Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000

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Introduction

The cost of space transportation has been nothing less than an obsession for many people in the space industry. The perceived high cost of space transportation is generally viewed as one of the biggest obstacles, if not the biggest, to the growth of space commercialization and exploration. Civil space agencies, entrepreneurs, policy makers, legislators, satellite operators, and others have all focused on the cost of space transportation at one time or another. Even though each group has different reasons for being interested in launch costs, they all share the same fixation – lowering the cost of transporting payloads into space.

However, evaluating current and future launch vehicles on the basis of cost has been problematic. The costs of launch vehicles are usually compared by computing the cost to place one pound of payload into orbit. This "cost per pound to orbit" metric has become widespread in the industry, and has been used to establish goals for the cost performance of future launch vehicles. However, this seemingly simple and widely used value is fraught with standardization issues that, if not fully understood, make it a far less useful tool. This White Paper attempts to clarify the concept of price per pound to orbit and to identify some trends in the cost of space transportation using this metric.

What Is Price Per Pound to Orbit and How Is It Calculated?

The simplest way to study the cost of space transportation is to compare the prices of launch vehicles. Unfortunately, this is generally a case of comparing apples to oranges: all launch vehicles are not equal. A Pegasus XL, for example, costs far less than an Ariane 5, but is also a much smaller vehicle. Differences in vehicle size can mask more important cost differences caused by vehicle design, nation of manufacture, and other factors.

To compensate for this, the "price per pound to orbit" metric was developed to compare vehicles for their cost effectiveness, mostly in the comparison of vehicles in the design phase. Price per pound offers a simple way to normalize launch costs, permitting more meaningful comparisons among vehicles of different capabilities. This metric has gained wide acceptance, with almost every proposed new launch vehicle since the Space Shuttle using some type of price-per-pound target.

While price per pound is simple to compute arithmetically, it has many shortcomings. Determining the real price of a launch can be difficult, since the terms of many launch contracts are not made public. In many cases only generic prices for launch vehicles are available, reducing the accuracy of the calculation. The choice of orbital altitude and inclination affects the payload capacity of a vehicle, thus affecting the calculation. These and other factors, if not properly accounted for, reduce the effectiveness of the price-per-pound metric.

Purpose of This White Paper

As stated in the Executive Summary, the purpose of this White Paper is to clarify the concept of price per pound to orbit and to identify some trends in the cost of space transportation using this metric. This White Paper describes how various vehicles fare, generically, using the price per pound metric, and it describes the trends in the metric during the 1990s for both commercial non-geosynchronous orbit (NGSO) – which includes low Earth orbit (LEO), medium Earth orbit, and highly elliptical orbits – and geosynchronous orbit (GSO) launches.

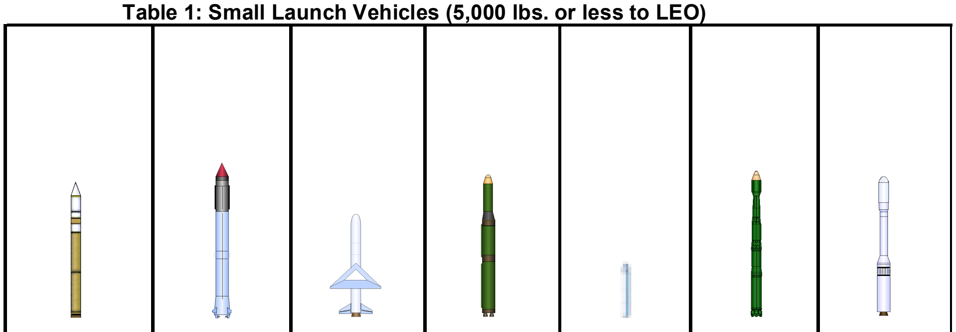
The analyses in this White Paper rely on a database of launch vehicle prices that Futron has maintained for almost a decade. The database is populated with publicly available information on launch prices and, every year, Futron performs an analysis to update the prices of all active launch vehicles in the database. This system worked well throughout the 1990s because there was sufficient publicly available information on launch prices that Futron could estimate price ranges with confidence.

