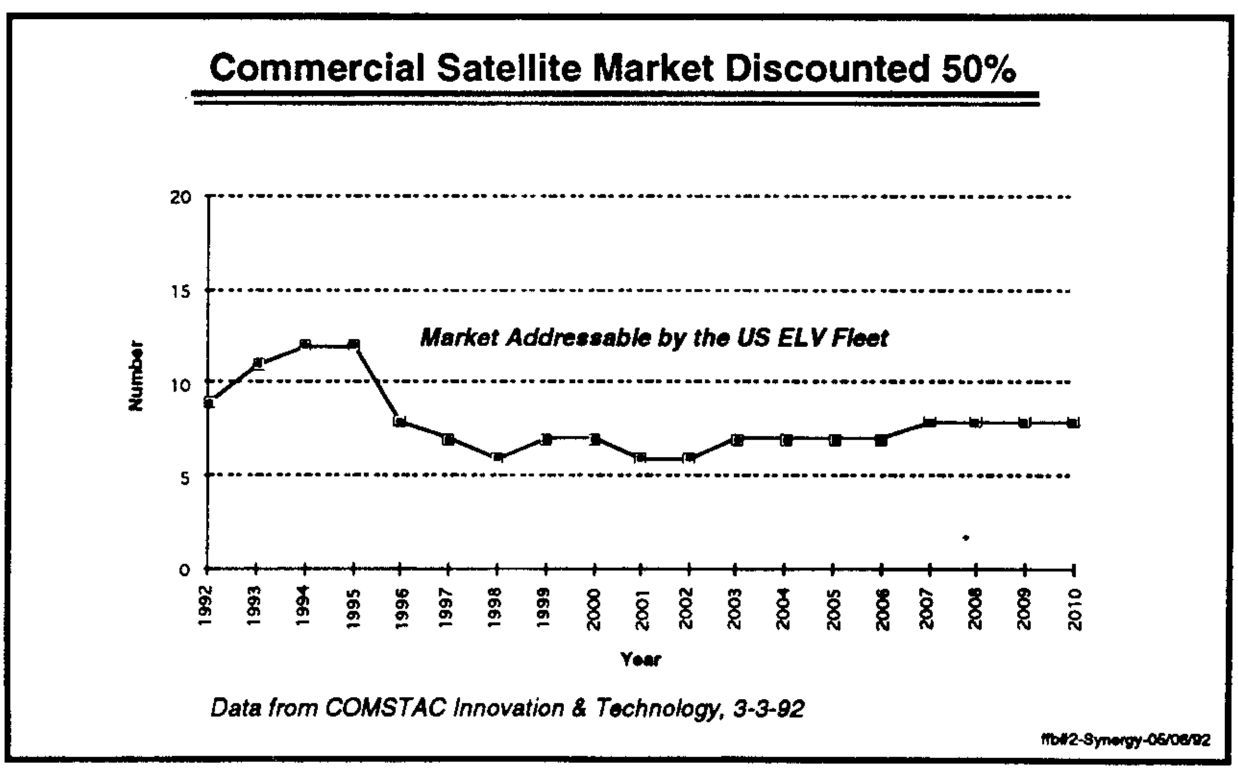


Figure 6

U.S. Commercial Launch Vehicles

- There is a capability gap for payloads between 15 and 30 Klbs
- There are three approaches for closing the gap
  - Expand capability of smaller vehicles
  - Reduce capability of larger vehicles
  - Develop new vehicles

