LAUNCH VEHICLES: AN ECONOMIC PERSPECTIVE[*]

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1) Introduction

To evaluate the role of economics in the industry and to emphasize a few important lessons learned as NASA approaches launch vehicle decisions.

Most consumer-oriented goods and services such as shoes or ice cream are priced to reflect the cost of investment, production, and marketing. Corporate decisions are made through analyses of supply and demand conditions signaled through the price mechanism.

On the other hand, market conditions for the space and launch vehicle industries have always been a stepchild of government policy and decision-making. Needs and missions of government agencies in the United States and throughout the rest of the World have controlled the access to outer space. In short, defense, security, and politics have trumped market economics.

Both public and private investment in the launch vehicle business is determined in large part by government research and development (R&D) budgets. Manufacturing plants are located either in politically sensitive localities (i.e. in the districts of influential politicians) or in strategic and secure areas. Many operational activities (launch facilities and range services) are in or very near military bases and are often performed by the government or by a private company under contract to the government. Competition exists in unique forms such as the oligopolistic bidding for government and private launch contracts where price is only one factor and often not the most important one in the contract. And, selected allocation decisions concerning the launch of government payloads are made in the political arena that excludes some competitors and rewards others. Arianespace, for example, has been barred from competing for U.S. Government payloads while at the same time the U.S. Government has an agreement with Russia (with no exchange of funds) for launching astronauts and cargo to the International Space Station (ISS) through 2005.[1] Finally, the availability of vehicles from China and Russia further muddies the economic picture of the launch industry since these nations still retain many non-market economic institutions.

This paper examines the launch vehicle industry as much as possible from a purely economic perspective, recognizing the legal, political, and security dimensions of the industry, but attempting to isolate as many of them as possible from the analysis. What could the industry look like if a free and open market approach were adopted? Would decisions that NASA and the U.S. Government made in the past have been radically different? What are the prospects for the future if decision-makers were to cut the industry free of all but the most necessary controls and let the market provide the

[1] Unless Congress intervenes or the Administration makes a decision that Russia is not proliferating specific technologies to Iran, the Iran Nonproliferation Act (P.L. 106-78) prohibits NASA from paying Russia for launch services.

services? This paper cannot answer all of these questions, but provides an analysis of the industry that has not been adequately considered by prior analyses.

This analysis is very relevant today as the appearance of entrepreneurs along with the entry into the industry of a number of new nations[2] with robust launching capabilities could open up domestic and international competition to an extent that previously never existed. How long can the governments of major space-faring nations continue to use the political system to control all aspects of launch decisions? What cost and price efficiencies might be forthcoming if launch services were "just another commodity." Can private companies survive without government support in this very high-risk business that requires very large up-front capital investments?

Beyond the history and speculation about the future, another window on these questions is provided by a brief retrospective review of the lessons learned from several of the many new U.S. Government launch vehicle initiatives that involved partnerships between the government and the private sector. This study will use as an example the X-33/Venture Star initiative.[3] These initiatives all failed to develop new operational vehicles. Their failures were a combination of technical factors and management/economic factors. We will focus on the latter, which can be just as detrimental to the success of a new high-technology program as a technical failure. Often these economic factors have been overlooked or misapplied by technical agencies dominated by an engineering or scientific culture.

[2] In recent years China, India, Japan, and Israel, all have developed competitive launching capabilities. Brazil and Australia are developing and marketing spaceports and related services and the former Soviet Union's launch systems are operated and regulated by Russia and Ukraine.

[3] Others have included the NASP (National Aerospace Plane), NLI (National Launch Initiative), SLI (Space Launch Initiative), X-34, X-38, and Shuttle Privatization initiatives. The total expenditures on these and other similar programs was well over $10 billion.

2) History vs. Current Entrepreneurial Approaches: Use of Economic Analysis

Early period (1960 to mid-1980s)

The race for technological superiority between the United States and the Soviet Union dominated the early period of the Space Age. Although there were many scientific and research experiments in the civilian space programs that required small to medium sized launch vehicles, the overall program was dominated by the race to put men on the moon. The extremely heavy lift capability needs of the U.S. Apollo Program spurred the development of the very powerful Saturn V rocket. Similar launch vehicle developments existed in the Soviet Union. No other country had a full-range launch capability in this era.

The Ariane rocket developed in Europe was a later entry into the market. Its primary purpose was to provide Europe with an independent means to access space. At the same time, and unlike the U.S. and Soviet launchers, Ariane was designed to optimize launching commercial communications satellites into geostationary orbit, the only market large enough for a potentially profitable business venture in space at the time.

Economic analyses in this era (which also included the development of the U.S. Space Shuttle) were performed to support government budget decisions to build these vehicles. Typically, government-supported estimates of the need for launch vehicles greatly overestimated the costs of producing the vehicles and severely underestimated the costs of operating them. The economic tools most commonly used were cost-benefit, cost-estimating, and cost-effectiveness analyses. It has often been documented that these tools, although conceptually sound, have failed to provide decision-makers with accurate results not only for launch vehicles, but for many other defense and space programs. The reasons are well documented, varied, and beyond the scope of this paper.[4] Rarely were market demand models constructed and when they were, they reflected perceived government needs and missions more than private or commercial applications.

Overestimates of demand were not only occurring in the government sector. In the 1980s the future demand for commercial communications satellites was also overstated. These estimates were based on the advent of direct broadcast TV services that were supposed to be available in the early 1990s. It was actually about five years later in the mid-1990s that these services began to grow. What delayed their commercial growth was not the launch sector but the unavailability of small and inexpensive home antennas. When that technology (the Very Small Aperture Terminal (VSAT)) was perfected and made available at a reasonable cost The VSAT market grew quickly.

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[4] Appendix A includes a discussion of some of the more recent examples of these studies as applied to NASA programs using CBO's 2004 recent analysis.

Other studies also misread the market. NASA sponsored a series of stdies of the commercial use of space studies in the early and mid-1970s. They ranged from case studies of specific potential new uses of space (e.g. manufacture of drugs in micro-gravity environment)[5] to macroeconomic analyses of the impact of NASA technology on the economy[6]. All pointed to robust space applications and a growing demand for space-related goods and services. And, all were conducted with NASA as the client and were tilted to the optimistic presentation of the results in order to justify continued R&D funds for NASA activities.

Of particular note were the assumptions of this era concerning the costs of access to space. Virtually every study, regardless of the bias of the sponsor[7], assumed that space transportation would become much less expensive over the next couple of decades. The basis for this assumption was twofold: 1) that a larger demand for space activity would result in the spreading of costs over more flights, and 2) on the analogy to other new technologies such as integrated circuits and microprocessors that experienced dramatic and exponential cost reductions over time through technological improvements.

The most common mistake in past economic studies has been the extension of historical trends into the indefinite future. Generally, the analysis of the historical data on launch vehicles has been accurately portrayed in the studies, given the paucity of good data on actual costs of manufacture and true contract prices charged by launch companies. The two types of extensions of the data that have mislead decision-makers are:

1. the "build it and they will come" assumptions on the demand side, and
2. the fallacy that the price for a launch will decrease from
    a. lower average costs with a surge in demand
    b. radical new technological advances that lower costs

These assumptions enabled many past studies to extend their historical analysis into the future and draw summary "demand" curves that show the average cost per kilogram launched into low earth orbit (LEO) to decrease two orders of magnitude, from approximately $20,000 to $200. Associated with this decrease in cost is a decrease in price charged to customers (including governments) that would automatically stimulate many new goods and services to be offered from space and space-related technologies.

[5] An example was the Space Industrialization Study, Science Applications, Inc., Huntsville, AL, Under NASA Contract NAS8-32197, April 1978.

[6] An example of macroeconomic economic studies of that era was: The Economic Impact of NASA R&D Spending, Chase Econometric Associates, Inc., Bala Cynwyd, PA, Under Contract No. NASW-2741, April 1976.

[7] Although most studies funded by NASA and were aimed at proactive support of the space initiatives, there were others that were neutral or critical as well. See, for example, Long-Term Prospects for Developments in Space, Brown, William and Kahn, Herman, Hudson Institute, Inc., New York, October 1977 (Under NASA Contract NASW-2924).

A Discussion of a Few of the Studies Indicating Large Potential Demand for Space Applications

A series of studies in the 1970s commissioned by NASA (particularly from the Marshall Space Flight Center) evaluated a number of potential space applications that offered possibilities for stimulating a large increase in demand for using space.[8] The economic study performed by Mathematica, Inc. that helped justify the Shuttle development program was based on a fleet of seven vehicles flying over forty times a year.[9] Unfortunately, none of these promised space technologies created the projected demand, nor did NASA have the financial resources available to build a Shuttle fleet and systems that would support the number of flights the Mathematica study based its analysis on.

The Commercial Space Transportation Study of 1994 is another example.[10] This study was performed by a coalition of major space companies in the United States. The economic methodology was logical and reasonable. They evaluated the different types of markets for using space and translated them into the needs (demand) for launches, recognizing that this demand would only occur in the future. The problem occurs when they project the demand for launch services at prices as low as $400/lb in the 2010 to 2030 time period. The number of flights was projected to rise to as many as 250/year; about one per business day. These conclusions, clearly, would support the development of a new launch vehicle system, which was the objective of the study to begin with. The problem is that the demand curves reflected the future, not the history of commercial space and launches. The fact remains that the cost of launches had not decreased between 1960 and 1994 and there was no convincing analysis to indicate that new technological approaches would be any different in terms of cost and price.

A series of studies on the economic feasibility of power generation in space were premised on the future availability of very low access costs to space.[11] Even very recent studies such as the Access study performed by Futron, Inc. clearly shows the history of relatively unchanged launch costs over time. That study realistically evaluates various elasticities of demand. Yet it also includes the unrealistic projections of much lower launch costs in the future.

Some cost reductions would be possible with an increased flight rate. But it still remains difficult today to project any costs less than $2,200/kg. ($1,000/lb), given that insurance,

[8] SAI, op. cit., also Feasibility Study of Commercial Space Manufacturing, McDonnell Douglas Astronautics Co., Under Contract #NAS8-31353, January 1977.

[9] Economic Analysis of New Space Transportation Systems, Heiss, Klaus and Morgenstern, Oskar, Mathematica, Inc. Princeton, NJ, Under Contract NASW-2018, May 1971.

