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FINANCIAL OPERATIONAL LOSSES IN SPACE LAUNCH

A DISSERTATION APPROVED FOR THE
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“For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it?”

Luke 14:28, KJV

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Abstract

The high cost of access to space has been a problem since the beginning of the space age. Most attempts to reduce this cost are centered on improvements to launch vehicle design. While this approach has been fruitful, less attention has been paid to other causes of high cost. Two of these are wastage of launch vehicle payload capacity and use of cost-ineffective launch vehicles. Both of these are associated with the way the launch vehicles are operated, and so are *operational losses.* This work examines the extent of operational losses in space launch over the period January 1, 2000, to September 29, 2013, and considers strategies for reducing these losses. The cumulative worldwide wastage for this period was 654 tons, which is 20.4% of total payload capacity, and represents a financial loss of no less than \$8.72 billion (2014\$). The cumulative loss due to cost-ineffective launch vehicle selection is less certain, but is no greater than 43.8% of total launch cost, or \$19.3 billion. Two possible strategies may combat operational losses: changing launch vehicle selection or rearranging payloads. Changing launch vehicle selection can in principle eliminate cost-ineffective launch vehicle use, but is prevented in some measure by non-economic considerations. Rearrangement of payloads cannot eliminate wastage, but can reduce it considerably, to as little as 2% in some cases. Combining these two strategies by applying a bin-packing algorithm to the set of launch vehicles and payloads can yield a considerable cost savings, reducing total launch costs to geosynchronous orbit by as much as 53% if both launch vehicle selection and payload arrangement are unrestricted. Even in the most restrictive scenario where payloads must be launched in the same calendar year they actually were and launch vehicle choice is restricted to the launch vehicles actually used during that year, cost savings of 19.1% over the actual launches are possible.

Chapter 1

Introduction

The space launch industry is currently at a crossroads. Over the past decade, it has experienced drastic shifts, and the pace of change is increasing. In the last decade, the United States retired Atlas II, Titan and the Space Shuttle, and drastically reduced use of the venerable workhorse Delta II in favor of three all-new launch vehicle families: Delta IV, Atlas V, and Falcon 9. Though progress has been slow, Russia plans to both roll out the all-new Angara launch vehicle family, whose modular configuration and elimination of reliance on toxic storable propellants addresses the two main weaknesses of Proton, and construct an entirely new cosmodrome at Vostochny to replace Baikonur. China became the third nation to achieve human spaceflight and construct a space station. Japan has introduced a powerful new launch vehicle, H-IIB, capable of delivering the 18-ton HTV to the International Space Station.

Equally important breakthroughs are on the horizon. The NASA COTS and CCDev initiatives have opened the door for commercial human spaceflight, with multiple competitors vying to supply America's next manned space vehicle. Reusable Falcon 9 core stages promise a five or ten-fold reduction in launch costs with a series of exciting tests that are ongoing.

Despite these advances, space launch is still an extremely expensive and exacting business. Minimum costs for orbital launches are still in the thousands of dollars per kilogram, and often the cost to deliver a payload to space can be higher than is immediately apparent. As will be shown in this work, the often-quoted cost per payload mass is often not what is actually paid. Wastage of launch vehicle payload capacity and insurance drive this cost upward. For example, Ariane 5ECA costs $15,670 per kilogram of geosynchronous transfer orbit payload capacity, but after a total wastage of 21.87%, customers actually paid an average of $20,056 per kilogram delivered to GTO before the cost of insurance, which averages an additional 15-20% [1].

1.1 Overview of Operational Losses

The intent of this research is to provide answers to three research questions:

- How much can launch costs be reduced through operational strategies?
- What usage patterns do these strategies create?
- Which type of operational loss causes the greater amount of financial loss?

In order to begin to answer these questions, it is necessary to quantify the operational losses associated with spaceflight. There are two types: wastage and cost-ineffective launch vehicle selection. Chapters 6 and 7 examine these in detail, quantifying the extent of both and their effects on the price to deliver a payload to space. Total wastage over the January 1, 2000 to September 29, 2013 period was 654 tons. This is 20.4% of total payload capacity, or a financial loss of $8.72 billion. The loss due to cost-ineffective launch vehicle selection alone is less certain owing to some non-technical constraints on launch vehicle selection, but could be as much as $19.3 billion, or 43.8% of total cost.

The second goal of this research is to determine how much reduction of these two sources of operational losses is possible. Implicit in this is some discussion of means, although any discussion of the means will be generic. The solution to cost-ineffective launch vehicle selection is simply selecting more cost-effective launch vehicles, although there are some complications to this discussed in Chapter 7. It is possible to limit wastage to some degree through launch vehicle selection, although this may not be the most cost-effective method to deal with that particular problem. Launching multiple payloads on the same launch vehicle is the primary method examined here to reduce wastage. While multiple payload launches are already a common practice, the majority of launches, 710 out of 913, are still single payloads. Many of these single payloads have significant wastage, and taking measures to utilize this unused capacity can reduce the cost per payload mass delivered to orbit.

The costs listed above illustrate the value of reducing operational losses. Analysis conducted in Chapter 7 concludes that a reduction in launch costs of up to 43% is possible with improved launch vehicle selection using the existing mission manifests. Coupled with an average wastage over the studied period of roughly 20%, there is potential for significant savings. Further savings may be possible. As stated in Chapter 4, larger launch vehicles tend to be more cost-effective than smaller launch vehicles, so rearranging payloads such that they can all launch on the largest launch vehicle possible has potential to reduce costs even further. Chapter 8 contains an analysis of this sort, showing that large reductions in the cost of payload delivery to geosynchronous orbit are possible through a combination of these strategies.

It is not, of course, possible to eliminate all operational losses. Cost is not the only factor considered when selecting launch vehicles or determining payload manifests for missions. These other considerations prevent realization of all possible gains. When applicable, chapters in this work discuss the potential obstacles to improvement. For launch vehicle selection, national security considerations, availability of the desired launch vehicles, and reliability of launch vehicles all play a role. Reduction of wastage by alteration of payload manifests is made more difficult by the time schedule requirements of payloads, the potential reduction in reliability caused by multiple payload releases, and institutional roadblocks such as those described by Buckley [2].

To summarize, the intent of this work is to quantify the two types of operational losses and determine how much it is possible to reduce them. In order to do so, it is necessary to gather data about both space payloads and the vehicles that launch them. Once this is complete, an assessment of the amount of wastage and the cost-effectiveness of launch vehicle choices is possible. Lastly, strategies for reducing launch costs via changing launch vehicle selection and/or payload arrangement are developed and assessed.

1.2 Structure of Dissertation

This work will take a four step approach to answering the research questions:

1. Gather, validate, and find any trends in data to determine the extent of the problem.

2. Determine how much may be saved with changing launch vehicle selection

alone.

3. Determine savings if payloads can be rearranged on the same launch vehicles.

4. Determine savings if payloads can be arranged in the most cost effective fashion on any launch vehicle.

Chapter 2 reviews relevant literature. There are only a few mentions of wastage in the literature. Of these Koelle approaches the subject most directly, and presents a value for wastage close to that obtained in the analysis in Chapter 6 [3]. Discussion of launch vehicle selection is also limited, although Chapter 4 of Greenberg contains some information [4]. Aside from the central research questions posed above, however, a considerable amount of background information in diverse topics such as launch insurance, launch vehicle pricing, and payload data is necessary. Chapter 2 enumerates the sources used to obtain necessary data for the analyses in Chapters 3 through 9.

Chapter 3 describes a payload database with data drawn from multiple sources and then analyzes the data for trends relevant to the problem of operational losses. The most important of these trends is the split between large payloads and small payloads. The vast majority of individual payloads are small low Earth orbit payloads, but large geosynchronous orbit payloads drive the demand for launch vehicles, accounting for the majority of launch vehicle usage. This problem is difficult to solve with launch vehicle design because as shown in Chapter 4, small launch vehicle designs are inherently less cost-effective. Appendix A contains the payload database.

Chapter 4 investigates trends in launch vehicle cost-effectiveness, including developing several cost models. An understanding of trends in launch vehicle cost-effectiveness with regard to design is important to both parts of the operational loss problem. Additionally, much of the existing launch vehicle price data is unreliable or fails to make statements about what the given price includes. Comparative analysis of cost models, both existing models and newly developed models, provides a check on the reasonableness of the cost data as well as providing insights into the design traits of cost-effective launch vehicles. Most critical of these are large size and high efficiency. Production numbers or flight rate seem to have little correlation with prices of existing launch vehicles. Appendix B contains the price data used in the analyses in this chapter.

Chapter 5 analyzes launch vehicle capability to launch payloads. Capability drives the potential market share of a launch vehicle. Large launch vehicles have much greater capability than small launch vehicles, with the smallest current launch vehicle, Pegasus XL, only having the capability to launch 1.12% of payload mass. This greater capability gives large launch vehicles another advantage in the market in addition to their inherently superior cost-effectiveness. Chapter 5 also investigates the market share of existing launch vehicles. Very few launch vehicle families have large individual shares of the market for payloads they are capable of launching, and the few exceptions, such as Soyuz, are the beneficiaries of exceptional situations.

Chapter 6 computes wastage for launches in the data set with sufficient data. Total wastage for the missions with sufficient data is 20.4%, or 653 tons out of a total capacity to all orbits of 3,208 tons. To place this value in perspective, it is greater than the mass of the International Space Station, at 416 tons, and nearly half of NASA's estimate of the low Earth orbit payload mass required for a manned Mars mission, at 1,316 tons [5]. In actuality, it is even greater than the value implied by raw mass because 58.9% of total wastage is to geosynchronous orbit, and launch vehicle payload capacity to low Earth orbit is usually two to four times that to geosynchronous orbit.

Chapter 7 investigates usage of launch vehicles. Surprisingly, while use of the cheapest launch vehicle capable of launching a mission is a plurality of launches, it is not the majority. Approximately 50% of missions select a launch vehicle that is ranked in the top four for cost-effectiveness for their particular mission, and 75% select one that is ranked in the top ten. Chapter 7 also analyzes total usage of each launch vehicle type. Some launchers, such as Dnepr and Delta IV, see usage on missions where they are not the most cost-effective, but missions where they are the most cost-effective choice do not use them.

Chapter 8 describes the use of bin-packing algorithms to assign payloads to launch vehicles in a manner designed to minimize total launch cost. Significant reductions in wastage and cost are possible, especially in the most permissive scenario where any payload from the dataset may be assigned to any launch. This scenario can result in a savings of up to 45% for geosynchronous payloads. Progressively more restrictive scenarios, such as those limiting the use of launch vehicles or requiring that payloads launch in the same year that they were launched in reality, decrease savings, but even the most restrictive scenario still nets savings of 19.1% for geosynchronous payloads.

Chapter 9 provides a metric for computing the additional risk imposed by multiple-payload launches. While launching in this fashion has the potential to greatly reduce launch cost to the payload owner, there is an increased risk imposed by carrying and separating multiple payloads. This risk should, all other things being equal, express itself in a higher insurance cost for the launch. Accordingly, Chapter 9 develops a simple model for the loss chance of a payload based on the reliability of the launch vehicle and the separation events. Under the assumptions of the analysis, ten equally sized payloads on a single launch would incur an additional insurance cost of roughly 5% of launch vehicle cost. This is half of 2013 wastage, and derives from several pessimistic assumptions that increase the risk and thus cost.

Chapter 10 provides a summary of the investigation into operational losses. Additionally, it contains recommendations for future reduction of these operational losses. The most important of these recommendations is the development of improved, standardized systems for multiple payload launch, ideally modeled on Earthbound logistics systems such as ISO containers. Such a system would enable a significant reduction in wastage and thus cost.

Chapter 2

Literature Review

Comparatively little has been written on the subject of launch vehicle capacity wastage. Passing references to it do exist in the literature, usually in the context of increasing multi-payload capabilities for launch vehicles. Steven J. Buckley's "Utilizing Excess Capacity of Current Launch Vehicles to Lift Secondary Payloads" is an excellent example of this type [2]. This paper is largely concerned with the operational difficulties associated with multiple manifests. While it is understood that wastage is a loss, there is no attempt to quantify it. He also provides insight into the human factors that cause wastage. As he puts it, "the primary payload and launch managers rightfully see the burden of manifesting secondary payloads on their mission as added risk and complexity".