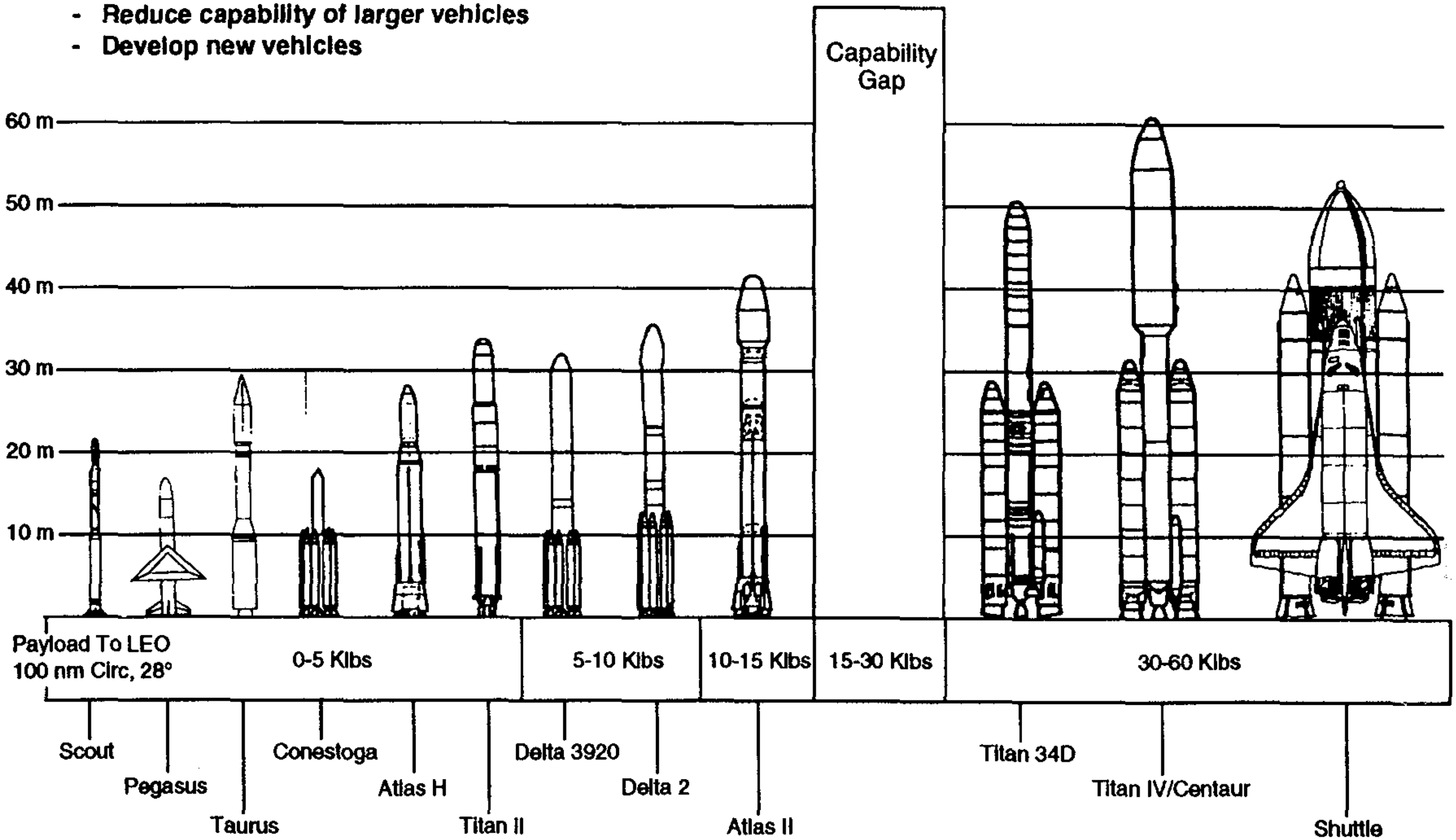


Figure 7

U.S. Commercial Launch Vehicles

Potential 15 - 30 Klb Vehicles	Propulsion Technology Requirement
• **Increase capability of smaller vehicles** - Add hybrid, liquid rocket boosters to Atlas, Delta 2 - Increase diameter of core (i.e., wide body Atlas) - Cryogenic second stage (LO2/LH2) for Delta	Hybrid LO2/RP-1 booster engine LO2/LH2 upper stage LO2/LH2 upper stage engine
• **Reduce capability of larger vehicles** - Add ballast to Titan - Fly more than one payload per vehicle	N/A
• **Develop new vehicles (15 - 30 Klb)** - ET/NLS derived first stage, LRB derived second stage - Clustered hybrid - LO2/RP-1 booster, LO2/LH2 upper stage	STME LO2/LH2 upper stage LO2/LH2 upper stage engine Hybrid LO2/RP-1 booster engine

Figure 8

Table IV. Ultimate Goals Versus Current Values for Medium Payload ETO Transportation System Attributes