[10] cite study

[11] Statement of John C. Mankins Manager, Advanced Concepts Studies Office of Space Flight Before the Subcommittee on Space and Aeronautics Committee on Science U.S. House of Representatives September 7, 2000

overhead, range costs, etc. will sum to at least $1,000/lb, even before the vehicle leaves the launch pad.[12]

The problem with these studies is not their economic methodology nor is it their analysis of historical launch events. The problem lies with the summary demand curves that include projections of very low cost access to space. The quick interpretation is clear—build new launch vehicle systems that are "cheap" and that can fly safely many times per year and the price will come down while the mass to orbit will grow rapidly.

The hard reality is that the underlying assumptions fly in the face of historical trends. Private investments in future systems occur only when identifiable markets are clearly evident. Other assumptions also have to be overcome. Launches need favorable weather conditions. Technical glitches are frequent in these complex systems. Environmental risks also have to be dealt with. Legal and regulatory hurdles can be problematic. None of these are "show-stoppers" but they all begin to erode the reality of the assumptions of these studies. Finally the biggest obstacle is the ability to develop new technology that is robust, reliable, and significantly less expensive than the propulsion systems that are now in use. Despite all the projections, this has not yet occurred, nor is it clearly on the horizon.

The common thread is the optimism that has always prevailed, in spite of 50 years of launch vehicle experience that hasn't made the access to significantly less expensive. And, most of these studies have been done by "interested parties" and under contract to either a space agency such as NASA or a major company that builds space hardware and provides associated launch services. The studies have, for the most part, been conducted to support government technology development programs that were already underway or which had been approved at the highest political levels for reasons other than their economic potential.

In summary, many decisions regarding the future use of space and how to develop new vehicles to get there have been based more on wishful thinking and overly optimistic technological assessments rather than on rigorous economic analysis. One of the major conclusions of this report is that there are two equally important parts to effective decisions: one is on technological feasibility and the second encompasses business, management, and economic inputs. **If *both* do not point to success, there is a high probability that the project will fail.** The heavy bias and the culture of an engineering-oriented R&D organization such as NASA often precludes having economic issues put on an equal footing with technological ones.

[12] An interesting recent analysis reaches just this conclusions—that there are inherent risks and costs in launches that set a much higher technical and business price floor than the assumed cost per lb. of $100 to $400 that some predict would be needed to stimulate rapid growth of the use of space for commercial purposes. When Physics, Economics, and Reality Collide, Jurist, John, Dinkin, Sam, and Livingston, David, July 2005 (draft).

Quasi-commercial period (mid-1980s to present)

Two major developments of the early and mid-1980s began to move the launch industry away from governments and into the commercial sector. The first was the successful development and launch of the European launch vehicle, Ariane. Although heavily subsidized by ESA and the French Government, the company, Arianespace, was structured as a private enterprise with the objective of providing launch services optimized for putting commercial communications satellites into Geostationary orbit. Over time the company has successfully captured over half of the worldwide commercial launch business.

The second development was the loss of the Space Shuttle Challenger in 1986. The United States had made the decision in the late 1970s to put virtually all of its civilian government and commercial launch payloads on the Shuttle vehicles (in part to build up demand so that the proposed fleet of seven vehicles could be used to its fullest extent and validate the economic/cost assumptions from earlier studies). With the loss of the Challenger and the realization that the U.S. could not rely on just one type of launch vehicle, a series of steps were taken that include the stimulation of private companies to develop commercial expendable launch vehicles.

The Commercial Space Act of 1984 established the foundation for this endeavor. It set up the U.S. Department of Transportation (DOT) as the promoter and regulator for the industry.[13] At the same time, the Department of Defense (DOD) approved larger orders of Expendable Launch Vehicles (ELVs) in order to stimulate companies to take advantage of scale economies and enlarge the production line for ELVs. Some entrepreneurs even formed fledging new companies such as TransSpace, Inc. in order to market the Delta launch vehicles commercially.[14]

The major customer of launch vehicles remained governments, but private companies were encouraged to bid for government launch contracts and were also actively seeking domestic and foreign customers. Because of the high level of regulation and the continuing reliance on the government for business, the industry has remained far less than truly commercial, but with a structure that now permits and encourages new private sector activity.

Entrepreneurs and Non-U.S. Vehicles (Present and future)

The advent of the array of new entrants into the launch services industry has the potential for changing the economic and market environment. Adding to the mix of players in the industry are a number of new entrants into the business from nations with maturing space programs and capabilities. Besides Europe, Russia, the Ukraine, and China, there are launch vehicles developed or being developed by India, Japan, Korea, and Israel. Brazil

[13] Commercial Space Launch Act of 1984, as codified at 49 U.S.C. §§ 70101–19 (2000). Subsequently, the functions were transferred to the Federal Aviation Administration within the DOT.

[14] ***insert new footnote and reference.

and Australia have launch facilities and actively hope to attract private customers to use their launch services.

Within the United States in the past several years a number of new, privately funded companies developing space capabilities have emerged. Kistler Aerospace and SpaceX both are developing launch vehicle systems capable of launching all but the largest payloads. (Both companies are targeting the near-term market for transporting cargo into space, but they also have human transport to space in their future plans.) Others are focusing on different market niches such as the winner of the "Ansari X" prize competition, Scaled Composite's SpaceShipOne's planned offering of suborbital passenger flights. Transformational Space Inc. is developing a vehicle for use in space to transfer payloads from one orbital location to another.

Although none of these companies has yet successfully launched a payload into an orbit around the Earth, they represent a new era in space that opens up many options to potential customers including NASA. What remains to be demonstrated is their ability to provide services equivalent to companies operating today's vehicles such as the Delta, Atlas, and Ariane launchers at a price that will be low enough to radically change the way we think about and use the space environment (that is, following on the projections of past economic studies, a price that is at least one order of magnitude lower than current prices, or about $2,000 per kg.).

We conclude in the analysis that follows in this report that their ability to offer services at a price that will revolutionize the use of space by both the private sector and the government is highly unlikely in a current business planning time frame of the next ten years. However, if they are technologically successful with the planned vehicles, they will have the potential to lower the price of a launch by significant increments, expecially if competition is allowed to play a strong part.

3) Why is Economic Analysis So Difficult?

The market for launch vehicles is not the same as the commercial market for most goods or services. It does not respond predictably to price changes in large part because resources are not allocated according to supply and demand conditions. And, since governments heavily subsidize launch vehicles, competition is often not "free and open." It is common for many other products and services in the economy to face government regulatory actions, to have defense agencies as well as civilian customers, and even to receive subsidies from governments. Yet the launch vehicle industry has to deal with all of these factors together to a much larger extent than other economic sectors.[15]

The industrial structure of the launch vehicle industry is fairly straightforward. There are a handful of firms worldwide that design and build launch vehicles and provide launch services such as payload integration and tracking and data handling. The industry is an oligopoly that heavily relies on research and development funds from governments and sells approximately 40 launches per year to government agencies and another 20 launches to private firms. As mentioned above, currently several small entrepreneurial firms that expect to provide similar services at lower cost are challenging this oligopoly.

It should be a straightforward and standard economic exercise to measure a demand curve and cost curves for these vehicles and services. But it is not because:

- Most launch vehicles are heavily subsidized by governments,
- The price charged to governments may not reflect the true costs to the government (i.e. infrastructure, internal R&D and other support functions such as tracking and data retrieval,
- The price of a launch is only one of many considerations for a commercial launch (others are: reliability, risks, on-time guarantees, re-flight options, insurance, etc.)
- There are many different destinations in space that require vehicles with different capabilities for:
    - LEO, MEO, GEO orbits, and deep space probes
    - Different planes and inclinations
    - Varying size (weight) of payloads
    - Human vs. cargo vehicles
- Each payload and customer generally requires customized services
- Demand for launches is derived from the various uses of space technologies that can range from telecommunications to Earth observations to human exploration
- Many vehicles that compete commercially are marketed through nations such as Russia and China that are historically non-market economies (i.e. the monetary system is not the "clearing house" for allocating resources)

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[15] The nuclear power industry probably comes closest to having parallels to the launch industry in these respects. However, there is a longer history of successful commercial business in nuclear energy and many of the trade issues have been resolved. Nuclear power also competes with other energy sources and therefore the price for nuclear power is tied to the market price of energy in general. No such pricing baseline exists for launch vehicles and services.

- Politics can overwhelm economics, even in mature market economies
  - Non-proliferation considerations
  - Export controls on sensitive technologies
  - Permitting or denying permission for launches based on political grounds
- Ultimate liability for private activities in space rests with the government of the launching/owner State which necessitates strict licensing/regulatory structure.
- The vertical integration of the industry as a result of mergers (e.g. Boeing acquiring Hughes, and EADS acquiring Astrium) has created the potential for bundling of products and services that would make it difficult for an outside analyst to separate the launch from other costs.
- There are too few launches in a particular year for each class of vehicle, payload, or destination to get an accurate snapshot of the price-quantity relationship which are necessary data inputs for a demand analysis.

Because of these non-economic factors and because there isn't a clear separation between the many different "markets" for launch vehicles, constructing a meaningful set of economic data to analyze demand, supply, and associated measures such as the elasticity of demand can never be as precise as it might be for a normal consumer commodity.

This study has evaluated prior attempts to develop an economic model of the launch vehicle industry and constructed a new set of price/quantity relationships for different classes of launch vehicles that provide commercial (and government) launch services. Although general conclusions and lessons learned can be made from this model of the industry, the economic analysis has to be used for general guidelines rather than as a precise estimator of current market conditions.

4) Role of Economic Analysis in NASA Decision Making

Examples from past launch vehicle programs

NASA, alone and in combination with the Department of Defense, has a long history of both successful and unsuccessful launch vehicle programs. Successions of failed or cancelled programs during the past 15 years have cost the U.S. Government upwards of $10 billion. One of the primary stated objectives of all of these programs has been to lower the cost of access to space—clearly an objective that is economic. Research and Development (R&D) expenditures for new technologies will continue to be expensive, but particularly in combination with partnerships with private firms, governments have attempted to reduce their direct outlays over time. The way to do this has been through new launch vehicle technology developments that have the promise to be less expensive to operate such as:

- Reusable vehicle or reusable components
- Single stage to orbit vehicles
- Radically new launch methods that do not use chemical propulsion.

The manufacturing and operating costs of launch vehicles can also be lowered through:

- Efficiencies in current production and operations
- Economies of scale from producing many more vehicles

Since NASA is an R&D agency, the cultural push is to develop new technological breakthroughs to eventually lower the cost of access to space. The other methods of reducing costs are largely left to the government contractors producing the vehicles and/or the commercial applications sector to find new ways of using space to increase demand and stimulate larger production runs.