Koelle refers to wastage in passing in "Specific Transportation Costs to GEO - Past, Present, and Future." [3] He discusses a 'payload utilization factor', which is simply the fraction of the launch vehicle's capacity that is composed of useful payload, or *1-W*. He comments that "A generic cost reduction of 25 to 35% is feasible." His comments on problems with multiple payload systems reducing payload capacities, however, seem to be overly conservative. If a launch vehicle can be built with a structural fraction of less than 5%, as Atlas D was more than 50 years ago [6], including complex thermomechanical and electronic systems for propulsion and guidance, then it does not seem reasonable to conclude that the necessary adapters for multiple payload deployments would erase most of the potential savings. Available data on multiple payload systems currently in use bears this out; most variants of the Ariane 5 SYLDA have a mass of approximately 500kg, slightly less than 5% of the maximum GTO payload capacity of that vehicle [7].

Koelle's comments on the real world difficulties of scheduling payloads together are well taken, and an effect that is difficult to quantify. His paper is also interesting in that it contains results of payload analyses similar to that performed in Chapter 3, giving the average mass of payloads to orbits. His work, however, rates geosynchronous payloads on their final mass after performing the circularization and plane change burns, and so is not directly comparable to results obtained in Chapter 3.

Like wastage, the literature does not extensively discuss launch vehicle selection. However, Greenberg examines the subject to some degree in Chapter 4 of *Economic Principles Applied to Space Industry Decisions* [4]. His analysis of a hypothetical choice between 'Proton' and 'Atlas' (given the date of his work, probably Proton-K and Atlas II) accounts for more variables than the comparisons of total launch cost executed in Chapter 7. Specifically, his model accounts for differences in the cost of insurance and payment schedules, and produces a 'net present value' for each potential launch vehicle choice.

While Greenberg's approach is more accurate in terms of making a correct decision, it requires information that is not readily available for contemporary launch vehicles. Knowledge of the prospective payment schedules and the cost of launch insurance is not widely available. As discussed in Chapter 4 a considerable amount of the current launch vehicle price data is unreliable. Additionally, while insurance cost is often given as a fraction of launch vehicle cost, the cost of the payload must have some influence on it, as the payload is typically at least two to four times more valuable than the launch vehicle itself [8], and so will constitute the majority of the insured value.

While little has been written on the overarching problem of wastage and launch vehicle selection, several of the subordinate topics in this work have been examined in detail. Some attempts have been made in the past to quantify the space launch market. The Federal Aviation Administration prepares Launch Reports and Year In Review reports [9–13] that list payloads launched into space and plot data such as the number of launches, their affiliation, their masses, and other information. Other than this work, they are the only source that attempts to quantify payload masses, although they do so by loose categories rather than listing the mass of each payload. These data are also only presented for each quarter or year, rather than for a longer period. They also track the number of commercial versus government launches.

Robert L. Sackheim's "Overview of United States Space Propulsion Technology and Associated Space Transportation Systems" [14] provides a general overview of launch vehicle technology. His arguments for development of improved propulsion systems are well taken, especially given the analysis presented in Chapter 4 tying improved propulsion system performance to cost-effectiveness.

Cost models for launch vehicle development and production are important to understand the consequences of launch vehicle usage and design choices. A number of models of varied complexity are extant, of which a review may be found in Trivailo et al [15]. These include the NASA and Air Force Cost Model

(NAFCOM), Koelle's TRANSCOST, and others. It is worth considering, however, that cost and price are not the same thing, and what matters to the owners of the payload is the price. Chapter 4 discusses trends in launch vehicle price. Nonetheless, knowing the cost and possible trends in cost is valuable in that no matter what price the end user pays, someone must absorb the costs in the end. Typically, that someone is a government entity if the costs are not passed on to the end user.

When discussing any new approach to an engineering problem, an assessment of the risk is necessary. The cost of insurance can provide a measure of risk. This is a subject that crosses diciplines between engineering and business. Greenberg and Herzfeld discuss launch insurance briefly in *Space Economics* [1]. While they do not examine the details of launch insurance pricing closely, they do state that it is approximately 15-20% for most payloads at the time of their writing. This estimate parallels that obtained in the analyses in Chapter 9. Gould and Linden discuss launch insurance in "Estimating Satellite Insurance Liabilities" from a more business-oriented perspective. They liken spacecraft insurance to human life insurance: there is a relatively high chance of infant mortality (launch failure, deployment failure, or payload failure during the first six months of operation) followed by a period of lower risk, which then slowly ramps up due to aging.

Gathering reference data for the various studies performed in this work required special effort, and so merits additional discussion aside from the brief overview given in Chapter 3. The payload database described in Chapter 3 draws data from multiple sources. Most important of these, as detailed in that chapter, is the Satellite Catalog, or SATCAT [16]. However, it does not contain all of the data required for payload trending, such as payload mass data, and occasionally the data it does contain is incomplete. This will be marked with the legend 'NEA' (No Elements Available) within the SATCAT data files. This not only necessitates obtaining mass data from other sources, but obtaining the orbital elements as well.

Another problem that arises with SATCAT is due to spacecraft whose orbits have decayed. In some places, instead of orbital elements for the satellite when it was in service, SATCAT contains orbital elements for its deorbit trajectory. This is of course quite different from whatever orbit the payload occupied in its useful career. In this case, other sources provided data for the payload's intended orbit.

For older (pre 2004) payloads, AIAA's *International Reference Guide to Space Launch Systems* [17] contains useful data on payloads. It also contains data for launch vehicle prices. Unfortunately, it is somewhat dated, and the majority of the data set postdates its publication.

Space enthusiasts and hobbyists maintain several websites that contain useful spacecraft data. Unfortunately, the provenance of some of it is suspect, and there is no commitment to archive data. Encyclopedia Astronautica [18] is a well-respected, longstanding resource of this type, to the point that *International Reference Guide to Space Launch Systems* actually uses it as a source. It was the first source consulted when searching for payload masses and the launch vehicle used. EOPortal [19] has a wealth of data on Earth science spacecraft, and has more frequent updates than Encyclopedia Astronautica, making it more useful for later missions in the data set.

Two additional United States government agencies maintain registries of space objects. NASA's National Space Science Data Center [20] contains much of the same data as SATCAT, in addition to brief descriptions of the payloads' missions and technical characteristics. The US Registry of Objects Launched into Outer Space [21] is maintained by the US Department of State in accordance with the

1976 UN Convention on Registration of Objects Launched into Outer Space. This contains much of the same information as SATCAT and the NSSDC database, but occasionally one of them will have data that the other two lack.

The Union of Concerned Scientists maintains a database of spacecraft [22]. This does not contain orbital elements but it has a few pieces of information that the other sources listed here lack, such as who constructed the payload. It also has some payload masses, including some for national security satellites that are not available elsewhere.

A single database compiles data from the above sources, along with notes that indicate potential inaccuracies, conflicts, or assumptions. Appendix A contains a table of the most critical data from the database, including payload masses and launch vehicle payload capacities.

Launch vehicle pricing poses a similar problem. Many of the extant sources are conflicting and few of them make clear statements about what the price they present includes. For instance, the 2006 FAA Q1 Launch Report gives the price of Delta IV Heavy as $155M, which is $182M in 2014 dollars [11]. The Congressional Budget Office indicates the current price may be as much as $411M (2014$), more than twice as much [23]. Some of this is an effect of different measures of cost. The Congressional Budget Office's 2006 study differentiates between the actual cost of the launch vehicle hardware and 'launch services' or the overhead associated with actually carrying out the launch. The hardware-only price given for Delta IV Heavy in that report is $235M in 2014 dollars, which is much more in line with the FAA's earlier estimate. Unfortunately, few of the other sources of launch vehicle data make this distinction.

The analyses herein use the lowest price given by a reputable source, adjusted for inflation to 2014 dollars. The intent of this practice is to avoid subjective evaluation of cost claims for launch vehicles. Such an evaluation would be based on little more than the evaluator's judgment. It is more valuable in this case to have an even basis for comparison, even if it may not be accurate. This also has the result of providing a 'best case' scenario. The financial losses incurred by wastage and cost-ineffective launch vehicle selection may be much greater than the values obtained in this work.

The preferred sources for price data are the launch vehicle providers. Of these, only SpaceX provides an upfront cost for their launch services. $56.5M was the Falcon 9 launch price in 2014 and in the analyses in this work, although in 2015 SpaceX raised this to $61.5M [24]. ULA released a price for Atlas V 401 of $164M in 2013 [25], but this includes government overhead, and as discussed in Chapter 4, this is a considerable expense, and one that is difficult to estimate. Cost data for the remainder of the launch vehicles must be obtained from other sources.

Many of the same sources used for payload data also contain launch vehicle data. Encyclopedia Astronautica contains a considerable amount of cost data for launch vehicles, although it has limited data on newer launch vehicles such as Falcon 9 and H-IIB. *International Reference Guide to Space Launch Systems* is similar in this respect, as it contains much of the same data.

FAA Launch Reports and Year In Review reports also contain cost data for launch vehicles. These provided the bulk of the launch vehicle cost data. Chapter 11 of *Satellite Communications Systems: Systems, Techniques, and Technology* by Maral and Bousquet provides some launch vehicle data [26]. It is similar in approach to *International Reference Guide to Space Launch Systems* but contains data that are more recent. Some individual papers contain launch vehicle price data, such as much of Koelle's work. "Specific Transportation Costs to GEO Past, Present, and Future" contains a table listing the cost of several launch vehicles. [3] Since Koelle also cites an older edition of *International Reference Guide to Space Launch Systems*, these data may be sourced from there.

Appendix B contains the compiled launch vehicle data. Some launch vehicle configurations do not have price data extant. For most of these, the price of some configuration in the same family is known. For instance, there is cost data for Delta IV Medium+ (4,2), but not for Delta IV Medium. If the price is unknown, the price of the nearest configuration in size is used. There is no price data available for H-IIB, and a price of $180M was assigned based on Ariane 5, which is a launch vehicle of similar size and configuration.

Chapter 3

Payload Trends

In order to perform any analysis on the employment of launch vehicles to carry payloads, some knowledge about the characteristics of these payloads is necessary. It is critical to know their mass and final orbit, as these two considerations determine the payload capacity of the launch vehicle for the mission in question. It is also important to know how these values trend over time. Changes in the average mass of payloads or the number of payloads going to each orbit are critical knowledge for future developers and users of launch vehicles.

It is difficult to look forward at payload trends. While some information is available, such as NASA budget estimates [27], and in FAA Launch Reports, it is incomplete. Very little of it goes more than a few years into the future, and given the nature of budgeting in both commercial and governmental organizations there must also be a great deal of uncertainty.

Fortunately, a good deal of information is available on past missions, raising the possibility of estimating future trends by projecting past trends into the future. The US Department of Defense tracks every object deliberately launched into space. This responsibility originally belonged to NORAD, the North American Aerospace Defense Command, and passed through several agencies before falling to US Strategic Command, where it currently resides. This Satellite Catalog, or SATCAT, lists the payload name, COSPAR and NORAD numbers, nationality, orbital elements, launch date, decay date (if applicable) and other information for all of these space objects. The most important part of this additional information consists of flags indicating the nature of the object. Objects marked 'R/B' (rocket body) or 'DEB' (debris) are not payloads and will not be counted as such.

Unfortunately, SATCAT alone is not sufficient for payload trend analysis of the type required because it does not contain mass data. Additional research is required to determine the mass of each payload. This data is available from several sources, including the payload registries discussed in Chapter 2, government reports, and press releases. Official sources, such as press releases from either the launching agency or the agency that owns the payload, are preferred. If official sources are unavailable, a number of secondary sources for payload mass data exist, such as AIAA's *International Reference Guide to Space Launch Systems* [17] and other secondary sources.

The data set under investigation consists of 1,405 payloads launched between January 1, 2000, and September 29, 2013, beginning with object 2000-001A, a DSCS 3 geosynchronous communications satellite belonging to the US Department of Defense, launched on January 21, 2000, and ending with object 2013-056A, SES' Astra 2E geosynchronous communications satellite, launched on September 29, 2013.