Attribute	Ultimate Goal	Current Values: Space Shuttle	Current Values: ELVs
Crew/Vehicle Safety	0.9995	Accepted (Inadequate for Future Systems)	Not Man Rated
Mission Reliability	0.999	Nominal (0.96) (Inadequate for Future Systems)	Acceptable (0.95)
Affordability	<$500/Lb	Expensive (> $5,000/Lb)	Poor ($4-6,000/Lb)
Operability*	0.90	Complex/Manpower Intensive	High Manpower Requirements
Availability	0.95	Nominal	Nominal
Responsiveness	7 Days	Poor	Poor
Payload Capability	20 KLbs to LEO	50 KLbs to LEO 28.5° Inclination	1 to 35 KLbs to LEO 28.5° Inclination
System Capacity	750 Klbs to LEO	7 to 8 Launches/Year	TBD

* In accordance with Operability Index (OI) methodology developed by Kennedy Space Center
Minimum value 0; Maximum value 1

It is widely recognized that foreign competition has taken a large portion of the launch services market from the U.S. industry. A major reason for this is that they are already more affordable (lower cost). However, they have not accomplished the major step in improvement of costs and other operational attributes that are required and believed to be eventually possible. Recognition of this situation leads to a conclusion that there is a need for a dual strategy approach:

1. Enhancing the current U.S. transportation systems as soon as possible to put it in a more competitive posture.

2. Initiation of a development of an advanced medium payload transportation system which will provide a major improvement in affordability and the other desired attributes. This should be proceeded by a technology program to provide a sound technical base and reduced risk.

Fortunately, as was demonstrated in the SPSG strategic planning support activities, the technologies needed to enhance the current fleet are to a large degree those technologies that will be needed by a new improved transportation system. Of course, there are additional enabling technologies required by a new advanced transportation system that will have to be addressed and validated [2].

Of course, there is the question of what is affordable. One answer is that amount which fits into the national or a specific organization's budget. Since ETO transportation is required to carry out almost all of NASA's and DoD's space missions, as well as the private sector's space ventures, and since transportation is a major element in their budgets, there is obviously a great need to keep the transportation costs to a minimum. Every dollar that is spent on transportation is a dollar that is not available for the space mission itself.

The current high (excessive) cost of space transportation particularly ETO transportation, is too high a percentage of the total space budget. This problematic situation applies to both NASA and DoD. The transportation portion of the NASA budget accounts for more than one half of the total budget. This is unacceptable, particularly when it is recognized that in the foreseeable future, the NASA budget, and most probably the DoD space budget, will remain at about their current levels.

Recognizing that there is a compelling need for both the enhancement of the existing launch systems and for developing a new advanced transportation system and supporting infrastructure, a major question that a strategic plan must address is: Which of the new viable launch vehicle/propulsion systems concepts shown in Figure 7 have the greatest potential of providing a new medium payload class transportation system which is affordable and has the desired attributes and characteristics?

Advanced Medium Payload Transportation Systems Options and Assessments

The approach used to identify the most viable options for a new advanced transportation system was to place a major emphasis on past and current space transportation architectures, and vehicle system studies and applicable advanced development activities; as well as the results of various propulsion system design concept analyses and studies conducted using the current technology base and anticipated technological advancements. The options identified from the results of these analyses are shown in Figure 9. As can be seen, there are several alternative paths to obtaining a medium payload space transportation system with the potential of attaining the desired capabilities and attributes.

These have been grouped as either "near term systems" or "future systems" according to an anticipated initial operating capability date. There are several compelling reasons for planning for a new near term medium payload transportation system with an IOC date of 2005 to 2010. First, it is generally observed that the Space Shuttle has a limited life and there is a potential for the loss of an orbiter. A near term system would provide a backup to the Shuttle in its final phase of operation and offer a much more affordable system at as early a date as possible. This will permit a distinctly lower percentage of the space budget to be utilized for transportation. In parallel to the near term system development, an aggressive program to build a technology base for a future, more optimum system would be developed. Following this line of logic, the transportation strategies addressed by the SPSG contain both a <u>near term</u> and a <u>future</u>, transportation system component.

An additional value of striving for a new near term medium payload transportation system is to provide a timely and effective way of supporting U.S. commercial launch vehicle needs. There is a strong consensus in the commercial community that the U.S. must have a next generation ETO launch vehicle that is superior (at least competitive) in the international market by 2005, if the U.S. is to survive and capture a major share of the future commercial market. This support may be in terms of enhancing technologies or major subsystems.