Since the year 2000, the launch vehicle industry has become extremely competitive. Public sources on launch vehicle prices have all but dried up. Executives at Arianespace and Boeing Launch Services have been quoted as saying prices have dropped by 20-30% recently. Because of this uncertainty in estimating current prices of launch vehicles, Futron has restricted the analysis in this White Paper to the time period 1990-2000.

Generic Price Per Pound Calculation

Although the price-per-pound metric appears straightforward, there are a number of methods of computing it. One approach is to simply divide the estimated cost of a launch vehicle by its payload capacity. This approach permits a basic comparison of launch prices among various vehicles at a given point in time. Price-per-pound figures for a representative sample of commercial launch vehicles most commonly in use in the 1990s, as well as the Space Shuttle, are presented in Tables 1 through 3. The vehicles are divided into the four mass classes defined by the FAA Office of Commercial Space Transportation: small, medium, intermediate, and heavy, although for this discussion medium and intermediate vehicles will be grouped together. Separate price-per-pound figures are calculated for each vehicle's LEO and, where relevant, GTO (geosynchronous transfer orbit) capacity. (GTO is used here because most launch vehicles place GSO-bound payloads in an intermediate transfer orbit, from which the spacecraft maneuvers into GSO.) All prices are given in year 2000 dollars based on the latest price information provided during the decade, and do not include the costs of apogee kick motors or other payload injection means.

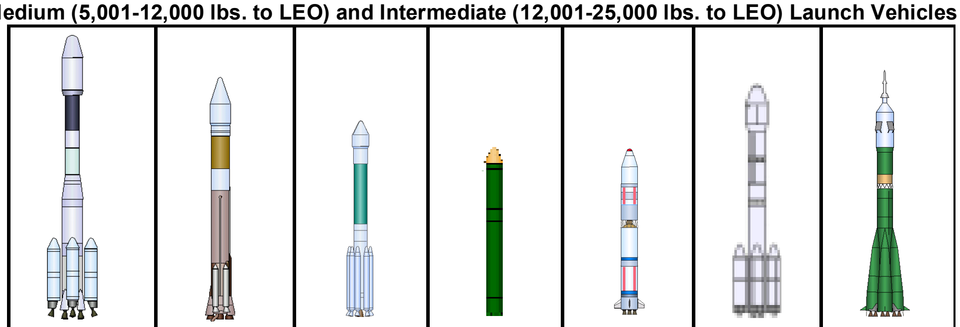
Table 1: Small Launch Vehicles (5,000 lbs. or less to LEO)



Vehicle name	Athena 2	Cosmos	Pegasus XL	Rockot	Shtil	START	Taurus
Country/Region of origin	USA	Russia	USA	Russia	Russia	Russia	USA
LEO capacity lb (kg)	4,520 (2,065)	3,300 (1,500)	976 (443)	4,075 (1,850)	947 (430)	1,392 (632)	3,036 (1,380)
Reference LEO altitude mi (km)	115 (185)	249 (400)	115 (185)	186 (300)	124 (200)	124 (200)	115 (185)
GTO capacity lb (kg)	1,301 (590)	0	0	0	0	0	988 (448)
Reference site and inclination	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	Barents Sea 77-88 deg.	Svobodny 51.8 deg.	CCAFS 28.5 deg.
Estimated launch price (2000 US$)	$24,000,000	$13,000,000	$13,500,000	$13,500,000	$200,000*	$7,500,000	$19,000,000
Estimated LEO payload cost per lb (kg)	$5,310 ($11,622)	$3,939 ($8,667)	$13,832 ($30,474)	$3,313 ($7,297)	$211 ($465)	$5,388 ($11,687)	$6,258 ($13,768)
Estimated GTO payload cost per lb (kg)	$18,448 ($40,678)	N/A	N/A	N/A	N/A	N/A	$19,234 ($42,411)