Most analyses in this work excluded payloads or missions with certain characteristics. 105 of the payloads have no mass data available, and were therefore excluded. This includes a number of United States, Russian, and Chinese national security payloads. The 85 manned missions were also excluded, since the safety requirements for manned missions are much more stringent than those for unmanned missions, which imposes additional costs. It is also difficult to make a level comparison between crew or passengers and cargo. That is, it can be difficult to determine the additional mission mass requirement for each passenger or crewmember for comparison purposes. For a system like Soyuz, this may be relatively easy to determine by dividing the mass of the capsule by the number of humans carried, but for a system like the Space Shuttle, it is less obvious. Finally, interplanetary and lunar craft were excluded, since it is difficult to find a basis for comparison between them and they constitute a small portion of all spacecraft, with only 29 in the data set. This leaves 1,186 payloads.

An important part of the analysis is assigning payloads to orbits. Throughout this work, LEO is defined as an orbit with perigee and apogee less than 2000km altitude, MEO is defined as having perigee and apogee greater than 2000km but less than GEO, and HEO is defined as having an apogee above 2000km and a perigee below it. Some payloads have orbits that do not correspond to these groupings, resulting in their exclusion from the analysis. There are five of these not already excluded for missing payload mass or payload capacity data, leaving a grand total of 1,181 payloads being considered in payload trending.

Figure 3.1 displays the number of payloads deployed to each orbit by year. 2013 is omitted since it is not complete. A number of trends are apparent. The first is the great increase since the middle of the last decade in LEO payloads, caused by the rise of the microsatellite. The second is the relatively slow, steady increase in the number of geosynchronous payloads.

Figure 3.2 contains the total payload mass delivered to each orbit by year. Total LEO payload mass is highly variable, with a large decline in 2003. This

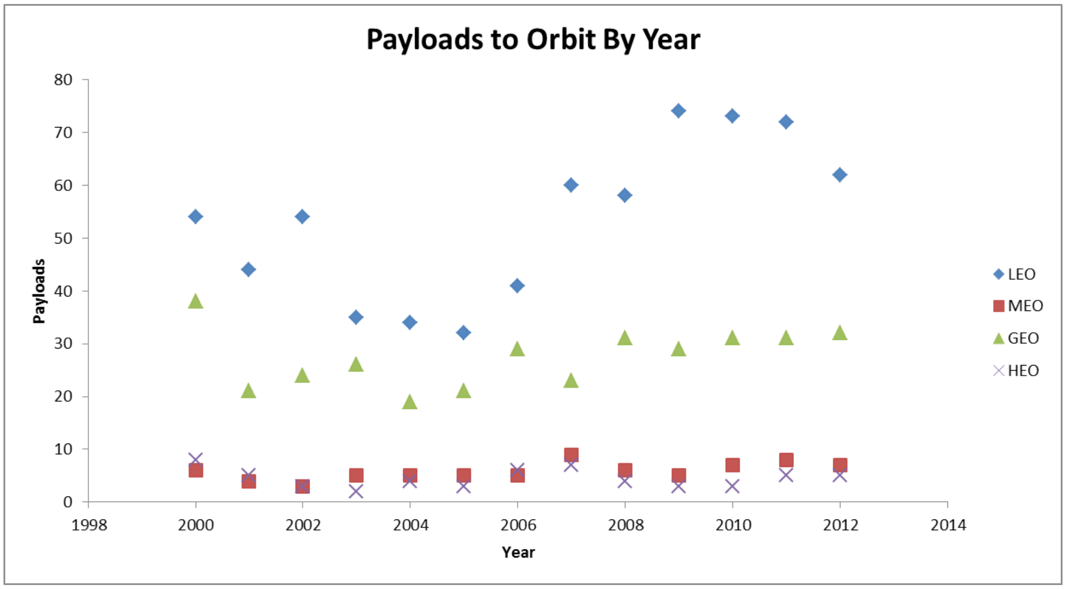

Figure 3.1: Payloads By Orbit, 2000-2013

coincides with the *Columbia* disaster, even though there are no Space Shuttle payloads included in this data. GEO payload mass has the same slow, steady rise shown in Figure 3.1.

Figures 3.3 and 3.4 contains a histogram and cumulative histogram of payload masses, respectively. This figure shows a conundrum that space launch presents: 51% of the payload mass, and therefore demand for launch vehicles, is for payloads in the 4000-8000kg range, but the majority of individual payloads are small payloads with a plurality massing less than 1000kg. This trend has significant consequences for launch vehicle development and operations, as outlined in subsequent chapters.

Given the great difference in energy requirements between orbits, it is important to know how these masses break down between orbits. The most important question from an operational perspective is determining which orbit this large majority of small individual payloads are being sent to.