The earliest initial operating capability date for each of the transportation system options shown in Figure 9 is directly dependent on the magnitude of the technology challenges accompanying that option. The options which provide a transportation system that best satisfies the capabilities and attributes desired generally requires the most advancements in technology, and hence the longest time to reach Initial Operational Capability (IOC). Therefore, to assure a near term transportation system probably means using existing or near term technology and thereby compromising the at

ETO Transportation Strategy (Options) For Medium Payloads (Personnel and Cargo)

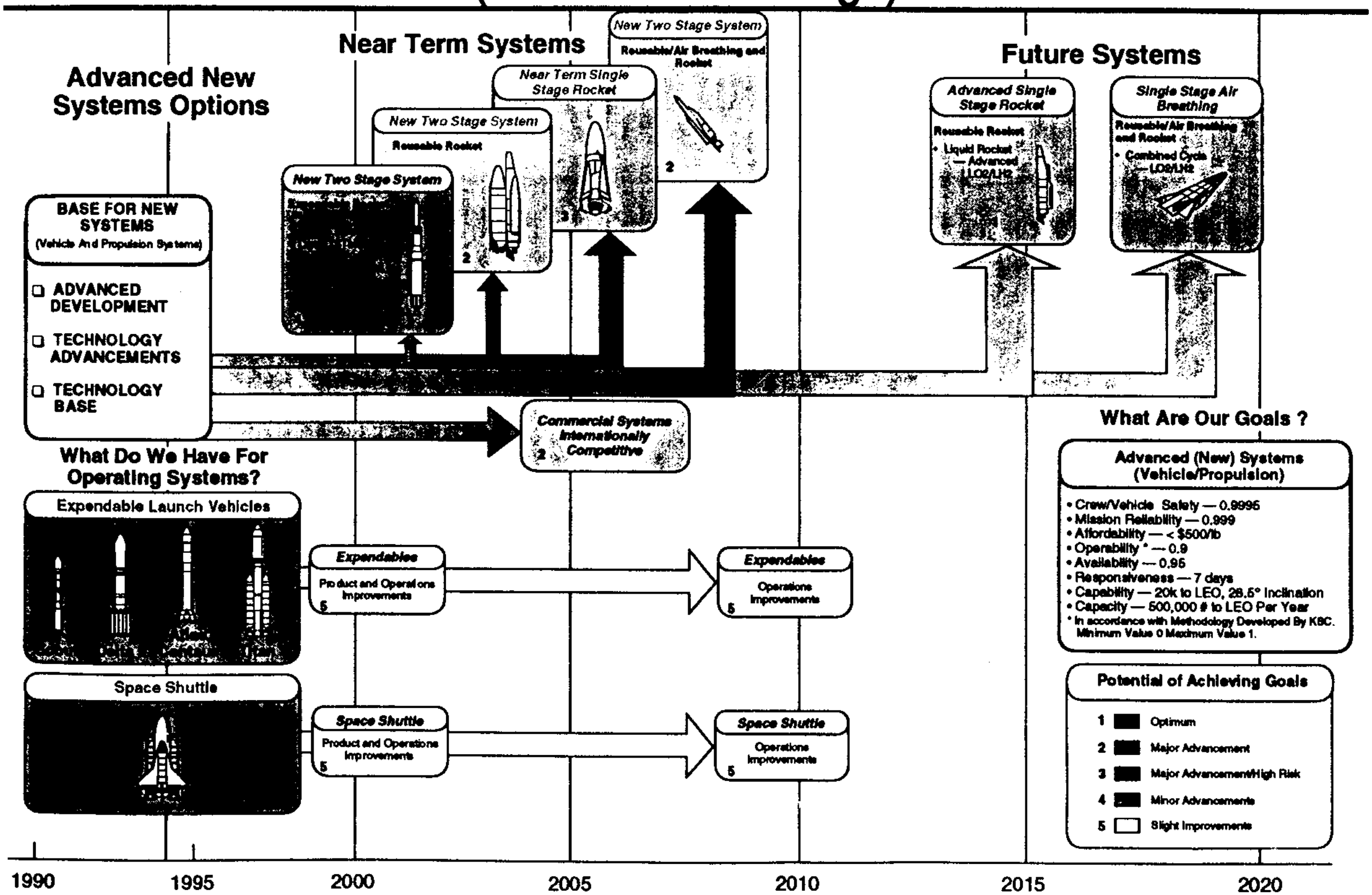


Figure 9

tributes this system will provide; that is, one has to accept less. This appears to be the situation with the National Launch System (NLS) program, which is shown as one option in Figure 9. The NLS does not appear to offer a transportation system with sufficient improvements to significantly affect attainment of the desired attributes/ goals.