From an economic perspective, there are several problems with meeting the objective of significantly reducing the cost of access to space.[16] They are:

- The cost of a launch is not the same as the price paid to a company for a launch.
- Government R&D is valued in the national economic accounts as a sunk cost—one that is not expected to be recovered and is not factored into marginal costs. In the private sector R&D is expected to be recovered during the life cycle of a product.
- Production and operating efficiencies cannot reduce the cost or price by an order of magnitude or more.

[16] A significant reduction in cost can be interpreted in many ways. In this analysis it will signify a reduction of an order of magnitude or more. This is the objective that many believe will create the threshold conditions for opening up space for many economically profitable opportunities. This conclusion is arguable since there is no proof that assumption is correct.

- Prices charged will be as much above average costs as the market will bear. New entrants are likely to set prices just below existing competitors and those prices certainly will not equal minimum average production costs.

The pricing of any good or service in a market economy is based on companies attempting to maximize profits. How that is done depends on a number of factors including the degree of competition in the industry, the market share the firm possesses, and a host of other basic economic conditions. A firm must, in the long-run, at least cover its costs of production. Those costs include the R&D.[17] A private firm, therefore, will have to set prices high enough to recover its full expenditures.

A government agency has the option of internally funding R&D and of manufacturing in government facilities. NASA, for example, funded the Space Shuttle (but chose to have it built by a private contractor in a company facility). When pricing launches the government uses the "marginal cost" of the flight. For a dedicated mission, the calculations approximated the annual cost of the Shuttle operations to NASA (in recent years approximately $4 billion/year) and divided that figure by the number of flights per year (5 to 8 flights before the Columbia accident). Therefore the minimum marginal cost was about $500,000,000 per flight.[18]

With one exception, a private company could never make a profit using the type of calculations the government uses. That exception is when a government subsidizes a company building a launch vehicle through direct R&D investments. Then, the company only has to recover its own up-front investment that would be many times smaller than if all of the funding were privately obtained. Different variants of this method are sometimes labeled Public-Private-Partnerships (PPPs). In the U.S. an example was the X-33/Venture Star program with NASA and Lockheed-Martin as the partners (see below).

As long as existing launch vehicles are able to have a dual pricing/costing environment, the cost of launches will remain high. Dual pricing occurs when companies can charge according to market conditions for commercial launches but have different arrangements for some customers; for example, the government. For government launches the price is usually higher since it is important for non-economic reasons (political, security, etc.) for governments to insure that the companies keep the production lines open. The Evolved Expendable Launch Vehicle (EELV) is a good example of this. The U.S. Government continues to heavily subsidize this vehicle by both paying premium prices *and* providing extra funds when necessary.[19]

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[17] Exactly how much of the R&D is recovered may depend on government tax policy which includes several different options for tax relief to stimulate corporate R&D expenditures.

[18] As noted below in Figure 2, this analysis assumed a range of marginal costs for each Shuttle flight from $100 million to $1 billion. The low figure was what NASA calculated would be the marginal cost in the late 1990s during an initiative to study the privatization of the Shuttle. The high figure would be the cost if the $4 billion annual budget for the Shuttle were divided by 8 flights per year. Current policy has prohibited NASA from putting all but "secondary" commercial payloads on the Shuttle.

[19] The additional investment of $1 billion in 2005 is a good example of these incremental subsidies. In addition, it has been reported that the cost overruns in the EELV program have been very large. The consolidation of Boeing's operations and Lockheed-Martin's in the new organization, United Launch

Based on past experience, the costs of an entirely new launch system to met either the very heavy lift requirements of NASA's Exploration Initiative or that will be a reusable human-rated vehicle will be very large, possibly ranging from $30 billion up. This is clearly beyond the means of most private companies. Even if a company were to find the funds and build a vehicle that would meet both financial and technical objectives, the price charged would not be instantly "an order of magnitude" less than current costs. Perhaps over a period of many years such a company can lower costs and prices significantly, but only when it has recovered its investment outlays.

In other words, the bottom line is that governments and commercial companies wishing to use space will have to continue to pay very high access prices for the indefinite future: prices that will not be near the estimated threshold levels to radically alter the market for using space.

NASA's need for exploration will contribute to the development of new technology in launch systems and will stimulate demand for launch vehicles. Yet these demands will be insufficient to alter the basic market economics of this industry. NASA has a need to use launch vehicles that conform to NASA specifications. Further, the number of launches of such a vehicle will be relatively low even compared to the very modest number of worldwide launches per year. A commercial launch company is unlikely to develop a vehicle to these specifications unless there is also a sizable private market; a very unlikely prospect given current conditions.

Alliance (ULA), will also factor into the cost calculations—but since this is very new, it is unclear whether the costs will decrease significantly as the companies claim, or will increase over time. What is clear is that it will be increasingly difficult for the Delta IV and the Atlas V series of launchers to effectively compete against each other in the commercial market, regardless of the press release claims upon the formation of the ULA. Recent news reports (Wall Street Journal, 13 September 2005) indicate that there are serious issues still being negotiated between Boeing, Lockheed-Martin, and the Air Force which, unless solved, could result in the cancellation of the plans.

5) Economics and Management Lessons Learned from Past Major New Vehicle Programs

A Brief History of New U.S. Launch Vehicle Programs

In 1972, President Nixon approved NASA's plan to create the first reusable launch vehicle, the space shuttle, and directed that it become the nation's primary launch vehicle, replacing all the existing ELVs. The resulting high launch rate was expected to reduce the cost per flight significantly. The shuttle was first launched in 1981, and was declared operational in 1982.

On January 28, 1986, the space shuttle *Challenger* exploded 73 seconds after launch. This accident deeply affected U.S. space launch policy, demonstrating the vulnerability of relying too heavily on a single system. Many military and civilian satellites had been designed to be launched on the shuttle, and could not have been transferred to ELVs even if the ELVs were not already being phased out.

Consequently, the Reagan Administration revised U.S. launch policy from primary dependence on the shuttle to a "mixed fleet" approach where a wide variety of launch vehicles are available. President Reagan also decided that commercial payloads could not be flown on the shuttle unless they were "shuttle-unique" (capable of being launched only by the shuttle or requiring crew interaction) or if there were foreign policy considerations fostering commercial space launch business. That action eventually facilitated the emergence of a U.S. commercial space launch industry whose participants had long argued that they could not compete against government-subsidized shuttle launch prices.

Despite many efforts to reduce their operating costs and improve capacity, U.S. expendable and reusable launch systems remained expensive and less efficient and reliable than desired. DOD and NASA initiated several efforts in the late 1980s and early 1990s to develop new systems, but each was terminated in turn because Congress or the agencies themselves were not convinced that the required investment had sufficient priority.

On August 5, 1994, President Clinton released a National Space Transportation Policy (NTSP) that gave DOD lead responsibility for improving ELVs and NASA lead responsibility for upgrading the space shuttle and technology development of new reusable launch vehicles. The policy also encourages an expanded private sector role in space transportation R&D.

In response to the Clinton policy, the two agencies initiated two programs: DOD's Evolved Expendable Launch Vehicle (EELV) program and NASA's Reusable Launch Vehicle (RLV) program.

The first of two goals established by the NSTP for the National Aeronautics and Space Administration (NASA) was to "continue to maintain the capability to operate the Space Shuttle fleet and associated facilities." The second goal for NASA was to be the "lead agency for technology development and demonstration for next generation reusable space transportation systems, such as the single-stage-to orbit concept."

From 1995 to 2000, NASA's approach was based on establishing new forms of cooperation with industry by sharing the costs of developing technology with the intent that industry take over development, operation, and financing of the operational vehicle. Two "X" (for "experimental") flight test programs were begun: X-33 and X-34.

X-33 was a joint program with Lockheed Martin to build a subscale prototype of a large RLV based on single stage- to-orbit (SSTO) technology. The ultimate goal was for *Venture Star* to be capable of delivering payloads into low earth orbit for $1,000 per pound (an order of magnitude reduction from the $10,000 per pound cost of existing launch systems). The X-34 was a small RLV "testbed" to demonstrate reusable two-stage-to-orbit technologies, which was being built under a traditional contract with Orbital Sciences Corporation.

NASA terminated X-33 and X-34 in March 2001 because it judged the costs to complete them was too high relative to the expected benefits. NASA spent $1.2 billion on X-33– although no flight vehicle was ever tested., and Lockheed Martin said that it spent $356 million of its own funding. NASA spent $205 million on X-34.[20]

The failure of the X-33 and X-34 programs, and of the National AeroSpace Plane (NASP) program before them, made some observers skeptical about NASA's ability to develop a 2nd generation RLV. In documentation accompanying a November 2002 budget amendment, NASA conceded that a new RLV lacked economic justification.

NASA restructured its RLV program in 2000 (as part of its FY2001 budget request) and initiated the Space Launch Initiative (SLI). It then restructured the SLI program in 2002 into two components: building an Orbital Space Plane (OSP), a spacecraft (not a launch vehicle) to take crews to and from the space station, and developing "Next Generation Launch Technology." The goal was to develop RLV technology that would be "10 times safer and crew survivability 100 times greater, all at one-tenth the cost of today's space launch systems." President Bush's announcement of the Vision in January 2004 led to the termination of the SLI Program.

DOD began what is now known as the EELV program in FY1995. The EELV program's objective called for the development of a expendable launch capability for assured access to space that would reduce the overall recurring cost of launch by at least 25 percent to 50 percent while maintaining or improving the reliability and capability levels over those of the heritage systems. The Air Force further identified four EELV system capabilities referred to as key performance parameters (mass to orbit, vehicle design reliability,

[20] See Congressional Research Service, Ref. #39.

standard launch pads, and standard vehicle interfaces) considered essential for mission success.

Two EELVs were developed in joint government-private sector programs: Boeing's Delta IV and Lockheed Martin's Atlas V. Both vehicles have successfully entered service. Originally, one of those companies would have been selected in 1998 to develop the EELV. In November 1997, responding to indicators at the time that the commercial space launch market would be larger than expected, DOD announced that it would help fund development of both Atlas V and Delta IV. In October 1998, DOD awarded Boeing $1.88 billion for the Delta IV ($500 million for further development plus $1.38 billion for 19 launches), and awarded Lockheed Martin $1.15 billion for the Atlas V ($500 million for further development plus $650 million for 9 launches). The companies were expected to pay the rest of the development costs themselves. (Boeing officials state that Boeing invested $2.5 billion in design, development, and infrastructure for the Delta IV, of which the company wrote off $2 billion.) In 2000, however, new market forecasts showed a reduction in expected commercial demand, and DOD began reevaluating its EELV strategy. It renegotiated the contracts with both companies. The companies also approached DOD to obtain additional government funding because of the downturn in the commercial market. This is called "assured access to space" in the sense of assuring that both companies remain in the EELV business so DOD has redundancy in capability should one of the launch vehicles experience difficulties.