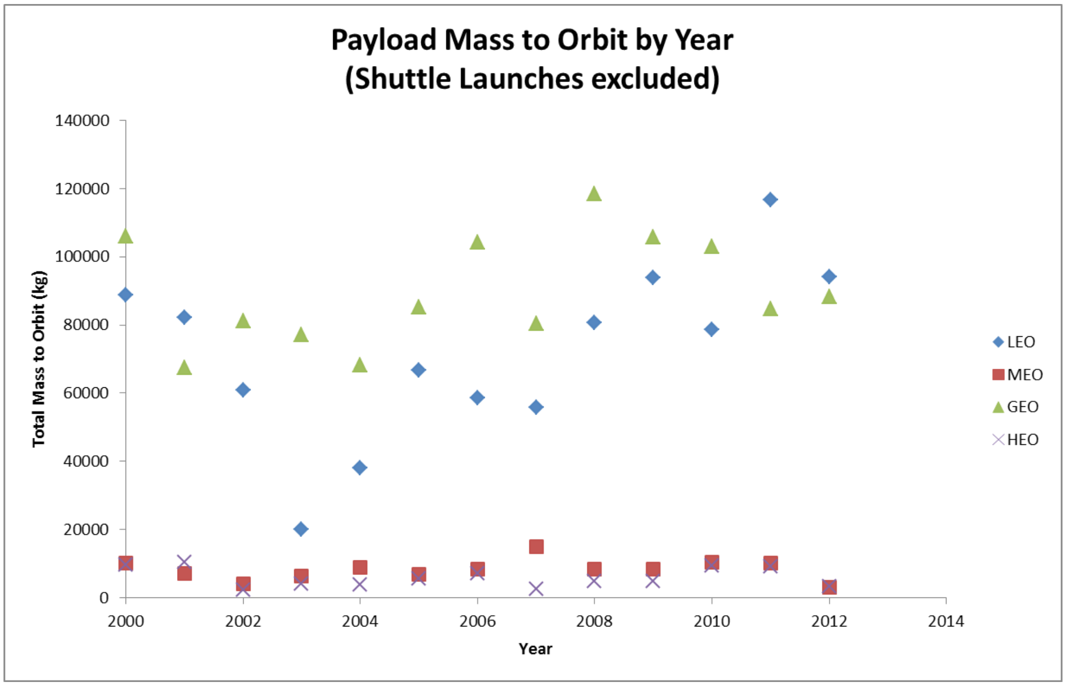

Figure 3.2: Payload Mass By Orbit, 2000-2013

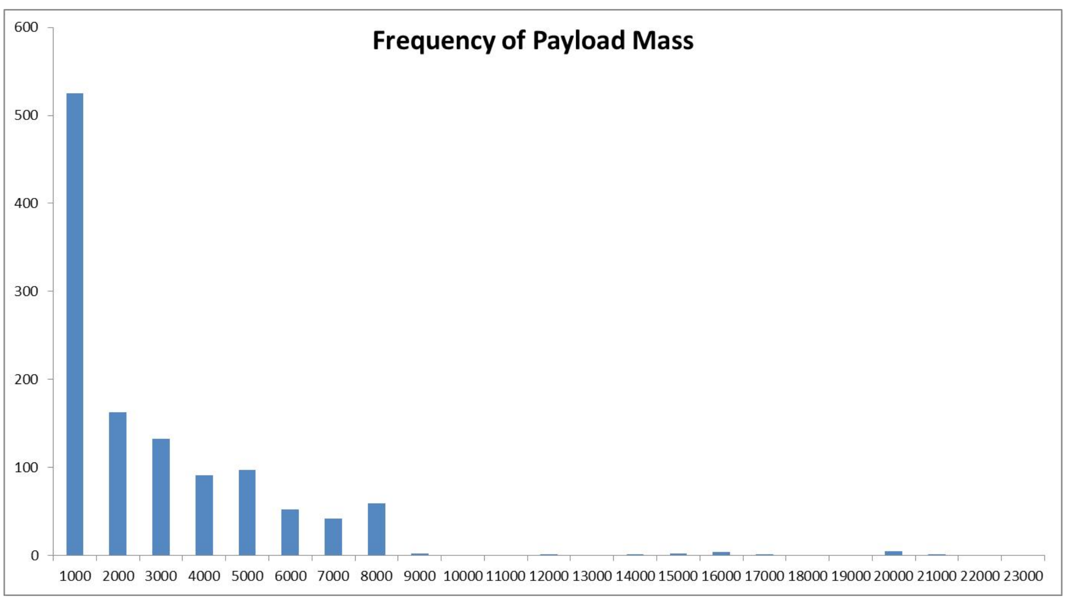

Figure 3.3: Number of Payloads of Mass, 2000-2013

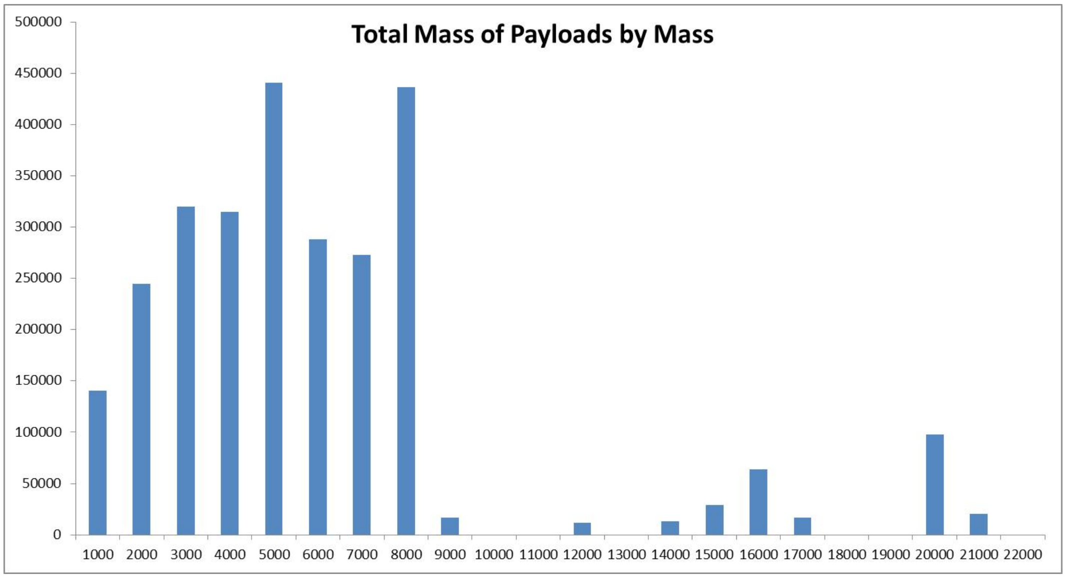

Figure 3.4: Total Mass of Payloads in kg by Individual Mass, 2000-2013

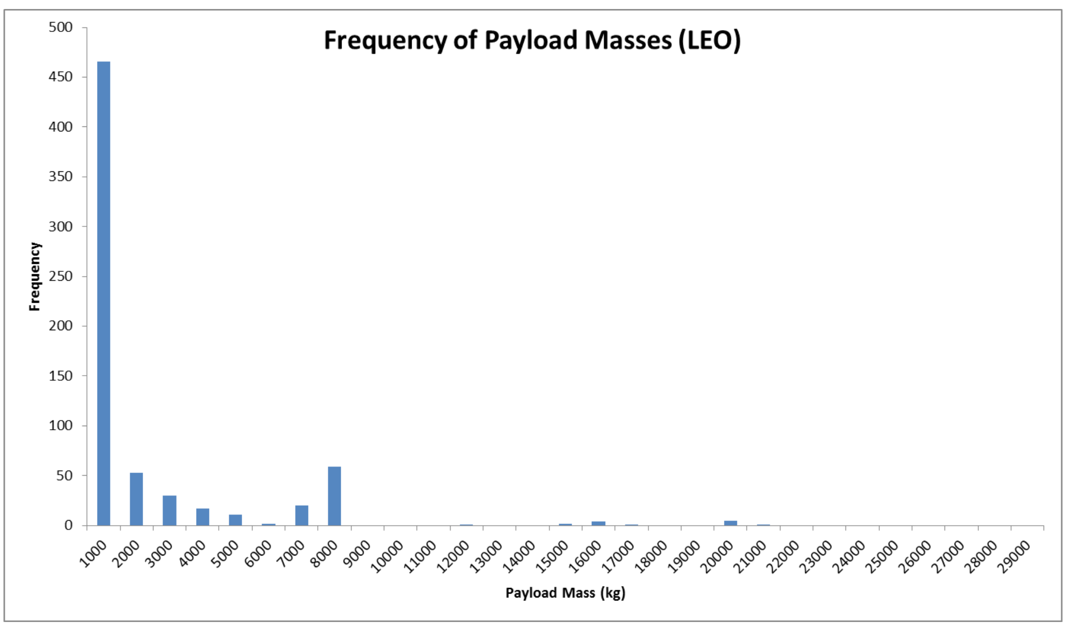

Figure 3.5: Number of LEO Payloads of Mass, 2000-2013

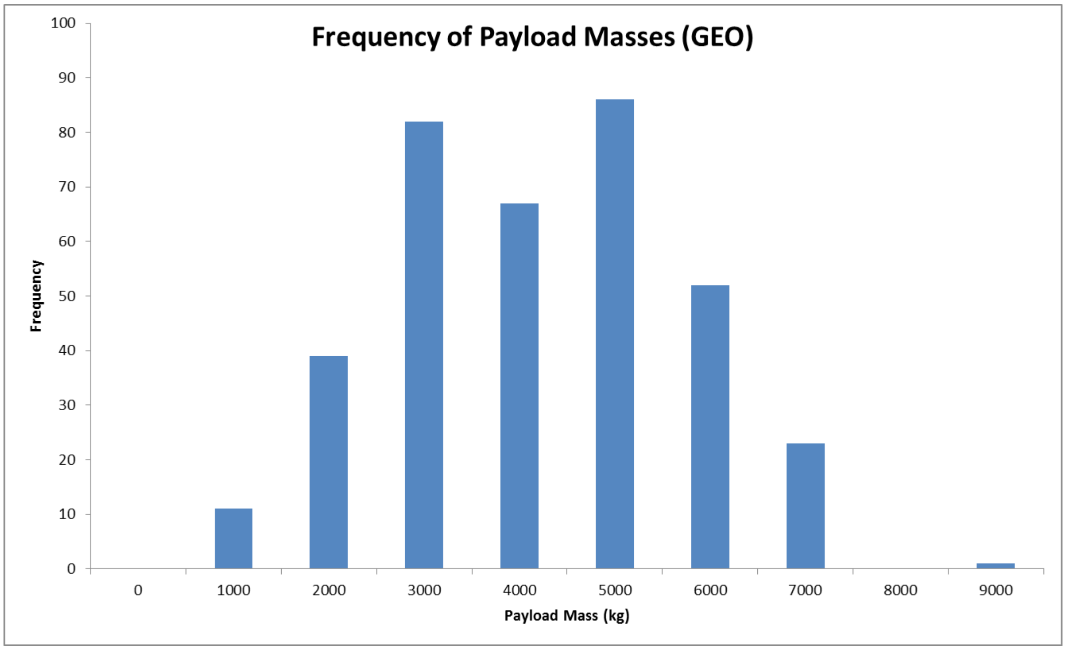

Figure 3.6: Number of GEO Payloads of Mass, 2000-2013

The majority of individual spacecraft are in LEO. LEO missions are extremely diverse, ranging from small student-built CubeSats to the NRO's twenty-ton *Lacrosse* radar surveillance satellite. It is clear that both the majority of LEO payloads are small (<1000kg) and the majority of small payloads are in LEO. 451 out of the 521 payloads massing less than 1000kg are in LEO. Notwithstanding their numbers, however, these payloads only constitute 9.47% of the total LEO payload mass. Figure 3.5 contains a histogram of LEO payload masses.

Figure 3.6 is a histogram of geosynchronous payloads. Geosynchronous orbit is generally the province of communications satellites. The fixed longitude of payloads there relative to the Earth's surface renders them uniquely suited to this task, and geosynchronous orbit's greater distance from the Earth renders surveillance assets placed there less effective. It also provides no added benefit to many types of space science. Accordingly, the masses of payloads to this orbit are close to normally distributed.

The remaining two Earth orbit categories see much less usage. Medium Earth orbit payloads are suitable for a few specialized tasks. The most important of these is navigation. The GPS and GLONASS constellations both have orbits of this sort. Due to this similarity, they exhibit trends in their masses similar to those of geosynchronous payloads. Like MEO spacecraft, highly elliptical orbit spacecraft see limited specialized use. The most important of this is provision of communications services to high latitudes, where geosynchronous spacecraft are unable to perform this mission. 'Molniya' is another term for this orbit, derived from a series of Soviet communications satellites that used it.

It is also important to consider the number of payloads per launch. Many launch vehicles launch multiple payloads at once. The COSPAR number assigned to each payload (shown in Appendix A) indicates which payloads launched together, with each launch having a different number and components that reach space having a letter suffix. Figure 3.7 presents the average number of payloads per launch for each year. This quantity increased relatively steadily throughout the entire period.

Finally, it can be instructive to examine the average mass of each payload. For missions with similar individual requirements, a reduction in mass over time might occur due to improvements in technology. The increase in the number of micro- and nano-satellites over time may also factor in to such a trend.

Examining these trends leads to a few conclusions of importance. The first is that LEO missions are highly variable, while GEO missions are much less so. This owes to the homogeneity of GEO missions. Virtually all GEO payloads are communications satellites. While there are varying degrees of capability, their missions are very similar.

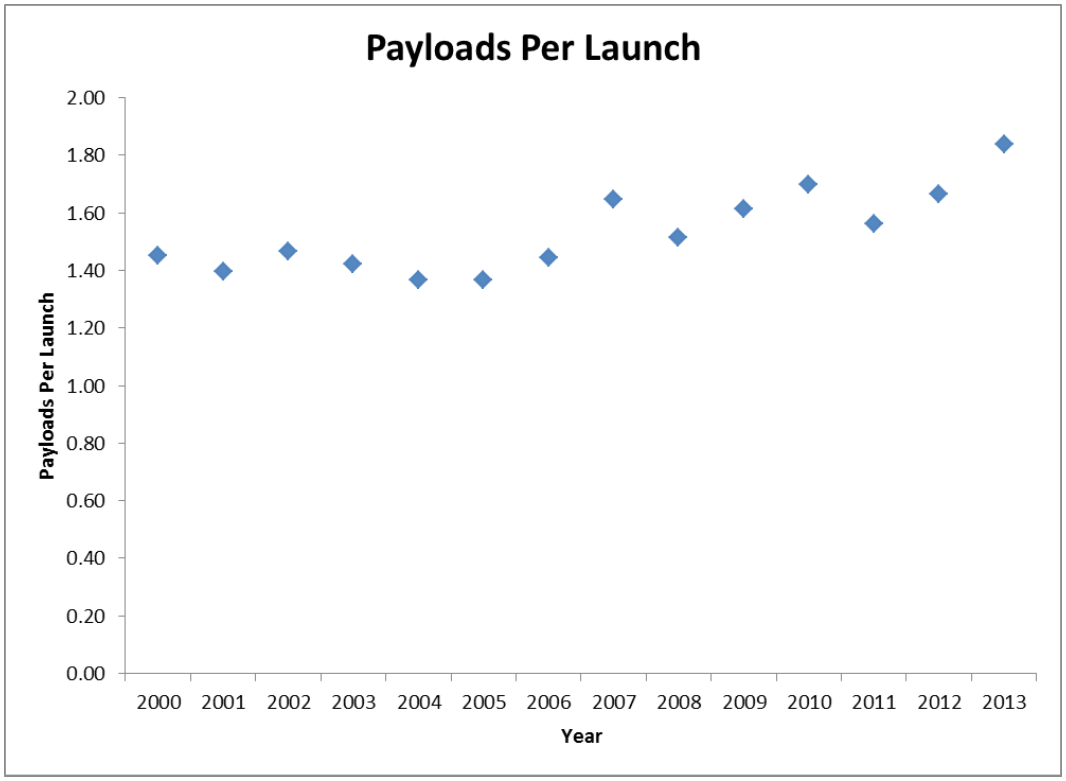

Figure 3.7: Payloads Per Launch, 2000-2013

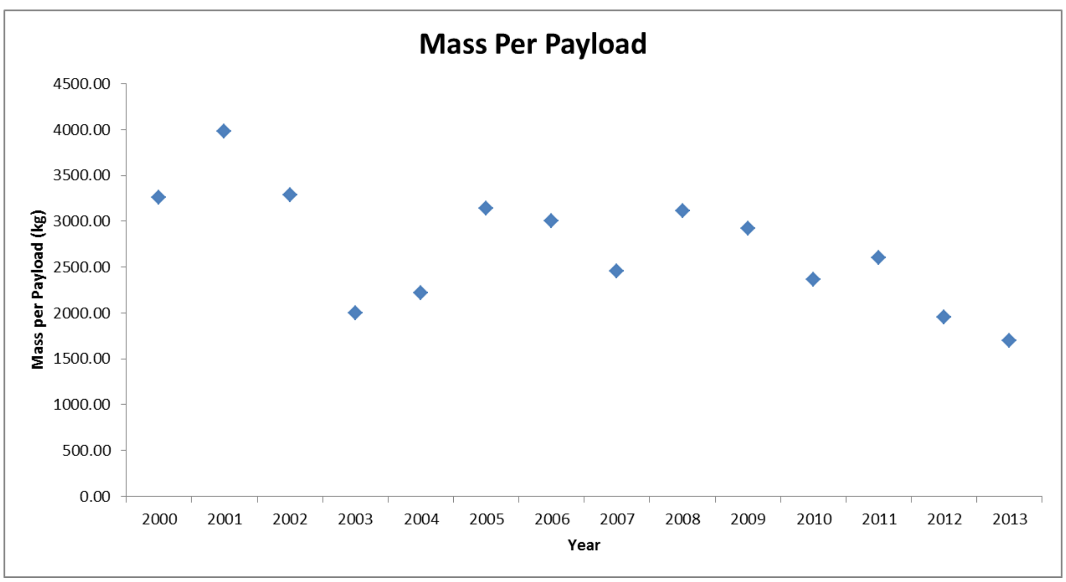

Figure 3.8: Average Mass Per Payload, All Orbits, 2000-2013

As stated in the previous discussion, however, LEO missions are highly variable. This results in their masses being highly variable, and having no real trends, other than the preponderance of small payloads. This behavior is again due to the increased presence of microsatellites and the improvement in electronics and other spacecraft systems, which makes reduction in mass and therefore expense possible.

For most years, the payload mass delivered to LEO and GEO are roughly similar, but this does not provide a clear picture of total launch vehicle requirements because GEO is a much more difficult orbit to reach, which reduces launch vehicle payload capacity. For example, a Falcon 9 v1.1 can place 13,150 kg into LEO, but only 4,850 kg into a GTO [24], making GEO payloads 2.71 times more expensive per mass for this launch vehicle. This ratio varies somewhat depending on launch vehicle design, but usually lies between two and three, as shown in Table 3.1.

This behavior results in significant consequences for the development and employment of launch vehicles. The most important of these consequences is wastage, as discussed and quantified in Chapter 6. Chapter 8 discusses strategies to alleviate wastage, but also demonstrates that given current payloads and launch vehicles, there is no way to completely eliminate wastage. However, it is possible to reduce wastage considerably.

Table 3.1: Ratio of LEO Payload to GTO Payload for Selected Launch Vehicles

LV	Config	P (LEO)	P (GTO)	Ratio
Long March	2C	4400	1400	3.14
	2E	9500	3500	2.71
	3A	6000	2600	2.31
	3B	11200	5100	2.20
	3C	9100	3800	2.39
Ariane 5	G	16000	6700	2.39
	ECA, ES	21000	10500	2.00
Proton-K	Block DM	19760	4930	4.01
Proton-M	Briz-M	21000	5500	3.82
Atlas V	401	9797	4950	1.98
	411	12150	5950	2.04
	421	14067	6830	2.06
	431	15718	7640	2.06
	501	10300	3970	2.59
	511	12590	5270	2.39
	521	15080	6285	2.40
	531	17250	7200	2.40
	541	18955	7980	2.38
	551	20520	8670	2.37
Delta IV	Medium	9420	4440	2.12
	Medium+ (4,2)	13140	6390	2.06
	Medium+ (5,2)	11470	5490	2.09
	Medium+ (5,4)	14140	7300	1.94
	Heavy	28790	14220	2.02
Falcon 9	-	13150	4850	2.71

Chapter 4

Launch Vehicle Trends

Understanding trends in launch vehicle usage, development, and pricing is a critical component of the operational loss problem. It is clear that selecting an overly large or cost-ineffective launch vehicle can greatly increase launch costs for the user. As shown in Appendix B, cost-effectiveness can vary by as much as a factor of ten between different launch vehicles. Losses of a similar order of magnitude are possible with excessive wastage; Appendix A contains several launches with wastage in excess of 80%, effectively increasing the cost of access to space by a factor of at least five.