Of course, the nation cannot afford to pursue all of the medium payload transportation alternatives/options shown in Figure 9 nor the associated propulsion system options and thus, some hard decisions have to be made in the face of "actual" requirements when these are officially elucidated. These decisions must take into consideration many factors, but especially the balance between IOC date and the quality of the transportation system that could reasonably be expected at that date. In this context, quality of the transportation system is equated to the "desired attributes" inherent in that system. In general, the higher the quality/ desired attributes, the greater the requirement for advancement in technology and hence, the later the IOC date. Some insight into this trade-off is shown in Table V where the major decisions are categorized by technology status.

Since the final objective of this SPSG activity, the development of a strategy for advanced propulsion systems and technologies, required a representative baseline strategy for the complete space transportation system, the necessary next step was for the SPSG Working Panel to develop one. The panel attempted to analyze and make a trade off between the payoff of the potential system in terms of achieving the desired attribute goals and the investment required in terms of time to make the required technology advances and the associated risks.

However, the team ran into some difficulties as they worked this problem and the next step, the assessment of the potential of candidate propulsion systems of achieving the desired attributes [3]. A baseline strategy for both a new near term and future medium payload transportation system was proposed as shown in Figure 10. Optional strategies were also developed. It was felt that an optional strategy with an early decision point (mid-1990's) was especially desirable for the near term single stage to orbit (SSTO) approach as shown in Figure 11. The reason being the technical risk associated with the development of an SSTO to start operations in the 2006 to 2007 time frame. The mid-1990's decision would be a choice between continuing with the SSTO or redirecting the technology development toward a two stage system, probably reusable.

However, this proposed medium payload transportation system strategy lacked the support of a structured analysis and assessment with measurable discriminators, and the associated propulsion system strategies (baseline and optional) that were proposed in Figure 12 had a similar problem. Basically, the team could not come to a consensus on which transportation and propulsion systems had the greatest potential of providing an ETO transportation system with the attributes most desired and demanded by the customer. One problem was that the SPSG panel members did not have criteria that could be used to measure the relative value (potential of meeting attribute goals) of each transportation and propulsion system. Also, the simultaneous consideration of programmatic factors such as technical risk and IOC date were adding to problem and making solutions impossible.