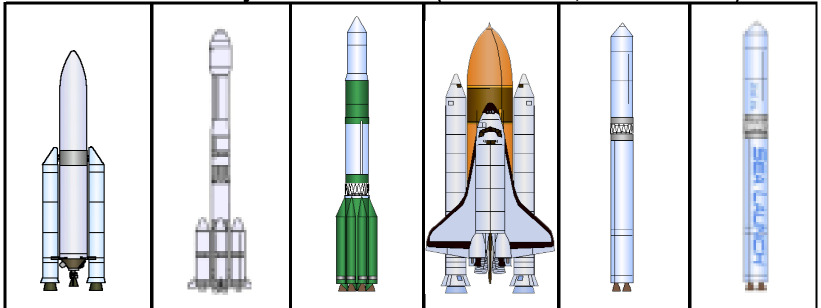
* Shtil launch costs partially subsidized by the Russian Navy as part of missile launch exercises

Table 2: Medium (5,001-12,000 lbs. to LEO) and Intermediate (12,001-25,000 lbs. to LEO) Launch Vehicles



Vehicle name	Ariane 44L	Atlas 2AS	Delta 2 (7920/5)	Dnepr	Long March 2C	Long March 2E	Soyuz
Country/Region of origin	Europe	USA	USA	Russia	China	China	Russia
LEO capacity lb (kg)	22,467 (10,200)	18,982 (8,618)	11,330 (5,144)	9,692 (4,400)	7,048 (3,200)	20,264 (9,200)	15,418 (7,000)
Reference LEO altitude mi (km)	124 (200)	115 (185)	115 (185)	124 (200)	124 (200)	124 (200)	124 (200)
GTO capacity lb (kg)	10,562 (4,790)	8,200 (3,719)	3,969 (1,800)	0	2,205 (1,000)	7,431 (3,370)	2,977 (1,350)
Reference site and inclination	Kourou 5.2 deg.	CCAFS 28.5 deg.	CCAFS 28.5 deg.	Baikonur 46.1 deg.	Taiyuan 37.8 deg.	Taiyuan 37.8 deg.	Baikonur 51.8 deg.
Estimated launch price (2000 US$)	$112,500,000	$97,500,000	$55,000,000	$15,000,000	$22,500,000	$50,000,000	$37,500,000
Estimated LEO payload cost per lb (kg)	$5,007 ($11,029)	$5,136 ($11,314)	$4,854 ($10,692)	$1,548 ($3,409)	$3,192 ($7,031)	$2,467 ($5,435)	$2,432 ($5,357)
Estimated GTO payload cost per lb (kg)	$10,651 ($23,486)	$11,890 ($26,217)	$13,857 ($30,556)	N/A	$10,204 ($22,500)	$6,729 ($14,837)	$12,598 ($27,778)

Table 3: Heavy Launch Vehicles (more than 25,000 lbs. to LEO)



Vehicle name	Ariane 5G	Long March 3B	Proton	Space Shuttle	Zenit 2	Zenit 3SL
Country/Region of origin	Europe	China	Russia	USA	Ukraine	Multinational
LEO capacity lb (kg)	39,648 (18,000)	29,956 (13,600)	43,524 (19,760)	63,443 (28,803)	30,264 (13,740)	34,969 (15,876)
Reference LEO altitude km (mi)	342 (550)	124 (200)	124 (200)	127 (204)	124 (200)	124 (200)
GTO capacity lb (kg)	14,994 (6,800)	11,466 (5,200)	10,209 (4,630)	13,010 (5,900)	0	11,576 (5,250)
Reference site and inclination	Kourou 5.2 deg.	Xichang 28.5 deg.	Baikonur 51.6 deg.	KSC 28.5 deg.	Baikonur 51.4 deg.	Odyssey Launch Platform 0 deg.
Estimated launch price (2000 US$)	$165,000,000	$60,000,000	$85,000,000	$300,000,000	$42,500,000	$85,000,000
Estimated LEO payload cost per lb (kg)	$4,162 ($9,167)	$2,003 ($4,412)	$1,953 ($4,302)	$4,729 ($10,416)	$1,404 ($3,093)	$2,431 ($5,354)
Estimated GTO payload cost per lb (kg)	$11,004 ($24,265)	$5,233 ($11,538)	$8,326 ($18,359)	$23,060 ($50,847)	N/A	$7,343 ($16,190)