Table 4.2 contains usage data by year for launch vehicle families. As elsewhere in this work, a 'family' uses the same core stage, e.g. the EELT (Extra-Extended Long Tank Thor) for Delta II or the CCB (Common Core Booster) for Atlas V. A 'family' may include multiple generations of the same basic launch vehicle as well, even though they are not strictly speaking identical and may have served concurrently. For instance, Proton-K launches continued after the introduction of Proton-M, a modernized and much more capable version of the same basic launch vehicle. Figure 4.1 contains representatives of selected launch vehicle

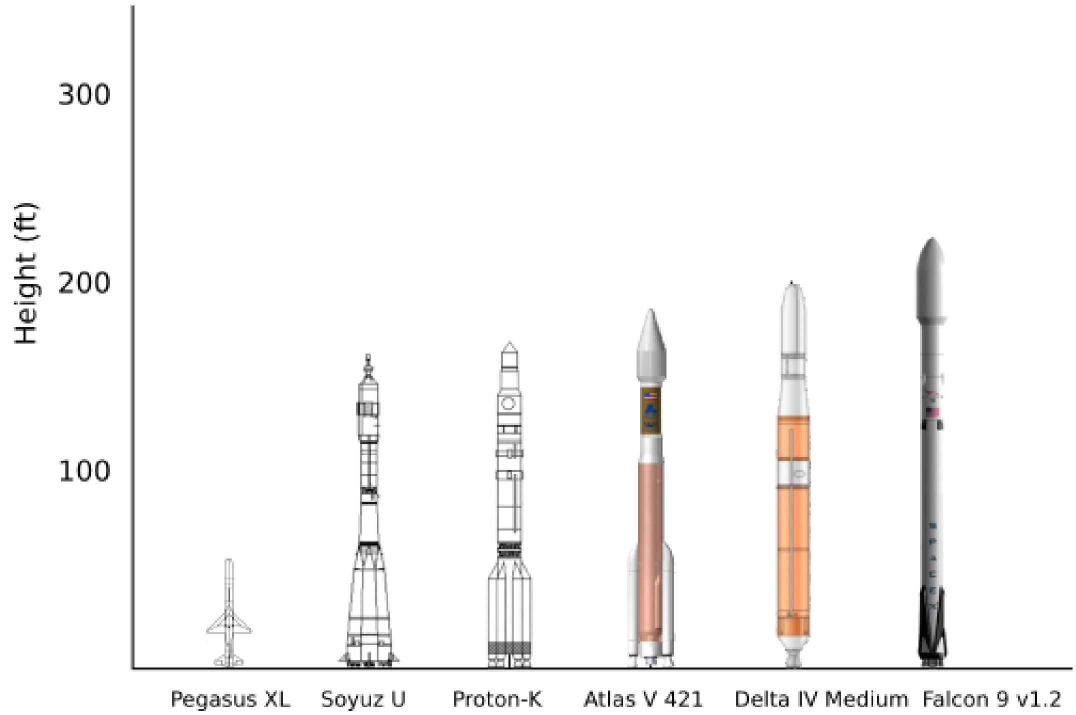

Figure 4.1: Selected Launch Vehicles Drawn to Scale (Adapted from Refs. [18], [28], [29])

families drawn to scale.

There is some confusion of terms regarding 'cost' and 'price' in the launch vehicle world. 'Launch cost' is often used to describe the money that must be paid to the launch vehicle provider to buy the launch vehicle, integrate the payload, and launch it into a desired orbit. This is really a price, which is subject in some degree to market forces and other influences [4].

As noted in Chapter 2, there are several models for estimating the costs of space missions and their components. These include TRANSCOST by Koelle [30], the NAFCOM cost model developed by the US Air Force and NASA, and other forms of cost estimation [15]. While these are valuable for estimating the cost of launch vehicle development and construction, it does not necessarily follow that trends in prices will mirror trends in cost. While there must be some relation, other considerations such as profit and subsidies can divorce cost from price to some degree.

The most common metric used to evaluate launch vehicles is price per maximum payload capacity. Determining pricing can be somewhat difficult. As of this writing, only SpaceX publicly provides price data for its launch vehicles. For other launch vehicle providers, the price data used herein are from secondary sources, which include FAA Launch Reports and AIAA's *International Reference Guide to Space Launch Systems*. Some sources, in particular the FAA reports, give a price range for launch vehicles, e.g. '$15-20M'. If this is the case, the lowest price in the range is used. If multiple sources disagree on what a launch vehicle's price is, the lowest price from a reputable source is used. These prices were converted to 2014 USD using Federal CPI data.

Determining payload capacity is much simpler. Most launch vehicle providers publish a users' guide for their launch vehicle, and these typically provide payload capacities to a wide variety of orbits [28, 29, 31–39]. Some users' guides are not available, such as those for the Titan launch vehicle family. In this case, secondary sources can provide maximum payload capacities, although few of these are as detailed as the users' guides.

One important detail that appears in the users' guides is the actual definition of 'payload capacity.' Some manufacturers, such as ULA, specify a 'payload systems weight' that is the sum of the actual payload weight and that of fairings and payload adapters, while other providers count these items as part of the launch vehicle. In this work, the latter approach is used, as the amount of useful payload delivered is what is valuable.

Since payload capacity varies greatly depending on the payload's final intended orbit and exactly how the payload gets there, providers usually give data for some typical mission, such as a 28.5-degree 185 km low Earth orbit from Cape Canaveral or a GTO. This work follows this approach. LEO cost effectiveness is rated by the highest maximum payload capacity to LEO. This is a minimum altitude circular orbit at an inclination corresponding to the launch site's latitude, e.g. 28.5 degrees for Cape Canaveral. GTO payload capacity will be rated by the launch vehicle's capacity to a 200 km perigee geosynchronous transfer orbit. As discussed in further detail in Chapter 6, this is the most common mission profile for geosynchronous missions.

Price and maximum payload capacity data for 101 launch vehicle configurations were obtained from the above sources. These are all launch vehicles available between 2000 and 2013. Some launch vehicles with very few flights, such as Epsilon, Naro-1, Unha 1, and others are not included. Appendix B contains the launch vehicle data used in this work.

Understanding how a launch vehicle's characteristics relate to its cost-effectiveness is critical to proper selection and development of launch vehicles. Evaluation of cost models also serves as a check on the cost data, which are uncertain. Several possible characteristics will be considered in order to determine if there is a correlation between any of them and the launch vehicle's price per maximum payload capacity. These include the maximum payload capacity itself, a 'performance number' detailed below, flight rate, and total production.

The function of sizing in cost and therefore price has been understood for some time. It is analogous to the same behavior in conventional aircraft design. Most previous models used empty mass and then related payload mass to it by setting a structural fraction [15]. These models will directly use maximum payload capacity to low Earth and geosynchronous orbits. They make use of logarithmic regression, since this is the trend observed both in cost models [15] and real price data.

It would be desirable to know how the performance of the launch vehicle relates to its price. That is, determine whether it is desirable to build the smallest empty weight launch vehicle possible by using advanced technologies, or if it is more cost-effective to select a simpler design, with lower performance, and consequently higher empty weight.

The rocket equation dictates two ways to improve launch vehicle performance: increase the specific impulse I_{sp} of the propulsion system, or reduce the structural fraction ϵ by either reducing the weight of the rocket structure or using an engine with greater thrust to weight ratio. Both approaches are used in any successful space vehicle design, and taken together they provide a measure of the vehicle's efficiency. A metric for this can be created by eliminating the constant g from the rocket equation as well as the payload fraction, resulting in $I_{sp} \ln \frac{1}{\epsilon}$, referred to in the remainder of this work as the 'performance number.' Vacuum specific impulse is used in all cases to ensure an equal comparison, although most first stage engines are not optimized for operation in vacuum.

Many space vehicles have different specific impulse values for each stage. For comparison purposes, a weighted specific impulse value was obtained using the weight fraction of each stage multiplied by the specific impulse of the stage. For instance, a Saturn V has a weighted I_{sp} of 328.66 s ((304s * 5040245lbs + 421s * 1346280lbs) / 6698700lbs). This provides a general overall estimate of the efficiency of the vehicle's propulsion systems.

Studying the effects of flight rate is also important, as many cost models [15] are very concerned with flight rate and the effects of the learning curve. An increase in the number of flights has historically been postulated as a primary

Table 4.1: Summary of Cost Estimation Models

	Coefficients				P-values				R^2
Model	a	b	c	d	a	b	c	d	Adjusted
$C = a \ln P + bn_p + c$, LEO	-3636	-23.03	61690	-	4.847×10^{-7}	8.158×10^{-5}	9.919×10^{-15}	-	0.4275
$C = a \ln P + bn_p + c$, GTO	-16230	-21.68	177800	-	4.055×10^{-9}	0.1897	2.495×10^{-14}	-	0.5070
$C = a \ln P + bn_p + cr_f + d$, LEO	-3832	-23.14	224.1	62730	6.670×10^{-7}	7.994×10^{-5}	0.4231	1.406×10^{-14}	0.4248
$C = a \ln P + bn_p + cn + d$, LEO	-3658	-22.89	-1.140	62020	4.91×10^{-7}	9.72×10^{-5}	0.5313	1.221×10^{-14}	0.4229
$C = a \ln P + bn_p + c$, US LEO	-4678	-29.43	78310	-	1.651×10^{-9}	4.984×10^{-7}	6.422×10^{-16}	-	0.7204
$C = a \ln P + bn_p + c$, US GTO	-18130	-48.41	217600	-	2.283×10^{-8}	0.02103	3.518×10^{-14}	-	0.7177

method to drastically reduce launch costs. Flight rates are computed by family, again defined as using the same core stage. Finally, the total number of each launch vehicle produced is a variable that requires study. This is the truest measure of the learning curve, although it is less of a measure for fixed costs that may have a cost associated with time as opposed to launches, such as launch facilities and engineering support.

With these data in hand, multiple regression analyses were performed on the data set. The baseline case consists of a linear regression in two variables, the natural logarithm of the maximum payload capacity and the 'performance number,' on all 101 configurations in the data set. This was done for both LEO and GEO payloads. Subsequent analyses investigated the effects of flight rate and total production number on launch vehicle prices. Surprisingly, there appears to be little or no correlation.

The final analysis is for US launch vehicles only. This is intended to determine if the trends observed in the two previous analyses are different for a single country of origin than they are for the world as a whole. The United States was selected for this analysis due to its greater diversity of launch vehicles and their configurations, which provides more data points. The results of this analysis are presented in Table 4.1 and Figure 4.2.