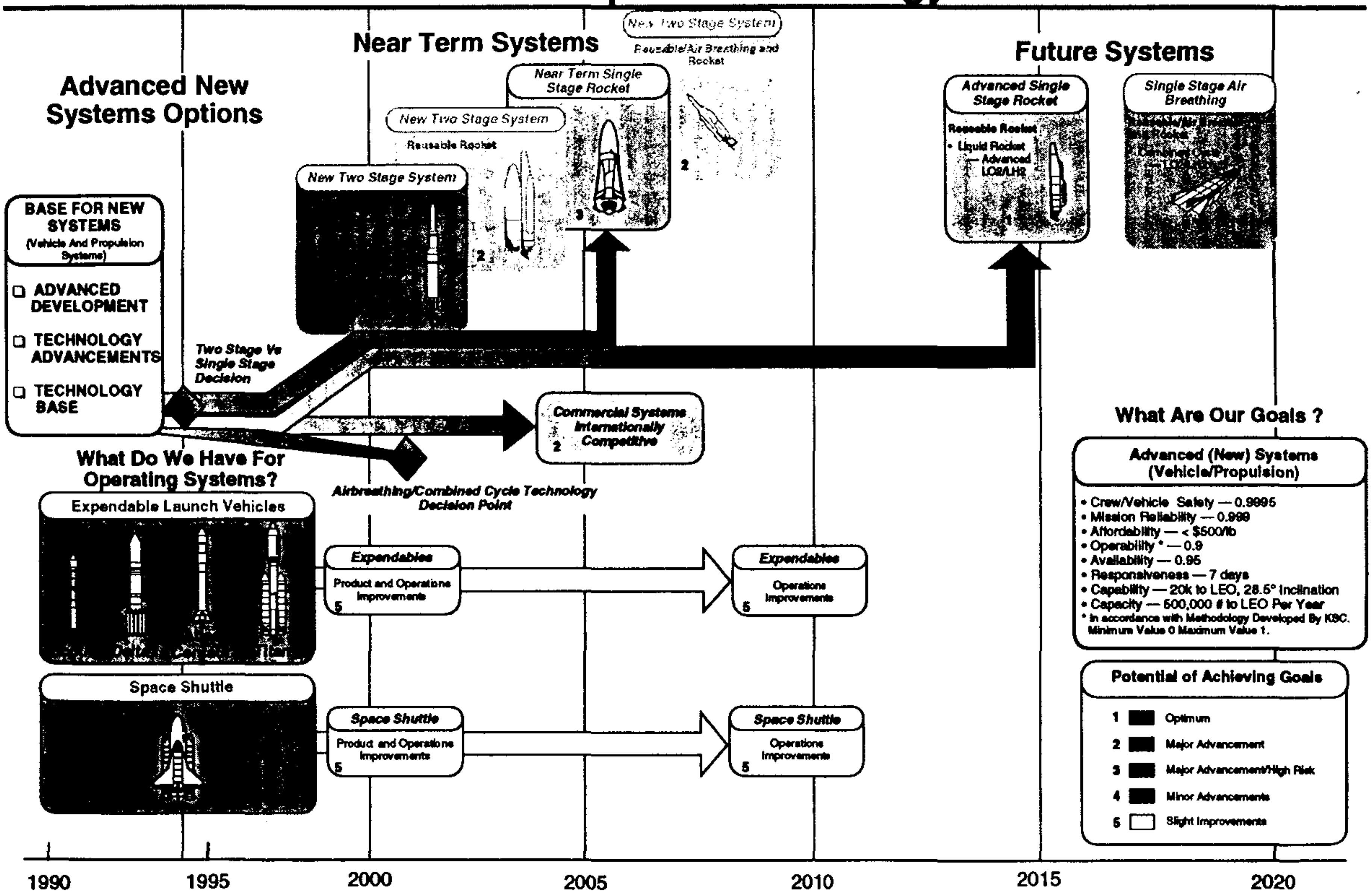
Table V. Major Space Transportation Decisions As Characterized By Technology Needs

Existing Technology Adequate		Technology Advancement Required
Two Stage Vehicle	or	Single Stage vehicle
Expendable/Partially Reusable	or	Reusable
Rocket	or	Rocket Based/Combined Cycle
Vertical Take-Off	or	Horizontal Take-Off
Horizontal Landing	or	Vertical Landing

Application of the QFD Process

At this point, several approaches to solving this problem were considered, but the decision was made to utilize a process known as Quality Function Deployment (QFD). This process (QFD) is part of the Total Quality Management program that is proving to be quite effective in the aerospace and in other industries internationally. This was a fortuitous decision as the application of the QFD process to the SPSG space transportation and propulsion strategic planning objectives has been very successful. A major reason for selecting the QFD process was that it not only provided a structured means of identifying and prioritizing the user/customer desired attributes, but also provided a

Medium Payload (Personnel and Cargo) Baseline ETO Transportation Strategy



Major Decision Point for "Future System"
• Airbreathing Combined cycle, or
• Advanced SSTO Rocket

Baseline Strategy Assumes Decision Favors Advanced SSTO Rocket

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Figure 10

Medium Payload (Personnel and Cargo) Alternate (Near Term) ETO Transportation Strategy