DOD notified Congress that the EELV program breached the "Nunn-McCurdy" limit of 25% cost growth, which requires DOD to cancel or restructure the program, or certify that it is essential to national security. In April 2004, DOD made that certification.

Table 1 summarizes the programs described above as well as other initiatives to develop reusable launch vehicles that could significantly lower the costs of access to space.

Table 1: Federal Investment in RLV Programs

Program	Investment	Overview
X-20 Dynasoar	~$400 million	Initiated in 1957 by the USAF to develop a reusable-piloted glider, with a small payload capacity. Cancelled in 1963 due to the complexity of the technology, rising costs, and competing budget priorities
Project START	~$1 billion	Initiated in 1963 by USAF to pursue manned space plane concepts. Cancelled in 1975 after a 12 year test flight program, which conducted more than 80 test flights and compiled a wealth of information on lifting body design
Space Shuttle	$11.4 billion initial development	Initiated in 1972 by NASA to provide human access to space. This "refurbishable launch vehicle" has conducted over one hundred flights, but remains extremely expensive to operate ($3.8 billion annually)
X-30 National Aerospace Plane	$3-5 billion	Initiated in the mid 80s by the DoD to develop a hydrogen-powered, single-stage-to-orbit air/spacecraft capable of horizontal takeoff and landing, operating at orbital speeds (Mach 25), and sustained hypersonic cruise

		within the atmosphere. Cancelled in the early 1990s prior to the production of a test flight vehicle
Delta Clipper Flight Experiment	$50 million	Initiated in 1991 by the Ballistic Missile Defense Organization to develop a reusable launch system to support the organization's multiple launch requirements. Terminated in 1996 following destruction of DC-XA vehicle during a test flight.
X-33 Advanced Technology Demonstrator	$1 billion	Initiated in 1996 by NASA to reduce business and technical risks, which would enable privately financed development and operation of a low next generation space transportation system. Cancelled in 2001 due to significant technical problems and budgetary considerations.
X-34 Technology Testbed Demonstrator	$ 219 million	Initiated in 1996 by NASA to validate key reusable launch vehicle operations and technologies. Cancelled in 2001 due to budgetary considerations.
X-37 Advanced Technology Flight Demonstrator	$ 301 million	Initiated in 1998 by NASA to test technologies for both the orbital and reentry phases of flight.

Source: RAND, National Space Transportation Policy. Issues for the Future. Science and Technology. October 2003

What is interesting and often overlooked in this industry is the steadily declining role of NASA in launch vehicle development. Most of the responsibility has been delegated to either the DOD or to the private sector, and after the X-33 and SLI cancellations; NASA's role is far more advisory than actually contracting for the R&D behind new launch technology.

It appears that NASA will have a much greater role in developing launch vehicles for the Exploration Initiative. The February 2004 "Vision" directs NASA to procure launch services from the private sector where possible and only reserves the option for NASA to invest in R&D for new vehicles if they cannot be obtained through other means. Given that a very heavy lift vehicle will be required for the lunar and Mars missions NASA is planning to invest and mange funds aimed at a new launch system.[21]

[21] On September 19, 2005 NASA released its new plans for the Exploration Program. Although NASA clearly will procure launch services when possible, the plans call for developing a new heavy lift vehicle (capable of lifting 125 metric tons to low earth orbit) using Shuttle derived technologies. In addition, NASA will develop the Crew Exploration Vehicle which will be used to transport cargo and humans to the moon and to the space station as well as return to Earth.

6) The X-33 Program: an example of the failure of economic inputs[22]

The Holy Grail of space transportation has always been the reusable launch vehicle, possessed with an ability routinely to launch payloads to orbit, over and over again with minimal refurbishment, much like modern passenger aircraft do today. Since operational costs consume some 30 percent of overall space transportation costs, a system that can operate routinely and efficiently promises to reduce significantly the cost per pound of reaching orbit.

Building such a craft is technically and managerially highly demanding, requiring substantial investment in new technology and innovative construction methods. Constructing the support system needed to launch and operate such a launch vehicle also brings significant challenges. It needs to be simple and efficient, capable of servicing and refurbishing the vehicle quickly with a minimum of operational personnel. At today's level of technology development, a single stage vehicle requires the development of revolutionary propulsion technologies at extremely high cost.

Because the launch system would serve a variety of launch needs and therefore be potentially attractive to private investors, NASA developed a plan to attract private financing for the project. It invited cost-sharing development proposals for a system that became known as the X-33, which was to be a single-stage-to-orbit launcher powered by a liquid-oxygen, liquid-hydrogen engine. The terms of the contract selection included provisions to examine the proposer's business plan for the vehicle. It also assumed that the winner would assume a significant proportion of the technical and market risk for the vehicle. In return, the private firm would be able to develop a private market for the vehicle (commercial and other non-U.S. government launches). The overall focus of the technology development was to economic: reduce operational launch costs.

Lockheed won the contract to develop the system, which it called VentureStar. Its design, fully supported by NASA, included lightweight graphite-epoxy composite tanks for the liquid oxygen and hydrogen and a linear aerospike engine. Both were, and remain, revolutionary technologies that will require much more time and funding to develop than was available to Lockheed Martin. NASA also set a demanding development schedule for the project with a highly constrained budget. There was little margin available for unexpected technical snags, though several "breakthrough technologies" were needed to achieve the desired technological and operational goals.

Little discussed at the time, at least openly, were the economic and market difficulties of satisfying the launch demands of the many future launch customers. They included:

- Serving multiple political constituencies (NASA, White House, DOD, Congress, Corporate)

[22] Many of the observations in this section are adopted from: Lane, Carol, *Lessons from X-33,* Presentation, August 17, 2004.

- Serving multiple customers (NASA, DOD, NOAA, commercial satellite operators)
- Carrying cargo to several different destinations (LEO, MEO, GTO) and
- Carrying human crews to LEO.

There was also little appreciation of the potential difference between the cost of a launch and its likely price in the launch market. Unless several firms entered the launch market with competing launchers, the firm developing the SSTO was likely to set the price just below the current price of an expendable launcher in order to recover its development costs and to earn a substantial profit.

Another factor that affected project success was the skepticism of private investors concerning the project. Bluntly put, corporate and Wall Street investors needed to be able to foresee predictable revenue from a new launch system. Yet market studies did not support the contention of SSTO proponents that substantially lower costs for space transportation would lead to substantially higher launch volume. Barring sufficient market data to support the financial risks of investment, investors wanted assurances that sufficient funding would become available from corporate or federal sources to underwrite substantial proportions of development costs or sufficient assured customers for an operational system to assure a reasonable profit for their investment.

Between 1996 and 2001 the management environment for the X-33 program changed dramatically, both at NASA and in the industrial environment within and outside of Lockheed. NASA became risk adverse. Technical problems that were envisioned as joint efforts between NASA and Lockheed were shifted from NASA to become the responsibility of the contractor alone.

Every teammate changed during the five years of the program. Lockheed became Lockheed-Martin. Rocketdyne/Rockwell became part of Boeing. Allied Signal merged with Honeywell. Rohr merged with BF Goodrich. These mergers meant rapid changes in personnel. The merger of the largest partner, Lockheed with Martin Marietta Corporation also had a profound change in the importance of the X-33 project to the company. The percentage of revenues the X-33 program represented of the combined company was much less, therefore making decisions on the X-33 a lower priority within Lockheed-Martin.

Finally, the external market environment for space applications, particularly communications services, collapsed during this period of time. Optimism turned towards pessimism. Enthusiasm for new LEO satellites dwindled in the financial community. And, therefore, access to the debt and investment markets for space projects became difficult.

Funding became an even more critical issue when Lockheed-Martin ran into major technical issues in developing the lightweight hydrogen tanks. Liquid hydrogen is extremely reactive and difficult to contain in composite tanks. Yet the composite tank construction was needed to keep overall vehicle dry weight within acceptable levels. The linear aerospike engines also experienced development problems. NASA was under significant pressure to show acceptable progress, but it soon became clear that considerable amounts of additional funding would be needed.

By April 2001, the X-33 program was history, its promise to reduce launch costs unfulfilled. Analysts cite a number of causes for the failure, including technical, political, managerial, and economic factors. Perhaps the most important reason was the failure to subject the project to cold, hard technical and economic analysis. From the start, technical and economic optimism pervaded the program. Skepticism about the project's viability became politically unacceptable.

At bottom, X-33 failed because of three primary factors:

- A mismatch in expectations and goals among different players: government agencies, Congress, vehicle developer, and commercial launch customers;
- Inadequate understanding of the commercial marketplace and market risks among government decision makers; and
- Overly optimistic technical and market goals

The failure of this project demonstrated that in a public-private partnership arrangement, an understanding on the part of both parties of the business and management risks is every bit as important as an appreciation of the technical risks.

A successful project that has commercial uses in its strategic or business plan also requires the type of hardnosed analysis that private companies apply to investments in new products. As witnessed by the many new products that fail the marketplace, this type of analysis is no guarantee of success or private sector profitability. The lesson for a governmental or public organization such as NASA is that the discipline needed to perform *and* adhere to that type of analysis is quite difficult in a highly charged political environment. And, if a realistic business/economic based analysis is not an integral part of the program, the chances of failure in a PPP are multiplied many times.

7) Analysis of the Economics of the Launch Vehicle Industry in 2005:

Objectives:

This study was designed to evaluate several important hypotheses about the economics of the launch vehicle industry and NASA's influence on the market. They are:

- The demand for heavy lift launch vehicles is inelastic.
- Launch vehicles designed for smaller payloads have a more elastic demand curve.
- Reducing the *cost* of a launch will not automatically translate into a reduction of the *price* charged for a launch.
- NASA's needs are not sufficient to change the demand function or the overall economics of the launch vehicle market.

A full understanding of these very basic economic observations will demonstrate the problems of current thinking and planning for future launch vehicles. Extending the analysis can lead to creative potential future policies that could result in a market-driven evolution toward expanding the commercial and government potential of space.

One caveat must be repeated. This study isolated economic rationales as much as possible, from legal, political, and military/security issues involving launch vehicles and the use of space. The latter are purposely suppressed at this stage of the study so that a far more clear view of space transportation from a market perspective can be evaluated.