The logarithmic relationship between sizing (either in the form of payload capacity or empty mass) and cost per payload capacity has been known and

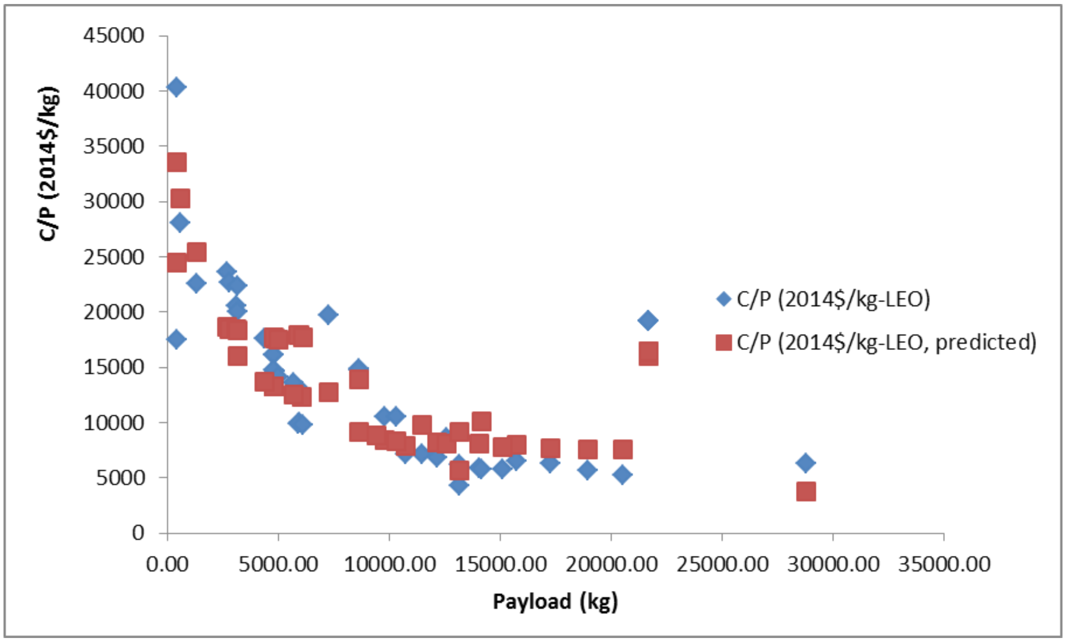

Figure 4.2: Payload Mass Versus Cost Per Unit Payload Mass Capacity to Low Earth Orbit, US Only

remarked on for many years. The relationship between efficiency and cost per payload capacity has been less clear. In the past, various design organizations proposed very large, low performance vehicles (so-called 'big dumb boosters') [8, 40]. Fierce debate accompanied these proposals. Analysis of the data shows, however, that among the designs actually built, cost decreases with increasing performance number. Therefore, the most cost-effective launch vehicle is not a 'big dumb booster,' but a 'big smart booster.'

One of the prevailing arguments against large boosters of both the 'smart' and 'dumb' types has been that the development cost begins to suffer a reverse economy of scale, i.e. if a large booster is constructed, the development cost associated with such a difficult engineering challenge grows out of proportion to the payload, destroying the economy of scale. Furthermore, it is often argued in parallel that the loss of the learning curve benefit associated with high production quantities is a disadvantage. Both of these arguments are in principle valid, but the price data here in general do not reflect their effects.

Surprisingly, flight rate seems to have little or no effect on current launch vehicle price, which seems to fly in the face of the accepted wisdom. In actuality, it might not, because of the distinction between cost and price. Using cost models to determine prices implicitly assumes that the user ultimately pays development costs, which is the exception rather than the rule for most real-world launch vehicles. Governments have historically financed launch vehicle development for national security or national space program purposes to some greater or lesser extent, whereas private space development of this size has typically proven to be a poor investment. For instance, SpaceX spent nearly $90M developing Falcon 1, which ended up having two paying launches at $7M apiece. While this was not a total loss, as SpaceX later used the same engine on Falcon 9, it represents a loss of at least $76M less whatever value SpaceX derived from having an engine design in place when beginning Falcon 9 development.

This gives rise to an interesting comparison. The USAF invested approximately $500M in 1998 dollars in EELV development for each of the winning designs in that program, or $726.1M in 2014 dollars [41]. NASA's investment in Falcon 9 and Dragon development was approximately $396M [42] [43], with SpaceX contributing an additional $450M of private funding. It is interesting to note that presumably the cost to develop Falcon 9 was on par with the cost to develop the EELVs, even if the unit cost of the final product is considerably cheaper.

These practices can 'hide' the development cost and some of the other fixed costs of most launch vehicles from the market. As a result, the 'flight rate' effects that were expected are virtually nonexistent. The sole possible exception to this is the learning curve, whose effects by themselves can in many cases be equal to or smaller than the residuals from the current models. For instance, at a 90% learning curve, the cost difference between the 100th and 1000th unit constructed is approximately 31%, with the 100th unit costing 49% of the original cost and the 1000th unit costing 34% of the original cost. The average residual from the baseline (np-lnP) model is 30% for all launch vehicles and 27% for US launch vehicles. Comparatively few launch vehicles have such high production numbers; the only launch vehicle with more than 1000 units produced is Soyuz, of which 1,727 had been built as of the end of the data set. The legacy Delta family (from the earliest Thor derivatives to Delta III) ranks second, with 701 units produced, and no other family has a production quantity higher than 500.

Another problem with using flight rate or total production as a variable is that the learning curve is not necessarily constant across designs or across development organizations. Some designs will have inherent advantages over others. As an example, compare Falcon 9 with Atlas V 401. Falcon 9 uses nine identical first stage engines and a second stage engine that is substantially identical with the exception of the nozzle. Atlas V 401 uses one first stage engine and a different second stage engine. Therefore, Falcon 9, all other things being equal, will be ten times farther down the learning curve than its competition on one of the key components of the launch vehicle. Of course, other compromises must be made to do this, but this results in even more cost changes, rendering the possibility of determining cost from flight rate or total production even more difficult.

From a more strictly engineering perspective, the results obtained here contradict the assertions made by Koelle and others [15] that advanced materials and other innovative techniques actually increase cost. For US launch vehicles, the relationship between increasing performance number and decreasing price is quite strong. It is difficult to say how much of the cost associated with the use of advanced technology is paid on the development side and how much is paid on the production side, but whatever additional costs are being incurred on the production side are more than being repaid.

Table 4.2: Launch Vehicles Used, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	7	6	7	1	0	0	0	0	0	0	0	0	0	0	21
Ariane 5	4	2	3	3	0	2	5	4	6	5	5	3	3	4	49
Atlas	8	2	4	2	4	0	0	0	0	0	0	0	0	0	20
Atlas V	0	0	0	2	1	1	1	2	1	3	3	1	1	1	17
Delta II	1	1	1	2	3	1	2	1	3	2	1	1	0	0	19
Delta IV	0	0	0	2	0	0	1	1	0	0	0	0	0	0	4
Proton	8	5	4	3	5	4	3	4	8	8	8	5	0	1	66
Soyuz	8	7	4	5	3	6	5	9	5	7	6	5	4	1	75
PSLV	0	1	1	1	0	1	0	2	1	0	0	1	0	0	8
GSLV	0	1	0	1	1	0	0	1	0	0	0	0	0	0	4
Long March 2	0	0	0	0	1	1	1	1	0	0	0	0	0	0	4
Long March 3	3	0	0	2	1	1	2	4	3	1	1	6	0	0	24
Long March 4	0	0	1	1	1	0	2	1	2	0	1	2	0	0	11

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Zenit	4	3	1	2	4	3	4	0	5	1	0	1	0	0	28
Titan	3	3	2	3	1	2	0	0	0	0	0	0	0	0	14
Kosmos	3	1	4	3	2	2	1	3	3	0	1	0	0	0	23
Molniya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dnepr	1	0	1	0	1	1	1	3	2	1	3	0	0	0	14
H-II	0	0	2	1	0	0	2	1	1	2	1	1	2	1	14
Rokot	1	0	2	2	0	1	1	0	1	2	2	1	0	1	14
Minotaur 1	2	0	0	0	0	2	2	1	0	1	0	1	0	0	9
Pegasus	1	0	1	4	0	0	0	1	2	0	0	0	0	1	10
Falcon 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Falcon 9	0	0	0	0	0	0	0	0	0	0	2	0	2	1	5
Antares	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Start-1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	3
Tsyklon	0	3	0	0	1	0	1	0	0	0	0	0	0	0	5
Vega	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Total	55	36	38	40	29	28	35	39	43	34	34	28	13	14	466

Chapter 5

Capability of Launch Vehicles

A launch vehicle is only useful for launching payloads that are less massive than its maximum payload capacity to the desired orbit. That is, it must have capability to carry the payload to the desired trajectory. Since sizing is a critical design decision for any aerospace vehicle, determining the relative capability and therefore usefulness of a launch vehicle requires evaluation of launch vehicle designs according to the payload trends observed in Chapter 3.

Payload capacity can vary widely within the orbital categories defined in Chapter 3. This is especially true for low Earth orbits, given the wide variety of desired altitudes and inclinations. A considerable number of these are in polar or sun-synchronous (98.1 degree inclination) orbits which impose a significant extra delta-V requirement and corresponding loss of payload capacity. Other orbit types are more consistent since they are typically tied to a single type of usage, but even geosynchronous transfer orbit capacity can change depending on mission profile [28, 31].

This analysis requires the same restrictions as the payload trending in Chapter 3, with a few additions. 201 additional payloads were excluded as there was no payload capacity data for their launch vehicles. The primary cause for this is missing data for capacities to certain sorts of orbits. For many launch vehicles where the users' guides are unavailable, payload capacity is only given to a few orbits, and if a payload is not in one of these, it is not possible to determine the launch vehicle's payload capacity for its mission. Some users' guides are also missing data for certain orbits, such as the Arianespace Soyuz users' guide [36], which is missing data for certain low Earth orbits. This leaves a total of 985 payloads.

Table 5.1 contains the percentage of individual payloads that each launch vehicle family could launch by year. 'Family' is again defined as using the same core stage or stages. As might be expected, Delta IV, which with Delta IV Heavy has the largest launcher in existence as of this writing, can launch any payload in the data set. The smallest launchers, Pegasus and Falcon 1, can launch approximately 33% of individual payloads. The remainder of launch vehicle families fall somewhere in between, depending on the maximum payload capacity of their largest configuration.

Table 5.2 lists the capability of each launcher as a percentage of the total payload mass. The picture here is completely different. Falcon 1 and Pegasus' 33% of individual *payloads* translate into less than 2% of total payload *mass*. Combined with the results of the analysis presented in Chapter 4, it is clear that small launch vehicles labor under a considerable disadvantage. Not only are they inherently more expensive per unit of payload mass capacity due to their small size, they are incapable of launching much of the revenue-generating payload mass required to repay their development costs.

Given the utilization data, it is also possible to make statements about each launch vehicle's real market share, i.e. fraction of individual payloads or payload mass that it launched versus the total number of payloads or payload mass that it was capable of launching. Tables 5.3, 5.4, and 5.5 present the market share of each launch vehicle family in terms of percentage of payload mass that it was capable of launch, percentage of individual payloads that it was capable of launching, and fraction of individual payloads that it was capable of launching. As elsewhere in this work, this is done only for the 525 LEO and GTO launches with complete data.

As can be seen, in terms of market share, Soyuz is far ahead of any of its competitors, with a payload mass market share of 45.48% of the payloads that it is capable of launching, or 17.2% of all payload mass. Single digit percentage market shares are far more typical.

This is an important consideration for launch vehicle development, especially privately funded development. Many launch vehicle design studies estimate the overall size of their market or their production numbers, which amounts to the same thing [15]. But it is clear that even a highly successful launch vehicle like Soyuz, which is both very cost-effective and very reliable, can only capture less than half of its possible market. Furthermore, even in Soyuz's case, a considerable percentage of its unmanned launches are Russian government launches in the form of Progress ISS logistics craft and military payloads. Progress alone accounted for 56 of the 83 unmanned Soyuz launches in the data set. Strictly speaking, it does not have to compete for either of these, as Progress is specifically designed to be launched on Soyuz and Russia, like most nations, will not launch national security payloads on another country's launch vehicles.

As touched on in Chapter 4, for a government developing a launch vehicle, this consideration may not be a problem. A government can estimate its own future need for launch vehicles based on its own requirements and determine whether the development costs, which it usually pays up front, are justified. Privately funded launch vehicle development cannot do this. It must estimate what the market will offer. Unfortunately, these data indicate that in the majority of cases the answer will be ‘very little.’