Unlike the other vehicles listed in Tables 1-3, the Space Shuttle is not available commercially and thus does not have a launch *price*, per se, associated with it. Instead, the estimated *cost* (to NASA) to fly one shuttle mission is listed in Table 3. There are several ways to compute the cost of a shuttle mission, ranging from dividing the total NASA budget for the shuttle by the number of launches each year to estimating the marginal cost of one additional shuttle flight. The former method can produce per-launch costs of over $500 million, while the latter can lower the cost below $100 million. NASA's Space Transportation Architecture Study in the late 1990s estimated a shuttle launch cost of $300 million, based on an annual budget of $2.4 billion and eight flights a year, a rate NASA approached or achieved for most of the 1990s. We adopt the $300 million cost figure for this analysis, although we note that in the last few years the shuttle flight rate has dropped significantly without an appreciable decrease in the shuttle program budget, which would result in a sharp increase in per-launch costs.

The price-per-pound figures in Tables 1 through 3 span a wide range. There is a general trend of lower prices per pound for larger launch vehicles due to the economies of scale that a larger vehicle provides. The data also show that non-Western (Chinese, Russian, and Ukrainian) vehicles tend to have lower prices than their Western (American and European) counterparts, primarily because of lower labor and infrastructure costs. Table 4 shows that these differences in average price per pound can be significant.

Table 4: Average Price Per Pound for Western and Non-Western Launch Vehicles

Vehicle Class	LEO		GTO	
	Western	Non-Western*	Western	Non-Western*
Small	$8,445	$3,208	$18,841	N/A
Medium/Intermediate	$4,994	$2,407	$12,133	$9,843
Heavy	$4,440	$1,946	$17,032	$6,967

* The Zenit 3SL is considered a non-Western launch vehicle because of its Ukrainian and Russian heritage.

While this approach is simple, it has a key disadvantage: it treats launch vehicles as commodity items with a fixed price and capacity. In reality this is not the case. Negotiations for launch vehicles can result in widely varying prices, depending on customer requirements, the existing supply of and demand for launch services, and any special provisions like bulk buys of launch vehicles or the exchange of equity or services for launch services. In addition, each launch vehicle is used for one time only and can be uniquely tailored to some degree to meet the needs of each payload.