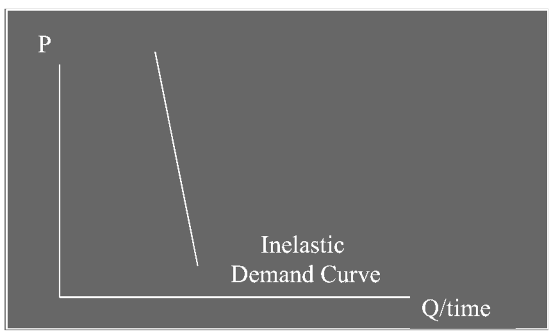
A Digression: Economic Terms Defined

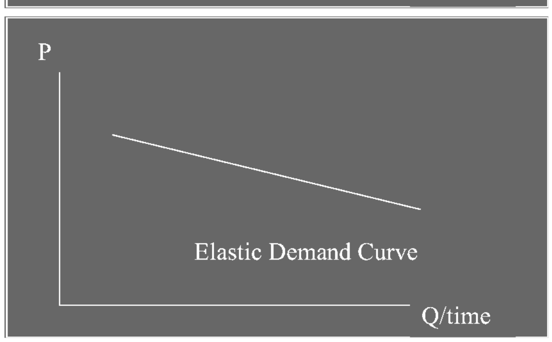
A demand curve shows the relationship between a price charged for a good or services and the quantity purchased. It reflects the willingness of customers to pay for the product based on the needs, uses, and, for business customers, the profit that can be made purchasing the product at a particular price.

The elasticity of demand is a measure of the sensitivity of the demand curve with respect to a change in price. If a company lowers the price, the elasticity measures not only how much more will be sold but the impact on the total revenue of the firm—will receipts go up by an equivalent amount or not. An elastic demand curve shows a large change in quantity demanded is associated with a small change in price. That is, if price is lowered, the amount purchased increases disproportionately. An inelastic demand curve indicates that a change in price will not alter the amount purchased very much. Elastic demand curves are generally associated with luxury type goods—ones that consumers will buy at low prices but they really don't need to buy or can postpone their purchases until the price is lower. Inelastic demand curves are characteristic of goods that must be bought at any virtually any price. Medicine for a sick patient is a good example of goods with an inelastic demand.

For comparison purposes, the elasticity for some normal consumer goods is as follows: beer and pleasure boats are very elastic (above 2.5), food inelastic (0.5), and cigarettes extremely inelastic (0.11).

The diagrams below illustrate the above principles.





Supply curves show the costs of producing a good or service and indicate what amounts of the goods or services companies are willing to offer on the market at various prices. Companies in their pricing decisions evaluate the costs of raw materials, labor, overhead, as well as a normal profit.

Measuring demand, economics, and launch vehicles:

Heavy lift vehicles such as the EELVs (Delta IV and Atlas V) are used for large payloads, which are often defense/security related satellites, and telecommunications satellites placed in Geo-transfer orbits. The price paid for a launch for one of these satellites is not the only criterion that is important to the customer. In the case of defense payloads, reliability and assured access to space are more important than the actual price paid.

For private communications satellites with many transponders onboard, the total cost of the satellite and the launch is reduced to a modest fraction (between 10% and 20%, depending on whether insurance and ground systems are included) of the revenues that are generated from the sale of services over the ten to fifteen year lifetime of the satellite. This makes the price of both manufacturing the satellite and launching it relatively unimportant to the overall business plan and life cycle net revenues.[23]

Thus, in both the government and many private cases, the major economic factor in launching decisions is not price and the fluctuations of a few million dollars or a few percentage points in either direction will not change the demand for launch vehicles. **Even though delays, reliability, insurance, and other criteria can be translated into costs and prices, the market price of a launch is not the only important determinant of the choice of a launch vehicle.** Demand for heavy lift vehicles will be price inelastic.

The demand for launching smaller payloads is likely to be more sensitive to price variations. Smaller payloads are often scientific, research, or offer specialized services. A delay in launch is often not as important to the client. The cost of these payloads, although not insignificant, is not as great as with a large satellite, therefore less up-front money is involved and the time-value of money assigned to risks of delay are not as great. Also, since the costs of developing smaller launch vehicles are less, there are more vehicles and options available to customers, which generally will result in more price competition. Thus if the price of a launch is greatly, a larger market is likely to develop. In economic terms, the price elasticity of demand for this class of launchers will be more elastic.

Reducing the cost of a launch vehicle will not necessarily reduce the total cost of a launch by the same amount or percentage

If the government were to design, manufacture, and operate a launch vehicle completely from government facilities using only civil servants, the total budgetary cost of developing and operating the system would be relatively easy to calculate. The price the government might charge to a non-government user could be determined from a large

[23] These factors are applicable for satellites with along life-time in space. Telecommunications satellites may produce revenues for 10 to 15 years after launch. Other space applications that require frequent trips back and forth to space will have a very different financial profile and will only be successful if there is inexpensive access to space available.

variety of options. These options range from completely non-economic political objectives to prices based on economic and business analyses. Because U.S federal policy treats R&D costs as "sunk", or unrecoverable, agencies generally charge "marginal costs." These marginal costs are not the same as those a private business might calculate (i.e. the additional cost for the next unit of output). Instead, the government usually takes an average annual budget for the operations of a program (in this case a launch vehicle) and charges according to the average cost per year per unit of output.[24]

A private firm operating in a competitive environment would have a very different pricing structure. First, a firm has to recover its net investment in both R&D and in plant and equipment.[25] Second, the firm will include in its costs a profit margin. Third, the firm will try to maximize its profits to the extent the competition (or lack of it) will allow. Thus, the actual cost of a privately financed launch vehicle will not be the same as the price it will charge to a customer. The price can be much higher than costs if there is little or no competition. Or, in the short-run, the price can even temporarily be below costs for a new firm attempting to enter the market or for a firm with excess inventory. Clearly, a firm cannot price below costs and stay in business over a longer period of time.

The launch vehicle industry is a mixture of government and private funding. Large government R&D contracts are performed by private industry in the U.S. Included in those R&D funds are Independent R&D (IR&D) money that permits the firms to invest in additional R&D of their choosing with the government funds. In addition, companies use privately generated funds for R&D, some of which is directed toward future government work and some is directed toward commercial goods and services. A fee above the cost to the companies is included in government contracts. Since the government is the primary customer of these companies for launches, the price paid per launch by the government will be determined by the negotiating power of the company along with whatever competition there might be among the few companies able to bid on government contracts for launches.[26]

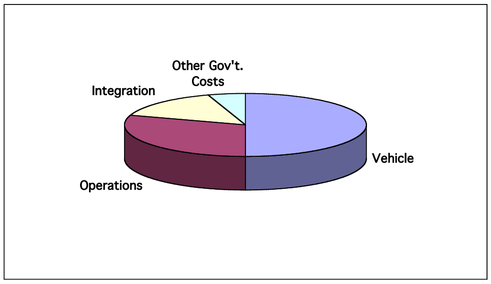
Therefore, the cost of a launch and the price of a launch are two different things and should not be confused. It is quite possible that the actual cost of accessing space could decrease, but the price paid to access space may not reflect this. This is particularly exaggerated where there are few firms and relatively little competition.

The Launch Vehicle as a Percent of Total Launch Cost

People generally assume that the development of a new low-cost launch vehicle would reduce the cost of access to space. This is only partially correct.

[24] There are many ways to calculate government costs and prices. Some are mandated by the OMB in its regulations; others are left to the discretion of the Agencies.
[25] The investment less any tax benefits. R&D expenditures, for example, can be amortized over time and can also qualify for tax credits.
[26] The actual prices paid by the government are held as proprietary information, making an economic analysis and comparison to commercial prices difficult (see below).

The 1994 study of DOD launch vehicles (mainly Titan and Atlas) showed the breakdown of the various components of a launch. The vehicle was only about half of the total cost. The remainder was divided among operations (30%), payload integration (5%) and “other” government costs (15%). [27]



However, the entrepreneurial firms now engaged in developing launch vehicles estimate that the vehicle manufacturing costs are closer to 75% of the total costs. [28] They appear to have been able to find efficiencies in overhead and in such operations as payload integration and tracking and data handling. In addition, although regulatory costs are significant, they are not foreseen as a major percentage of the total costs. The exception is the export control laws that are costly and time consuming for companies involved in partnerships with non-U.S. firms. Insurance costs may be harder to predict since the price of insurance can vary with external factors (such as a major hurricane or other disaster) that influence the amount of funds in the insurance pool available to underwriters.

Additional Observations

Over the years the manufacturing base for space components has changed dramatically. The number of suppliers to the major space companies is much smaller. Specialty companies have either been acquired by larger companies, gone out of business, or are now found abroad rather than in the United States. Fewer suppliers leads to less price competition, most often resulting in higher prices for components, more variable quality controls, and lack of availability. This has led entrepreneurial companies such as SpaceX to develop in-house capabilities for their launch vehicles.

Customization of launches will also have a dramatic effect on the price of the launch. Even a vehicle such as the Space Shuttle that has flown over 100 times has had to be modified each time to accommodate the specific payload and mission of the flight. Expendable vehicles, likewise, incur varying degrees of modification for each launch.

In short, there is no such thing as a standardized launch. Each launch is unique (and consequently expensive).

One way entrepreneurs expect to quote and maintain lower prices is to offer a standardized launch. However, given the predisposition of launch customers to want to modify and “tweak” a vehicle for their particular needs, it remains to be seen if the prices that are actually paid for specific launches of these new vehicles will be as low as advertised. It is almost self-evident that companies will charge much higher prices for customization.

[27] DOD Space Launch Modernization Plan, 12 April 1994
[28] Conversation with E. Musk, President of SpaceX, June 2005.

Some of the entrepreneurial firms have also obtained contracts from the U.S. DOD for launch services. There are often additional burdens associated with DOD contracts such as technical oversight, audits, and issues dealing with security. These translate into higher costs that have to be reflected in the price of the launch.

The question for the future may revolve around whether there can be a radical change over time in the industry to design payloads to fit a vehicle rather than altering the vehicle for each payload. Will policy and uses drive launch vehicles in the future to be a standard assembly-line truck or will they be customized Rolls Royces?

Study Method, Findings, and effect on U.S. perspective(s)

Up to this point, the report has focused on the reasons that estimates of the demand for launch vehicles have failed the test of reality and have contributed to misleading interpretations of the future. Economic studies have been used for decision-making in both the public and the closely coupled private aerospace sector in the United States to support what are essentially non-economic goals and objectives.