Table 5.1: Percentage of the Number of Payloads Launchable, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2000-2013
Ariane 4	87.23%	81.25%	80.00%	88.24%	89.09%	76.36%	77.46%	84.52%	75.31%	82.42%	81.82%	77.22%	77.97%	87.50%	81.91%
Ariane 5	93.62%	89.06%	93.33%	98.53%	100.00%	96.36%	95.77%	96.43%	93.83%	94.51%	96.59%	94.94%	98.31%	98.44%	95.53%
Atlas	74.47%	67.19%	73.33%	79.41%	72.73%	61.82%	63.38%	76.19%	64.20%	68.13%	73.86%	69.62%	69.49%	81.25%	71.21%
Atlas V	94.68%	90.63%	93.33%	98.53%	100.00%	98.18%	95.77%	96.43%	95.06%	94.51%	96.59%	96.20%	100.00%	100.00%	96.21%
Delta II	91.49%	89.06%	92.00%	95.59%	94.55%	81.82%	85.92%	92.86%	79.01%	83.52%	82.95%	79.75%	81.36%	87.50%	86.87%
Delta IV	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Proton	93.62%	90.63%	93.33%	98.53%	100.00%	96.36%	94.37%	96.43%	95.06%	94.51%	96.59%	96.20%	100.00%	100.00%	95.91%
Soyuz	78.72%	73.44%	76.00%	83.82%	81.82%	69.09%	70.42%	82.14%	69.14%	75.82%	80.68%	75.95%	72.88%	82.81%	76.75%
PSLV	44.68%	42.19%	48.00%	54.41%	54.55%	45.45%	45.07%	63.10%	48.15%	56.04%	56.82%	55.70%	49.15%	68.75%	52.43%
GSLV	17.02%	12.50%	6.67%	16.18%	10.91%	7.27%	9.86%	10.71%	7.41%	6.59%	6.82%	6.33%	5.08%	4.69%	9.24%
Long March 2	52.13%	54.69%	61.33%	60.29%	65.45%	56.36%	56.34%	70.24%	56.79%	64.84%	67.05%	64.56%	62.71%	76.56%	62.06%
Long March 3	92.55%	89.06%	93.33%	98.53%	96.36%	85.45%	91.55%	94.05%	87.65%	85.71%	90.91%	91.14%	84.75%	90.63%	90.86%
Long March 4	46.81%	45.31%	57.33%	61.76%	58.18%	45.45%	53.52%	63.10%	51.85%	58.24%	59.09%	59.49%	55.93%	73.44%	56.42%
Zenit	92.55%	89.06%	93.33%	98.53%	94.55%	85.45%	90.14%	94.05%	86.42%	84.62%	85.23%	88.61%	84.75%	89.06%	89.69%
STS	60.64%	65.63%	68.00%	61.76%	65.45%	61.82%	60.56%	73.81%	62.96%	71.43%	70.45%	70.89%	66.10%	79.69%	67.22%
Titan IV	94.68%	90.63%	93.33%	98.53%	98.18%	89.09%	91.55%	94.05%	91.36%	90.11%	92.05%	94.94%	88.14%	93.75%	92.90%
Kosmos	38.30%	31.25%	36.00%	33.82%	36.36%	34.55%	28.17%	45.24%	44.44%	42.86%	45.45%	48.10%	40.68%	60.94%	40.76%
Dnepr	43.62%	42.19%	48.00%	54.41%	54.55%	45.45%	45.07%	63.10%	48.15%	56.04%	56.82%	55.70%	49.15%	65.63%	52.14%
H-II	93.62%	89.06%	93.33%	98.53%	100.00%	96.36%	94.37%	96.43%	93.83%	94.51%	96.59%	94.94%	98.31%	98.44%	95.43%
Rokot	42.55%	37.50%	44.00%	52.94%	41.82%	41.82%	40.85%	57.14%	46.91%	52.75%	54.55%	55.70%	47.46%	64.06%	48.93%
Minotaur 1	40.43%	35.94%	40.00%	44.12%	40.00%	36.36%	39.44%	52.38%	44.44%	49.45%	53.41%	51.90%	45.76%	62.50%	45.82%
Minotaur V	42.55%	35.94%	41.33%	48.53%	40.00%	40.00%	40.85%	54.76%	44.44%	50.55%	53.41%	54.43%	45.76%	64.06%	47.28%
Pegasus	25.53%	28.13%	22.67%	33.82%	34.55%	29.09%	23.94%	29.76%	34.57%	40.66%	36.36%	31.65%	30.51%	48.44%	32.10%
Falcon 1	26.60%	28.13%	22.67%	33.82%	34.55%	29.09%	23.94%	29.76%	35.80%	41.76%	36.36%	31.65%	35.59%	50.00%	32.78%
Falcon 9	91.49%	89.06%	93.33%	95.59%	94.55%	81.82%	85.92%	92.86%	80.25%	83.52%	84.09%	81.01%	81.36%	87.50%	87.26%
Antares	44.68%	43.75%	54.67%	54.41%	56.36%	45.45%	47.89%	63.10%	49.38%	57.14%	60.23%	56.96%	55.93%	70.31%	54.38%

Table 5.2: Percentage of Total Payload Mass Launchable, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Ariane 4	45.41%	38.43%	39.89%	62.15%	77.17%	43.79%	43.86%	47.16%	33.78%	39.44%	44.00%	32.64%	45.99%	49.98%
Ariane 5	58.66%	46.17%	57.39%	84.01%	100.00%	77.99%	70.76%	68.42%	60.60%	62.06%	71.69%	65.22%	89.40%	86.27%
Atlas	25.73%	20.30%	29.61%	37.94%	38.21%	20.36%	20.44%	27.87%	15.10%	16.26%	25.38%	17.53%	27.57%	31.42%
Atlas V	64.55%	51.67%	57.39%	84.01%	100.00%	87.90%	70.76%	68.42%	67.12%	62.06%	71.69%	72.49%	100.00%	100.00%
Delta II	52.96%	46.17%	55.69%	77.21%	87.45%	50.68%	54.61%	61.04%	38.49%	40.92%	45.73%	37.37%	51.07%	49.98%
Delta IV	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Proton	58.66%	51.67%	57.39%	84.01%	100.00%	77.99%	67.49%	68.42%	67.12%	62.06%	71.69%	72.49%	100.00%	100.00%
Soyuz	36.86%	32.21%	35.95%	54.56%	64.91%	36.67%	36.33%	43.62%	27.31%	32.12%	42.46%	31.21%	40.21%	42.50%
PSLV	5.55%	5.29%	8.41%	14.55%	19.95%	7.34%	8.68%	15.21%	4.71%	7.01%	8.26%	7.07%	6.53%	14.10%
GSLV	9.56%	4.93%	2.34%	11.80%	9.12%	4.03%	3.64%	8.55%	2.79%	4.09%	5.28%	2.82%	2.94%	3.18%
Long March 2	19.72%	23.35%	29.06%	33.43%	49.75%	28.53%	29.11%	33.76%	20.68%	24.18%	30.36%	25.64%	32.22%	37.44%
Long March 3	54.44%	46.17%	57.39%	84.01%	91.50%	55.63%	62.73%	63.26%	50.36%	44.15%	60.01%	54.60%	56.65%	57.33%
Long March 4	6.32%	6.22%	14.13%	18.62%	24.06%	7.34%	12.86%	15.21%	5.29%	8.67%	11.35%	8.41%	13.78%	18.65%
Zenit	54.44%	46.17%	57.39%	84.01%	87.45%	55.63%	65.34%	60.09%	67.09%	58.67%	66.43%	51.59%	62.51%	63.39%
Titan IV	64.55%	51.67%	57.39%	84.01%	95.61%	72.73%	62.73%	63.26%	60.63%	54.38%	62.15%	69.96%	76.02%	82.40%
Kosmos	2.22%	1.04%	2.70%	1.53%	1.74%	1.65%	1.34%	3.92%	2.75%	1.08%	2.93%	4.04%	2.49%	5.33%
Dnepr	4.51%	5.29%	8.41%	14.55%	19.95%	7.34%	8.68%	15.21%	4.71%	7.01%	8.26%	7.07%	6.53%	9.14%
H-II	58.66%	46.17%	57.39%	84.01%	100.00%	77.99%	67.49%	68.42%	60.60%	62.06%	71.69%	65.22%	89.40%	86.27%
Rokot	3.58%	2.68%	5.40%	12.59%	4.88%	4.37%	5.15%	9.47%	3.97%	4.52%	6.25%	7.07%	5.16%	7.22%
Minotaur 1	2.74%	2.01%	3.62%	5.91%	3.33%	2.06%	4.60%	6.79%	2.75%	2.94%	5.59%	5.24%	4.07%	6.23%
Minotaur V	3.58%	2.01%	4.13%	8.84%	3.33%	3.54%	5.15%	8.01%	2.75%	3.38%	5.59%	6.33%	4.07%	7.22%
Pegasus	0.41%	0.72%	0.56%	1.53%	1.18%	0.82%	0.54%	0.96%	0.98%	0.75%	0.78%	0.70%	0.92%	1.71%
Falcon 1	0.52%	0.72%	0.56%	1.53%	1.18%	0.82%	0.54%	0.96%	1.11%	0.87%	0.78%	0.70%	1.58%	2.00%
Falcon 9	52.96%	46.17%	57.39%	77.21%	87.45%	50.68%	54.61%	61.04%	40.10%	40.92%	47.59%	39.18%	51.07%	49.98%
Antares	5.55%	6.94%	16.42%	14.55%	23.05%	7.34%	11.91%	15.21%	6.16%	8.32%	13.29%	8.95%	15.90%	16.94%

Table 5.3: Market Share as a Percentage of Possible Payload Mass

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	16.94%	21.39%	27.78%	4.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5.93%
Ariane 5	8.79%	4.84%	12.50%	11.74%	7.86%	15.95%	23.05%	27.20%	30.76%	20.12%	24.41%	24.33%	30.75%	29.27%	19.93%
Atlas I	24.98%	18.00%	17.27%	12.51%	22.33%	10.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	8.62%
Atlas V	0.00%	0.00%	0.00%	6.06%	3.06%	3.27%	2.43%	5.57%	3.31%	5.15%	7.43%	2.46%	2.22%	9.18%	3.45%
Delta 7	1.74%	1.42%	3.97%	4.39%	6.20%	1.32%	1.76%	4.17%	7.36%	6.47%	1.44%	3.20%	0.00%	0.00%	3.19%
Delta IV	0.00%	0.00%	1.91%	3.10%	0.00%	0.00%	2.44%	1.38%	0.00%	1.56%	1.70%	0.00%	0.00%	0.00%	0.80%
Proton	25.18%	8.78%	18.38%	9.00%	18.63%	14.41%	11.20%	10.34%	15.82%	19.83%	26.88%	13.54%	20.87%	14.25%	16.76%
Soyuz	37.66%	52.05%	28.11%	35.79%	40.45%	56.77%	51.73%	48.26%	53.17%	51.47%	40.21%	53.23%	43.43%	54.72%	45.58%
PSLV	0.00%	9.27%	4.37%	6.12%	0.00%	10.81%	0.00%	4.66%	7.86%	5.16%	3.83%	17.28%	15.73%	10.09%	6.21%
GSLV	0.00%	10.24%	0.00%	10.14%	15.77%	0.00%	0.00%	10.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4.04%
Long March 2	0.00%	0.00%	0.00%	5.88%	7.73%	9.59%	4.12%	3.91%	2.35%	0.00%	3.19%	11.16%	6.33%	2.37%	3.92%
Long March 3	4.01%	0.00%	0.00%	3.51%	1.10%	3.99%	5.55%	9.65%	5.82%	4.84%	1.37%	18.61%	4.98%	5.91%	4.95%
Long March 4	6.08%	0.00%	7.98%	5.63%	12.31%	0.00%	16.07%	11.78%	17.85%	3.39%	22.82%	15.84%	8.58%	0.00%	9.66%
Zenit	11.86%	8.73%	2.93%	7.73%	15.01%	14.29%	12.61%	2.18%	18.68%	8.31%	0.00%	6.82%	13.71%	1.24%	9.05%
Titan	7.75%	15.34%	3.63%	9.11%	1.82%	22.74%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4.23%
Kosmos	33.49%	26.07%	29.29%	73.06%	53.77%	55.64%	22.99%	26.02%	21.67%	0.00%	10.88%	0.00%	0.00%	0.00%	19.81%
Dnepr	0.76%	0.00%	0.59%	0.00%	0.81%	4.25%	6.26%	8.25%	10.54%	1.57%	10.76%	0.00%	0.00%	0.00%	3.30%
H-II	0.00%	0.00%	5.08%	1.60%	0.00%	2.03%	8.02%	1.25%	1.50%	8.72%	2.10%	8.68%	9.18%	11.57%	4.40%
Rokot	9.51%	0.00%	13.24%	5.01%	0.00%	7.94%	6.19%	0.00%	7.63%	10.15%	9.75%	6.29%	4.93%	13.95%	6.97%
Minotaur 1	2.98%	0.00%	0.00%	0.00%	0.00%	13.53%	6.90%	3.14%	0.00%	3.45%	0.00%	3.10%	0.00%	0.00%	2.19%
Minotaur V	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Pegasus	26.91%	0.00%	28.08%	47.70%	0.00%	21.86%	0.00%	8.86%	17.27%	0.00%	0.00%	0.00%	20.83%	7.65%	12.67%
Falcon 1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.41%	0.00%	0.00%	0.00%	0.00%	0.58%
Falcon 9	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.51%	0.00%	7.50%	6.54%	1.17%
Antares	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	28.53%	1.80%