Specific Price Per Pound Calculation

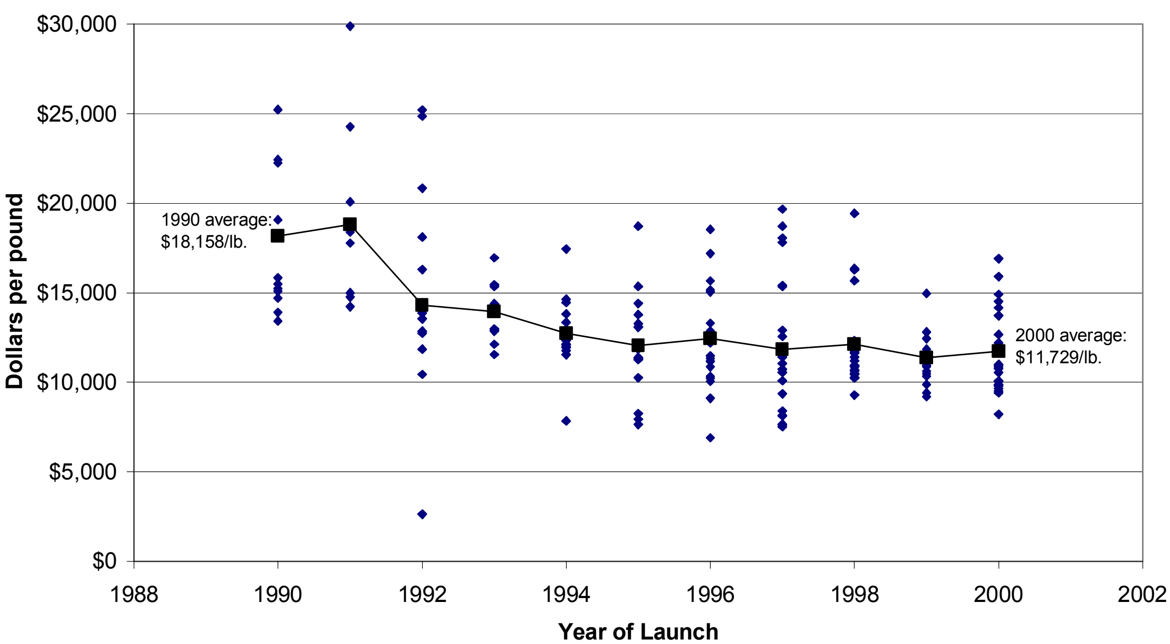
A more robust approach is to compute the price per pound of each launch individually. This increases the fidelity of the data and also provides a clearer view of pricing trends over time. The pricing information used in this study comes from Futron's database of launch vehicle prices. Wherever possible, the specific price for each launch is used; otherwise, the average price for that launch vehicle is used instead. All prices are normalized to constant year 2000 dollars to permit meaningful comparisons from year to year. For each launch the total mass of the payload, rather than the rated capacity of the vehicle, is used to compute the price per pound. Using payload mass instead of capacity makes only a modest difference in the price-per-pound results for GSO launches, as the mass of the payloads averaged 80-90% of the capacity of the vehicles (for some launches the payload mass exceeds the capacity of the vehicle – in those cases vehicles use reserve propellant designed to guarantee proper orbital insertion, trading away some accuracy for increased performance). For launches into NGSO the choice in approach does make a significant difference in the results, as noted later in this White Paper.

For this analysis we treat the GSO and NGSO launch markets separately. Other than the Delta 2, there is little overlap between these markets in the launch vehicles used. The technical requirements for reaching these orbits are also very different, affecting the payload capacity and thus price per pound. While the GSO market has a single, well-defined orbit, the NGSO market encompasses a wide array of orbital altitudes and inclinations. For this analysis, we will treat these as a group despite these differences, noting that most of these payloads are launched into low-Earth orbits several hundred kilometers high in non-polar inclinations. The results of this analysis are discussed in the following sections.

GSO Experience

The cost of launching commercial payloads into GSO, as measured using the price-per-pound metric, dropped significantly in the 1990s. The average price per pound fell from $18,158 in 1990 to $11,729 in 2000 (measured using constant year 2000 dollars), a drop of 35% during the decade. As illustrated in Figure 1, however, prices did not decrease steadily throughout the decade. Instead, there was a sharp decrease in launch prices in the first half of the decade, with prices then holding constant around $12,000 per pound through the latter half of the 1990s.