Below we report on what can be accomplished to measure the elasticity of demand for launch vehicles. These demand functions are not accurate enough for true investment decisions. However, they tell a very interesting story that is based solely on launch vehicles that have flown in the past five years. And they clearly illustrate what markets new vehicles can enter in the near future rather than speculate on what might be accomplished beyond any companies or government's reasonable strategic or business planning time frame.

The data behind these charts are from a number of public sources and reflect mostly prices reported by commercial firms for commercial launches for the period 1999-2004. Unfortunately, the prices paid for government launches are considered confidential and are not publicly available. However data were included where estimates could be made of the cost of a government launch from secondary sources or where data were reported in public media. The primary public sources included the series of reports from the FAA on launch vehicles and payloads and the AIAA Handbook. In many cases the reports gave a range of prices. To present the most conservative estimates and maintain consistency, the study used the highest price in the range for the data analysis.

Ideally, a demand curve compares prices paid for a commodity with the quantity bought. For launch vehicles this presents a problem. The ideal measurements would be the prices paid to launch a specific payload mass to a specific location in space compared to the number of such payloads launched at each price at a given point in time. Unfortunately the following complications make this virtually an impossible measurement:[29]

There is no "standard" destination in space for all payloads.

- A given launch may include multiple payloads in a given launch event and the secondary payloads may be deeply discounted in price.
- Different launch vehicles have different capabilities—mass, orbit, and fairing configurations.
- Even for the same basic vehicle, almost every launch includes a number of modifications specified by the user for a particular payload.
- There are so few launches per year that even aggregate data are inadequate to estimate price/quantity relationships, let alone those for subclasses of vehicles.

[29] The items in the following list closely parallel those in Chapter 3 and are repeated here.

- Prices quoted vary in what is actually included (payload integration, launch, tracking and data, time sequence of payments, other services, insurance, etc.); all public documents give only summary costs/prices.

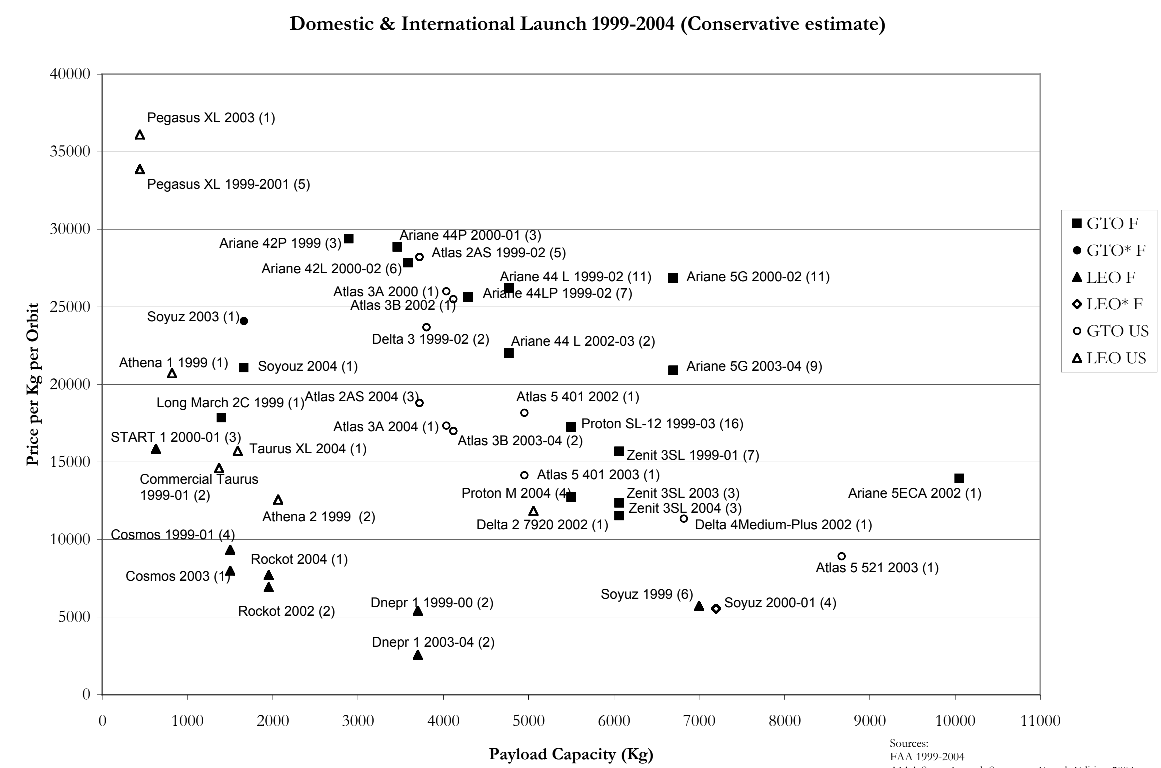
Therefore, a number of additional assumptions and approximations were required to construct the charts for this report. They include:

- Using a five-year time span to include enough price/quantity points for a meaningful analysis.
- Using price/kilogram for the combined payload of any given launch event based on the total published capacity of the vehicle, whether it was actually launched with the total mass or not.
- Using the weight in kilograms as a measure of quantity rather than the number of launches at that weight.
- Combining all types of vehicles on one chart, but separately analyzing different classes of vehicles as subsets for measuring elasticity of demand.

Because of these assumptions, the results should be viewed as top-level planning relationships; nevertheless they clearly indicate general trends and relationships in the launch vehicle industry.

Figure 1 maps all of the reported commercial worldwide launch events during the five-year period from 1999-2004. The family of vehicles is identified with the date(s) of launches and the number of launches in parentheses.

Figure 1: Summary of Launch Prices



The first observation is the general downward slope of the data points in the chart, meaning that the lower the price the more that was launched into space. This fits two economic observations. The first is on the demand side: a downward sloping demand curve is the normal mode for goods and services. The second is on the supply side: that as quantity produced increases, the average cost per kilogram is less. This analysis is constructed to measure demand conditions. However, because of the variables used in the axes of the chart, some bias from scale efficiencies is unavoidably measured as well.

The second observation is that the Ariane series of launch vehicles is at the top of the price range for its payload weight class. When Ariane was first launched and competed with the commercial launches of the Space Shuttle in the early 1980s, it priced just below the U.S. vehicles. This was mainly to generate business and to prove in its initial flights that its reliability was equal to or greater than its competitors. Over time, Arianespace has captured more than one-half of the commercial launches and is now the market leader. As such, it has the flexibility to price higher than others.

The third observation is that the Russian vehicles are priced lower than the others. This is a result of both economies of scale and the difficulty of establishing a price related to true cost in an historically non-market economy. The Souyz vehicles have launched about 1,700 times since 1957; it is the family of vehicles with the longest and best reliability record in the World.

Figure 2: Domestic & International Launch Price 1999-2004
Compared to of Range of Shuttle Cost Estimates

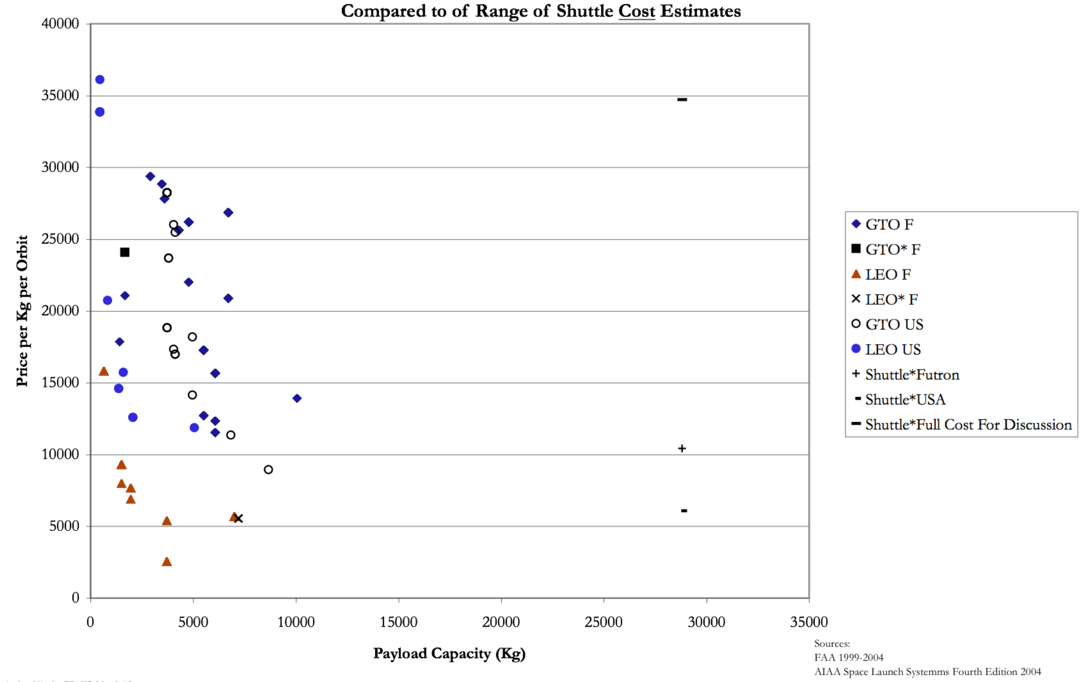


Figure 2 includes the same data as Figure 1, but with the Space Shuttle mass-to-orbit capability added. Because the cost of launching the Shuttle (but excluding the costs of the accident investigation and changes following the Columbia disaster) can be calculated in a variety of ways, a very wide range of costs is presented. The low figure of about $100 million is approximately what NASA quoted as the "marginal cost" of launching the Shuttle during the period when the government was considering privatizing some or all Shuttle flights.[30] The high figure of $1 billion is an estimate that includes R&D, overhead, and costs above and beyond what NASA's accounting system considers in its calculations. One commonly used figure of about $350 million is also given on the chart.[31]

What is interesting is that the range of estimates for the Shuttle is well within the cost/kilogram of every other launch vehicle. On the high end, the Pegasus rocket is roughly equivalent and on the low end, the Russian vehicles such as the Cosmos and Rockot are priced about the same per kilogram to LEO. It must also be noted that the Shuttle numbers are estimates of costs, not prices charged, since there is no real price for a Shuttle launch on the commercial market.

Figures 3 and 4 illustrate market areas where U.S. vehicles are not competitive with non-U.S. launchers. The two regions (marked with blank circles in Figure 3) are in: 1)cheaper launches of lighter payload mass to LEO and 2) in less costly launches of approximately the Delta II class vehicles. (These have risen greatly in price during the past several years—from about $50 million to about $75 million, allowing an opening for new competitors).