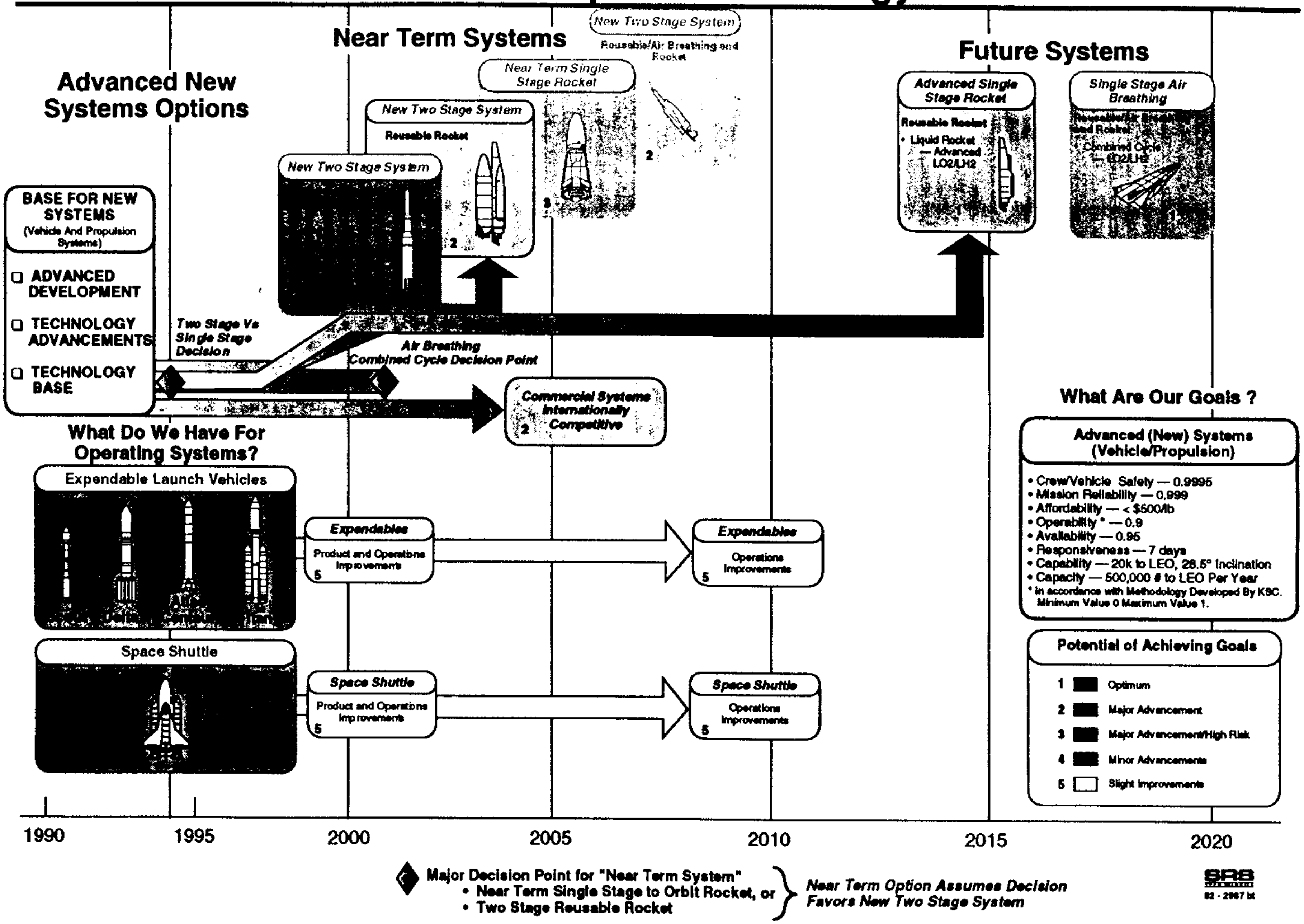

Figure 11

Propulsion System Strategic Planning For Near Term Medium Payload ETO Transportation Systems