Figure 1: Estimated Launch Price Per Pound for Commercial GSO Payloads (constant 2000$)



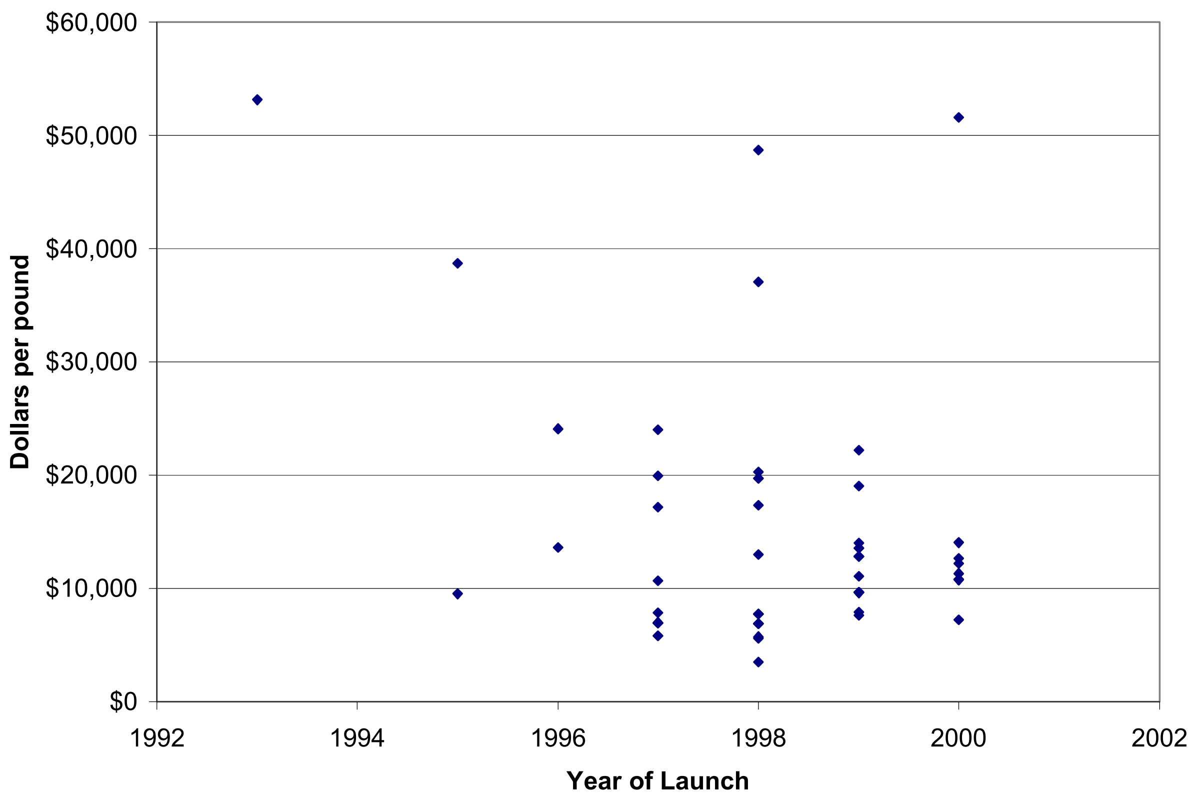
This pricing trend can be explained in large part by increased competition in the commercial launch industry, notably the introduction of the Chinese Long March and the Russian Proton launch vehicles to the market in the early and mid 1990s, respectively. These vehicles were aggressively priced compared to their Western counterparts, creating downward pressure on prices for the overall launch market. While three families of

Western launch vehicles – Ariane, Atlas, and Delta – account for 81% of the commercial GSO launches in this time frame, the average price per pound for these launches in a given year was as much as $1,000 higher than the average for all vehicles. By the end of the decade, however, Western vehicles had reached rough parity on a price-per-pound basis with their non-Western counterparts; this can be seen in Figure 1 by noticing the reduced scatter in the data points in the late 1990s versus the early 1990s. The departure of Chinese boosters from the commercial GSO market in the late 1990s because of reliability and export control issues likely also played a role in stabilizing prices by removing one of the sources of downward pressure on prices.

NGSO Experience

There is considerably less data for commercial NGSO launch pricing, simply because there have been far fewer commercial launches to NGSO than to GSO: there were 64 commercial NGSO launches in the 1990-2000 period, compared to nearly 200 commercial GSO launches. The price-per-pound data for those commercial NGSO launches, normalized to constant year 2000 dollars, are plotted in Figure 2.