These market areas are the ones targeted by at least two of the leading potential new entrants to the industry. The Falcon 1 series of launchers of the Space X Corporation will initially offer less expensive flights of smaller payloads. The expected price will be on the order of $15 to $20 million per launch.[32] In the future, Space X plans to develop the Falcon 9 vehicle, a heavier-lift version that can compete with the Delta II vehicles is planned.

Kistler Aerospace Corporation, until it went out of business late in 2005, was developing a reusable launch system that targeted the Delta II payload mass to orbit market. It, too, was projected to have lower prices than the current Delta series.

Since both are vehicles manufactured in the United States, they can compete not only for commercial business but also for launches of U.S. Government payloads. With the demise of Kisler, the competition in that market will obviously be reduced and could result in less of a decrease in prices than would exist with multiple vehicle options open to the purchaser of a launch.

[30] This differs from the $500 million mentioned earlier in this report since as stated previously,there are many ways to calculate costs.
[31] This is a figure quoted from a United Space Alliance study.
[32] The new European launcher, Vega, will also compete in this market niche.

Figure 3: FAA Licensed Launches 1999-2004 (Conservative estimate)

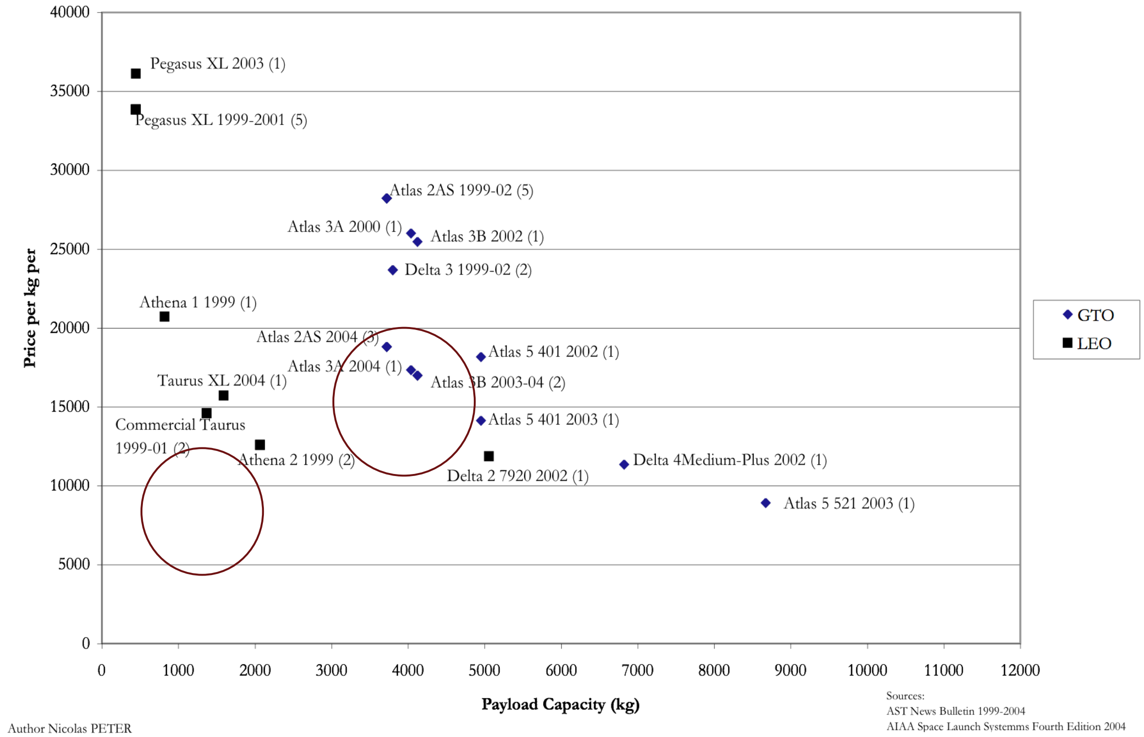
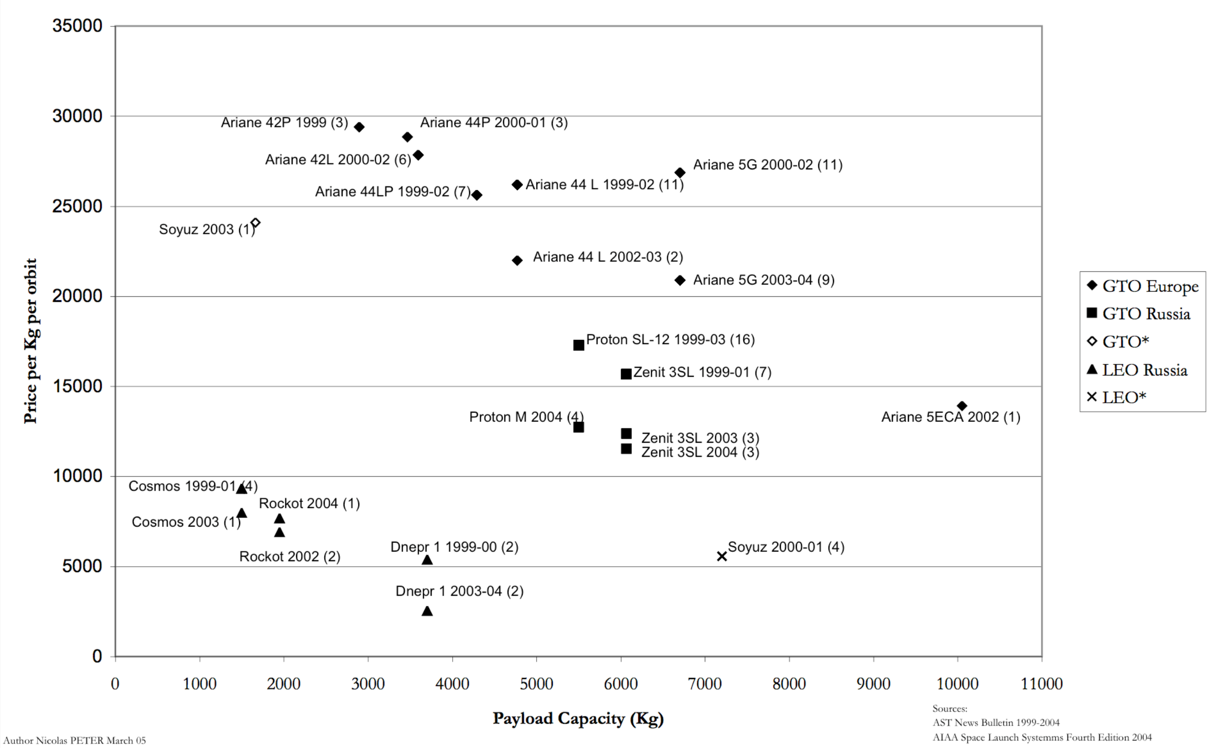


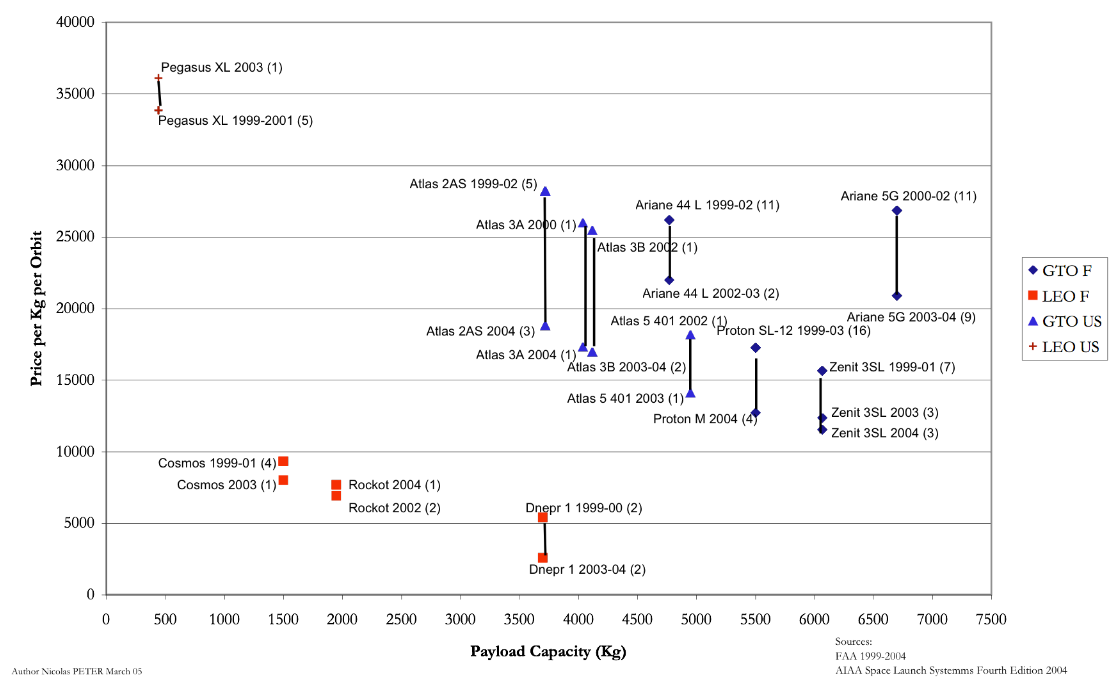
Figure 4: Selected Foreign launch 1999-2004 (Conservative estimate)



Neither vehicle nor their anticipated prices are included in these charts since neither has flown successfully as yet. When they are operational it will be important to observe how they can compete for government payloads, given that NASA and the DOD are now in a decision making policy mode on how to allocate and handle future payloads in this vehicle class. If NASA uses the very expensive EELV series of vehicles for Delta II class payloads, then what effects will much less expensive private vehicles have on future policies? In general, U.S. Space Transportation Policy as well as the NASA "Vision" call for the purchase of private launches when possible. However, exceptions are frequently made for political or technical reasons and this issue concerning Delta II class payloads is still an open question.

Finally, Figure 5 illustrates just how much the industry can respond to short—term changes in demand. In the 2000-2002 time frame a number of external economic events

Figure 5: Domestic & International Launch 1999-2004 (Conservative Estiamte)



reshaped the economics of the industry, at least for a short period of time. First, the economic slowdown severely hit the telecommunications industry. Projections of rapid growth in satellites suddenly evaporated. Plans for launching constellations of satellites to provide broadband services directly to consumers (e.g. Teledesic, Celestri, etc.) were abandoned for both financial and technical reasons. The bankruptcy of Iridium and Orbcom also caused investors to reconsider future systems. Second, an oversupply of vehicles existed, partly as a result of the sudden decrease in demand, but also because of the new entrants from other nations building vehicles to provide their own independent access to space.