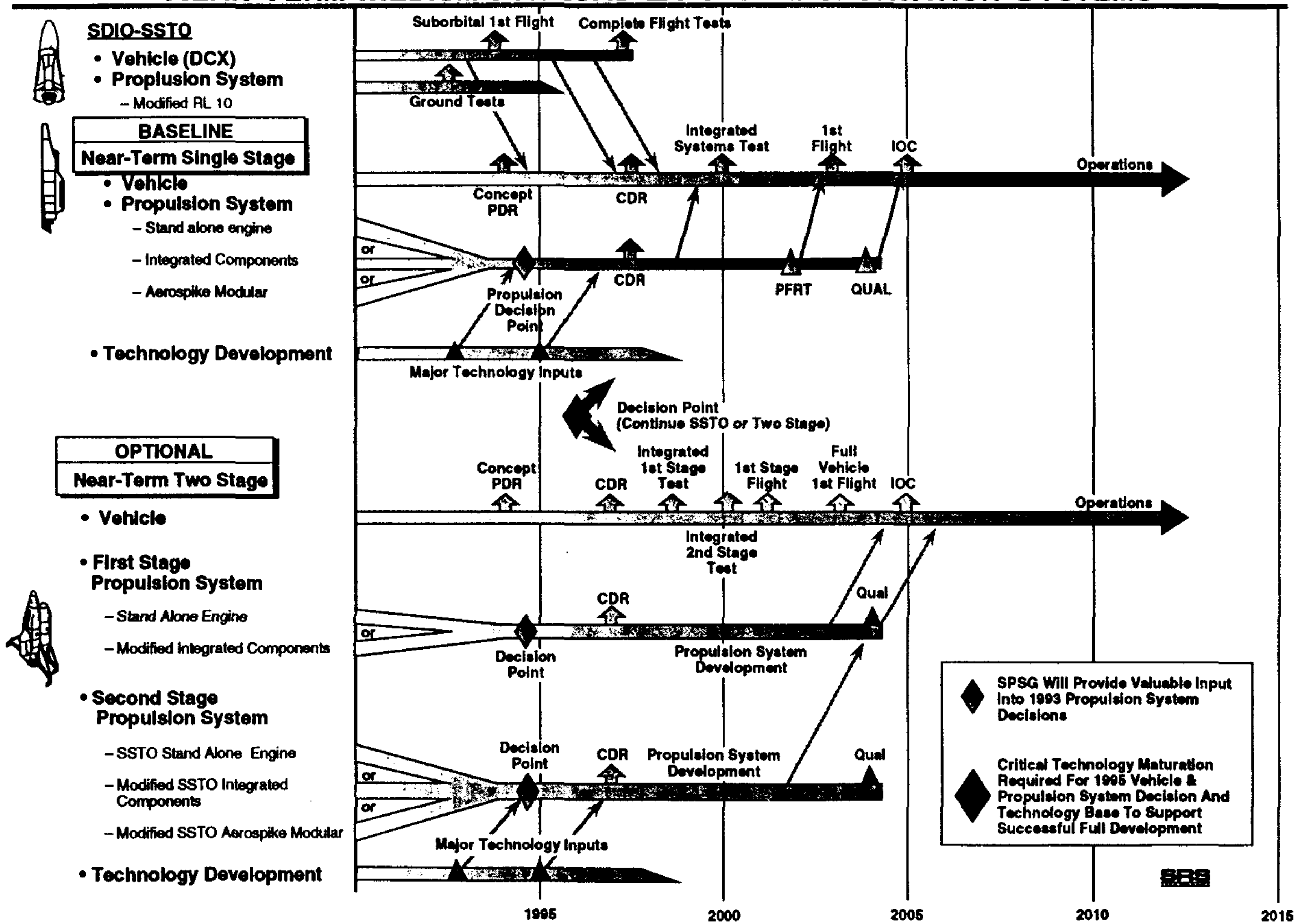

Figure 12

means for identifying and prioritizing those design and functional characteristics in terms of which could have the greatest impact on the attainment of the most desired attributes in an ETO transportation system. And, since these characteristics, identified as "quality characteristics" in the QFD system, must be measurable they provide design requirements (design drivers) that an engineer can utilize in the system design process.

It is beyond the scope of this paper to describe how the QFD process was applied by the SPSG and to summarize the results. However, it should be noted that there were several unique and innovative features that evolved from application of the QFD process to the SPSG Working Panel, some of which can be considered breakthroughs:

- The scope of the system or product: the ETO transportation system may represent one of the largest systems successfully utilizing the QFD process.
- The techniques developed allow traceability from the top level transportation system through the subsystem (propulsion) to the technology level.
- There is a clear identification of the two types of technologies that must be considered:
  - Enhancing
  - Enabling
- There are two distinct and separate steps in the process:
  - Potential benefit to system attributes
  - Programmatic factors
- Means of concurrent assessment

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