Figure 2: Estimated Launch Price Per Pound for Commercial NGSO Payloads (constant 2000$)



Unlike the commercial GSO data, there are no clear trends in the price per pound of commercial NGSO launches. Most launches since 1995 cluster near $10,000 per pound, although there are some significantly higher outliers. These results can be explained in large part by the fact that commercial NGSO payloads have generally utilized a far smaller portion of the vehicle's stated capacity than GSO launches. While GSO payloads used 80-90% of a vehicle's capacity on average during the 1990-2000 period, NGSO payloads have used less than half of a vehicle's stated capacity during this time, even though many NGSO launches are multi-manifested with several spacecraft on each launch vehicle. Technical limitations of putting spacecraft in multiple orbital planes on one launch, as well as a desire to limit the exposure of a satellite constellation to a launch failure, put limits on multi-manifested launches that fall short of the vehicle's payload capacity. Many of the data points in Figure 2 with values greater than $20,000 a pound can be explained by launches that use a quarter or less of the capacity of the vehicles.

Conclusions

The price per pound of launch vehicles can be computed in two ways: a generic estimate using estimated launch vehicle costs and published payload capacities, and a more specific computation for each launch event using the cost of the vehicle for that launch and the mass of its payload. The generic metric offers a qualitative measure of launch industry costs, with lower prices per pound for larger as well as non-Western vehicles. The specific metric avoids a number of disadvantages of the generic metric and permits a more detailed, quantitative study of launch costs over the period.

The commercial GSO launch market has shown, on a specific price-per-pound basis, significant reductions in launch costs between 1990 and 2000. This can be attributed in large part to increased competition, particularly the introduction in the first half of the decade of lower-priced Chinese and Russian launch vehicles. The overall commercial launch market adjusted by lowering prices, stabilizing around $12,000 per pound in the latter half of the 1990s, nearly one-third less than launch costs at the beginning of the decade.

While this decrease is significant, it has failed to stimulate increased commercial activity. Since the late 1990s demand for commercial launches has dropped dramatically, from over 35 launches a year in the late 1990s to only 16 in 2001. Most industry forecasts show that commercial launch activity is unlikely to return to the peak levels of the late 1990s for the next ten years, despite the reduction in launch costs. This demonstrates the price inelasticity of the current launch market.

Regarding NGSO launch prices, there is no clear trend in the price-per-pound metric, other than a clustering around $10,000 per pound in the late 1990s. While this is lower than GSO launches, it is not as low as one might expect, because NGSO payloads have generally used a lower fraction of a vehicle's capacity than GSO payloads.

Although any decrease in the cost of space access is heartening, the decreases in price per pound seen in the last decade, as significant as they may be, appear to fall well short of what is needed to trigger major increases in commercial space activity. Far deeper cuts in the price per pound to orbit, such as the $1,000/pound goal of NASA's Space Launch Initiative, may be necessary to promote growth of the commercial space sector.

Futron Overview

Futron applies analytically rigorous decision-support methods to transform data into information. We collaborate closely with clients to relate decisions to future outcomes and measures of value. Our aerospace consulting services include market and industry analyses, safety and risk management, remote sensing, and communications and information management. Futron's vision and commitment to innovation, quality and excellence results in a higher performing future for clients.

Futron's headquarters in Bethesda, Maryland

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- We have surveyed hundreds of aerospace firms to develop a unique revenue, employment, and productivity profile of the industry.

- We have developed country-by-country models of demand for telecommunication services that aggregate a global forecast up from the individual household PC or business network; these models have accurately predicted future launch levels and business changes in the satellite industry.

- Futron helps clients win competitions, analyze competitors, estimate costs and prices, and track opportunities.

- Futron also performs cost estimates and economic analyses. Futron generates bottoms up, parametric, and analogous cost estimates for commercial satellite and launch vehicle programs.

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