Excess capacity did result in price drops in launches. Some were as great as 50%. However, none of these price decreases resulted in an increase in demand. In the past year, as the industry stabilized and demand forecasts have increased slightly, prices are once again rising. The lack of demand response to a price decrease is a result of both the long lead time for new payloads and launches as well as the companies generally trying to recover as much as they can in a difficult market.

Two other factors could have accounted for price dropping during this period of time. First was the end of the Ariane 4 series in 2003. Second, the major data source, the FAA price reports, changed from using a range for each launch (we used the highest price quoted in our charts) to quoting a specific price for each launch. The FAA does not reveal where this specific price was located in the range, nor precisely what was included or excluded in that single price.

It is also clear from this evidence that it would take a much larger price decrease to open up space to commercial users on the scale that the "build it and they will come" advocates envision. No such price changes are on the horizon, for either existing or near-term future vehicles.

Returning to Figure 1, we did calculate the price elasticity of demand for two classes of vehicles: vehicles that have LEO capabilities and vehicles with GTO capabilities.[33] Our initial calculations support the hypotheses of this study:

- LEO vehicles have a demand elasticity of demand above 1.0
- GTO vehicles have a demand elasticity of demand of 0.5

In other words, our data show that within the price range of today's vehicles, lowering price will not result in increased business for heavier lift, GTO vehicles. For lighter lift LEO vehicles, price decreases may lead to more customers, but not in large numbers.

[33] The smaller rockets capable of only putting payloads into a LEO orbit were separated from the heavier-lift vehicles. Then, using the data points on the Chart, a linear regression line was calculated for each type of vehicle. This line represents the price/quantity (demand) relationship. The arc elasticity (percent change in quantity/percent change in price) of these demand curves was then calculated. Note that mathematically, all price elasticities are negative (a downward sloping curve), but are reported in absolute numbers.

8) An Outline Summary: Economic and Management Lessons Learned, Not Learned, and Not Possible to Learn:

Lessons Learned From History

- Cheap access to space involves more than just a technically better launch vehicle.
- Projections and estimates of time and cost for new programs have been overly optimistic and incorrect.
- The U.S. is not the only nation with robust launching capability or with the capability to build a heavy lift vehicle.

Lessons Not Learned

- To collect better financial and economic data.
- To use economic analysis for more than the support of policies and program decisions that have already been approved for other reasons.
- To make better use of worldwide resources for launching U.S. Government payloads.
- To value launches at full accounting costs, including public funds for R&D.
- To develop realistic cost estimates.
- NASA's influence on demand is not large enough to affect the price-quantity relationship for all launch vehicles.
- NASA's R&D plans and spending are not enough to stimulate the development of a new launch vehicle that will serve both government and private commercial interests. This jeopardizes the long-term success of public-private partnerships that may be contemplated.

Lessons That May Not Be Possible to Implement

- To encourage the U.S. Government and NASA selection of R&D projects and vehicles based on economic analyses including cost estimates.
- To encourage NASA to use standardized vehicles and design payloads to fit rather than customize every launch.
- To engage in cost effective international cooperative efforts.
- To allow critical technologies to be developed abroad in cooperative efforts.
- To relax export controls and allow free international movement of at least all technologies that are available on open markets outside the United States.
- To allow foreign companies to compete with U.S. companies for U.S. Government launches and services.

9) Future risks and possibilities using better economic analysis

As mentioned above, some policies that make sense from many perspectives just cannot be implemented in the near term. The world is not perfect and, even if it were, it would not march to economic measures alone.

The space sector has a clear objective to develop much less expensive and much more reliable launching capability. All space-faring nations would directly benefit and all other nations would indirectly benefit from the use of space technologies to address many societal inequities and problems.

Two major barriers limit the ability to meet the goal of cheaper access to space. The first is technological: nobody yet has found and proved that a better and less expensive way of getting into orbit exists than the chemical propulsion multi-stage rockets now being used.

The second is overcoming the obvious high cost of new R&D programs for launch vehicles. Since the Apollo Program, no nation has been willing to invest enough resources over a long enough period of time on the challenge of very cheap access to space. Nor is it assured that even with sufficient time and money that such an effort would be successful.

In the decades of the 1960s and 1970s only two nations had a full spectrum of capabilities to access space: the United States and the Soviet Union. Today, a host of other nations have the technology, the manpower, and the manufacturing capability to build and launch payloads to orbit.

International cooperative efforts in space have mainly been formal agreements between governments. The largest of these, the International Space Station, involved protracted and difficult formal negotiations. This agreement has been remarkably successful. However it has fallen short in many areas. The cost of cooperative programs is most typically greater than if one nation developed a program alone. The reliance of one nation on another's meeting time and technical deadlines for critical parts of the program has always proved difficult. Further, the constantly changing political world both inside of each nation and among nations makes these long-term, expensive inter-government agreements risky, vulnerable, and even more costly than anticipated.

If singly, or even in limited cooperative programs, nations appear to be incapable of changing the paradigm for launches to space, then perhaps there are other ways to approach a solution. One that might deserve some thought and research is to explore the possibility of expanded private ventures among companies in different nations. The argument can be outlined as follows:

- All major U.S. and most foreign space companies are multinationals with facilities in all parts of the world or with business partnerships around the world.

- Each company has the business and manufacturing intelligence to know what the technical specialties are of their close competitors.
- Multinational businesses are not constrained by the same diplomatic protocols and policy issues that confront government agencies.
- Launch vehicle companies manufacture the vehicles either under contract with government agencies or to meet government needs in each country.
- Most government R&D for launch vehicles is directed toward the private sector.
- Since it is cumbersome and difficult for governments to negotiate MOUs and international agreements, it could be much easier to allow companies to find agreement on new launch vehicle R&D.
- To accomplish this, several policies would have to radically change:
    - Export controls in partner countries would have to be relaxed.
    - Governments would have to become anchor tenants and "guarantee" a market to give companies the incentives to invest.
    - Additional investment might have to come from public funds to companies within their borders, but with the realization and approval to spend those funds in partnerships in other nations.

The above is a skeleton outline of the issues. A significant amount of research would still have to be done to look in more detail at several of unknown issues, including:

- Technical feasibility of accomplishing the objectives with additional detail on types and capabilities of vehicles.
- An analysis of what objectives can reasonably be met. For instance, it is unlikely that one vehicle will fit all the needs of all countries or customers. Therefore, realistic objectives of cooperative programs might include:
    - Development of generic new technologies with applicability to a family/class of vehicles.
    - Development of vehicle components that are modular.
- An in-depth analysis of the national and international legal and regulatory issues that encourage or discourage this type of private sector cooperative effort and which could also affect the operations of future vehicles across borders.

A second and related area for additional research underlies the relationship of the government to public-private partnerships. A wide variety of options exist for these arrangements. They have frequently failed to be successful in the space environment, particularly in the United States.

A policy study on the types of partnerships and the reasons they have succeeded or failed in various parts of the World could help to shape new and future relationships in the United States. The space environment has rapidly moved from government-only programs to those that involve industry in its role as a competitor and as a developer of commercial access to and a developer of uses of space. It is, therefore, very appropriate to study new business models and ways of incorporating the very unique nature of the space sector with the private sector that will provide future successes instead of failures.

10) Appendix A: Cost overruns

As underlined previously, the issue of reducing the price of access to space is a major impediment to the development of a fully functioning launch market, but the recurrent cost overruns and program cost growth[34] of space transportation programs are also of concern when developing new launch vehicles.

The Congressional Budget Office (CBO) study[35] prepared at the request of the Subcommittee on Science, Technology, and Space of the Senate Commerce, Science and transportation Committee to assess the implications of the new vision for both the context of NASA's future exploration programs and the funding that might be needed to execute them, underlined that NASA's complex technical programs have often experienced higher costs and delays in schedules relative to their earlier estimates and plans.[36]

It is difficult to estimate the future program cost when starting a new project. However, there is a tendency to have a program cost growth with all the recent U.S. launcher development projects, with as aforementioned little results (Cf. "X" series). CBO estimated that in the case of selected NASA reusable launch vehicles programs, the cost of programs overruns range between 59 and 200%[37] as illustrated in table. In the case of any complex technical programs, the cost may rise above anticipated levels for a variety of reasons, including overly optimistic estimation in gauging costs, unexpected technical hurdles requiring more costly solutions than planners had anticipated and causing schedule delays while solutions are sought, and a modification of the technical requirements. In the case of any additional work added to a project, both the total budget and the total cost of that project will necessarily increase.

Appendix Table 1. NASA's recent launch vehicles development programs

Programs	Initial Budget	Most recent Budget	Percent increase	Year of initial budget	Termination
X-33	1124	1789.7	59	1995	2001
X-34	171	378	121	1995	2001
X-38	500	1500	200	1995	2004

(source: adapted from CBO (2004)

34 A cost overrun is the difference between the budget for the completed work and the actual cost of the completed work, whereas cost growth is the difference between the initial budget for a project and its final cost

35 Congressional Budget Office (CBO) Study: "A Budgetary Analysis of NASA's New Vision for Space Exploration", September 2004.

36 CBO analyzed NASA's historical cost-growth experience to estimate how cost increases might affect the space agency's current program and budget. Its analysis was based on budget data provided by NASA and on three Government Accountability Office (formerly, the General Accounting Office), or GAO, reports that looked at the costs and schedules of many of NASA's programs, including the most prominent, such as the Hubble Space Telescope and the Mars Exploration Rovers. The total data set comprised 72 programs that spanned more than 30 years; it contained a broad cross-section of the agency's projects that included most of NASA's research enterprises.

37 Based on the results of the 2004 CBO study

Notwithstanding the magnitude of cost overrun and cost growth witnessed in the space transportation sector, it is similar to many large and complex projects (defense projects, general transport infrastructures etc.) especially when they include the development of significant new technologies. Furthermore, as underlined by Flyvbjerg et al., the cost performances in transport infrastructure projects also haven't also historically performed well historically. For rail infrastructure there is an average cost escalation of 45%, for fixed links (tunnels and bridges) as 34% overruns and 20% for roads[38]. Cost escalation appears therefore to be a global phenomenon and systematic when dealing with large and complex technical programs.

[38] Bent Flyvbjerg, Mette K. Skamris Hom and Soren L. Buhl: How common and how large are cost overruns in transport infrastructure projects? Transport Review, 2003 Vol 23., No.1 71-88

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Journals, Newspapers & Online resources

- Space News
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- Journal of Reducing Space Mission Cost
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