Table 5.4: Market Share as a Percentage of Possible Individual Payloads

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	10.34%	13.73%	16.39%	1.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.09%
Ariane 5	9.57%	5.26%	7.04%	8.96%	14.29%	14.55%	14.49%	14.63%	14.29%	11.24%	14.12%	10.00%	16.25%	9.86%	11.81%
Atlas I	11.11%	7.14%	9.09%	3.70%	9.76%	2.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.03%
Atlas V	0.00%	0.00%	0.00%	2.99%	1.79%	1.82%	1.45%	9.76%	1.30%	3.37%	3.53%	1.25%	12.50%	5.63%	3.39%
Delta 7	7.69%	5.36%	8.57%	7.69%	5.66%	2.17%	8.06%	3.85%	6.25%	7.59%	1.39%	10.61%	0.00%	0.00%	5.51%
Delta IV	0.00%	0.00%	1.41%	2.99%	0.00%	0.00%	2.90%	1.22%	0.00%	1.12%	1.18%	0.00%	0.00%	0.00%	0.77%
Proton	12.90%	8.77%	9.86%	7.46%	12.50%	11.11%	7.35%	4.88%	10.39%	12.36%	18.82%	10.00%	12.50%	5.63%	10.49%
Soyuz	10.53%	17.39%	7.02%	8.77%	10.87%	20.51%	15.69%	21.74%	10.71%	18.06%	8.57%	36.51%	18.97%	26.32%	16.52%
PSLV	0.00%	11.54%	2.78%	2.70%	0.00%	8.00%	0.00%	9.43%	25.64%	11.32%	10.20%	17.39%	7.32%	16.67%	9.30%
GSLV	0.00%	12.50%	0.00%	9.09%	16.67%	0.00%	0.00%	11.11%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.96%
Long March 2	0.00%	0.00%	0.00%	2.44%	10.81%	6.25%	2.50%	3.39%	6.52%	0.00%	5.17%	1.89%	10.20%	7.55%	3.95%
Long March 3	4.35%	0.00%	0.00%	2.99%	1.85%	2.08%	4.55%	5.06%	4.23%	2.47%	1.25%	8.00%	2.94%	1.56%	3.09%
Long March 4	2.17%	0.00%	7.14%	4.76%	6.06%	0.00%	7.69%	3.77%	7.14%	3.64%	11.76%	20.00%	6.52%	0.00%	6.14%
Zenit	4.35%	12.50%	1.41%	2.99%	7.55%	6.25%	6.15%	1.27%	8.57%	5.00%	0.00%	5.48%	4.41%	1.61%	4.59%
Titan	3.19%	5.26%	2.82%	5.97%	1.82%	4.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.51%
Kosmos	19.44%	5.00%	22.22%	39.13%	15.00%	63.16%	5.00%	7.89%	22.22%	0.00%	2.56%	0.00%	0.00%	0.00%	11.83%
Dnepr	11.90%	0.00%	16.67%	0.00%	25.81%	8.00%	3.13%	30.19%	15.38%	11.32%	8.16%	0.00%	0.00%	0.00%	9.71%
H-II	0.00%	0.00%	8.45%	2.99%	0.00%	1.85%	5.88%	2.44%	1.32%	10.11%	4.71%	1.27%	5.06%	1.43%	3.41%
Rokot	4.88%	0.00%	11.76%	25.00%	0.00%	4.35%	3.45%	0.00%	10.53%	10.00%	8.51%	2.17%	5.13%	13.33%	7.46%
Minotaur 1	28.95%	0.00%	0.00%	0.00%	0.00%	10.00%	28.57%	2.27%	0.00%	10.87%	0.00%	2.38%	0.00%	0.00%	5.76%
Minotaur V	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Pegasus	8.33%	0.00%	5.88%	17.39%	0.00%	6.25%	0.00%	4.00%	7.14%	0.00%	0.00%	0.00%	3.57%	2.86%	3.80%
Falcon 1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.70%	0.00%	0.00%	0.00%	0.00%	0.29%
Falcon 9	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	13.70%	0.00%	4.69%	13.11%	2.26%
Antares	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	12.24%	1.04%

Table 5.5: Market Share as a Fraction of Possible Individual Payloads

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	9/87	7/51	10/61	1/60	0/50	0/43	0/56	0/71	0/61	0/78	0/71	0/64	0/61	0/60	27/874
Ariane 5	9/94	3/57	5/71	6/67	8/56	8/55	10/69	12/82	11/77	10/89	12/85	8/80	13/80	7/71	122/1033
Atlas I	8/72	3/42	5/55	2/54	4/41	1/35	0/46	0/64	0/52	0/65	0/64	0/58	0/56	0/56	23/760
Atlas V	0/94	0/57	0/71	2/67	1/56	1/55	1/69	8/82	1/77	3/89	3/85	1/80	10/80	4/71	35/1033
Delta 7	7/91	3/56	6/70	5/65	3/53	1/46	5/62	3/78	4/64	6/79	1/72	7/66	0/63	0/61	51/926
Delta IV	0/94	0/57	1/71	2/67	0/56	0/55	2/69	1/82	0/77	1/89	1/85	0/80	0/80	0/71	8/1033
Proton	12/93	5/57	7/71	5/67	7/56	6/54	5/68	4/82	8/77	11/89	16/85	8/80	10/80	4/71	108/1030
Soyuz	8/76	8/46	4/57	5/57	5/46	8/39	8/51	15/69	6/56	13/72	6/70	23/63	11/58	15/57	135/817
PSLV	0/43	3/26	1/36	1/37	0/31	2/25	0/32	5/53	10/39	6/53	5/49	8/46	3/41	8/48	52/559
GSLV	0/17	1/8	0/5	1/11	1/6	0/4	0/8	1/9	0/6	0/7	0/6	0/6	0/5	0/3	4/101
Long March 2	0/50	0/34	0/45	1/41	4/37	2/32	1/40	2/59	3/46	0/61	3/58	1/53	5/49	4/53	26/658
Long March 3	4/92	0/56	0/71	2/67	1/54	1/48	3/66	4/79	3/71	2/81	1/80	6/75	2/68	1/64	30/972
Long March 4	1/46	0/28	3/42	2/42	2/33	0/25	3/39	2/53	3/42	2/55	6/51	10/50	3/46	0/51	37/603
Zenit	4/92	7/56	1/71	2/67	4/53	3/48	4/65	1/79	6/70	4/80	0/74	4/73	3/68	1/62	44/958
Titan	3/94	3/57	2/71	4/67	1/55	2/50	0/66	0/79	0/74	0/85	0/81	0/78	0/70	0/66	15/993
Kosmos	7/36	1/20	6/27	9/23	3/20	12/19	1/20	3/38	8/36	0/38	1/39	0/38	0/34	0/43	51/431
Dnepr	5/42	0/26	6/36	0/37	8/31	2/25	1/32	16/53	6/39	6/53	4/49	0/46	0/41	0/46	54/556
H-II	0/93	0/56	6/71	2/67	0/56	1/54	4/68	2/82	1/76	9/89	4/85	1/79	4/79	1/70	35/1025
Rokot	2/41	0/23	4/34	9/36	0/24	1/23	1/29	0/48	4/38	5/50	4/47	1/46	2/39	6/45	39/523
Minotaur 1	11/38	0/23	0/30	0/30	0/22	2/20	8/28	1/44	0/36	5/46	0/46	1/42	0/37	0/44	28/486
Minotaur V	0/41	0/23	0/32	0/33	0/23	0/22	0/29	0/46	0/36	0/47	0/46	0/44	0/37	0/45	0/504
Pegasus	2/24	0/18	1/17	4/23	0/19	1/16	0/17	1/25	2/28	0/36	0/31	0/25	1/28	1/35	13/342
Falcon 1	0/25	0/18	0/17	0/23	0/19	0/16	0/17	0/25	0/29	1/37	0/31	0/25	0/31	0/36	1/349
Falcon 9	0/91	0/56	0/71	0/65	0/53	0/46	0/62	0/78	0/65	0/79	10/73	0/67	3/64	8/61	21/931
Antares	0/43	0/27	0/40	0/37	0/32	0/26	0/34	0/53	0/40	0/54	0/52	0/47	0/45	6/49	6/579

Chapter 6

Wastage of Launch Vehicle Capacity

The confluence of several trends in the space launch industry results in wastage of launch vehicle capacity. As noted in Chapter 4, larger launch vehicles tend to benefit from an economy of scale in several ways. Since cost per maximum payload capacity is an often-used performance metric when evaluating launch vehicles, this encourages the design and construction of larger launch vehicles. In addition to this, the market itself encourages the development of larger launch vehicles. As stated in Chapter 5, small launch vehicles are incapable of launching many of the payloads that are in demand. This prevents their use, even if the cost-effectiveness penalty associated with losing the economy of scale benefits of larger boosters is not a factor.

This bias towards heavier launch vehicles, coupled with the significant numbers of small payloads, results in wastage of launch vehicle capacity. This wastage is here defined as payload mass subtracted from the launch vehicle's maximum capacity to the desired orbit. It specifically does not include fairings or payload adapters, which count against the launch vehicle. Some care is required, since some manufacturers count some or all such items as payload mass, as discussed in Chapter 4 [28].

While this definition of wastage may appear simple, several complications expose themselves in the process of determining wastage. The first is the role that the payload's own propulsion system plays in determining the mission payload capacity. For low Earth orbit missions this is seldom problematic as the launch vehicle will generally place the payload directly into an orbit close to the one desired, and any onboard orbital maneuvering systems only perform small adjustments. In contrast, most geosynchronous missions place the payload into a geosynchronous transfer orbit, or GTO, which is a transfer orbit from the Earth's surface to the geosynchronous orbital radius, and then rely on the payload itself to perform circularization and plane change if necessary. However, this is not the only mission profile that is possible. Many upper stages, such as Centaur, Briz-M, and others, have the capability to place a payload directly into geosynchronous orbit at a drastically reduced payload capacity.

Typically, mission planners assign the payload to provide approximately 1500-2300 m/s of delta V, as shown in the various ULA users' guides [28, 31, 32] and Chapter 11 of Maral and Bosquet [26]. This is dependent on the latitude of the launch site, although some variation is possible; for example, the ULA users' guides have data for a 1500 m/s GTO launched from Canaveral as distinct from the 1800 m/s normally required for plane change and circularization from that launch site. Often, sources do not provide the exact trajectory used by the payload or details about the payload's onboard orbital maneuvering systems. Since the industry standard for geosynchronous payloads is to use a geosynchronous transfer orbit, the listed capacity for that trajectory will be assumed unless there is specific evidence otherwise. This does introduce a potential for error into calculations of geosynchronous orbit wastage.

Some missions have negative wastage. There are multiple possible reasons for this. The first is that the listed maximum payload capacity may have some additional margin. For example, ULA specifies in their users' guides that their payload capacities are computed to 2.33 standard deviations, or 99% confidence. They note in the Atlas V Users' Guide that "It is practical for Centaur to burn all its propellants when the SC [spacecraft] has a liquid propulsion system capable of correcting for variations in LV performance." [28] The payload may also have an onboard propulsion system. Both of these scenarios imply a complete use of launch vehicle capacity, and so any analysis of wastage in this work assigns these missions zero wastage.

Figure 6.1 shows the worldwide wastage percentage for LEO and GEO missions. As can be seen, wastage in general has declined over the period studied, but is still generally above 10%. The outlier for LEO wastage in 2007, at nearly 35%, was due to several US and Japanese national security missions that had high wastage. On March 9, 2007, OE-ASTRO, a DARPA payload, launched on an Atlas V 401 with a LEO payload capacity of 9000kg, despite only massing 1839kg. This resulted in wastage of 7161kg, or 79.6% of payload capacity.

Figure 6.2 is a histogram of wastage for all 589 launches in the data set with complete payload and payload capacity data. While the overall wastage percentage for the data set is 20.35%, it is most common for launches to have low wastage, with 167 launches having negligible wastage and 329 of 589 being below the average.

The preceding data gives some idea of overall wastage trends by year. Further analysis is necessary to determine whether any other factors affect wastage. These

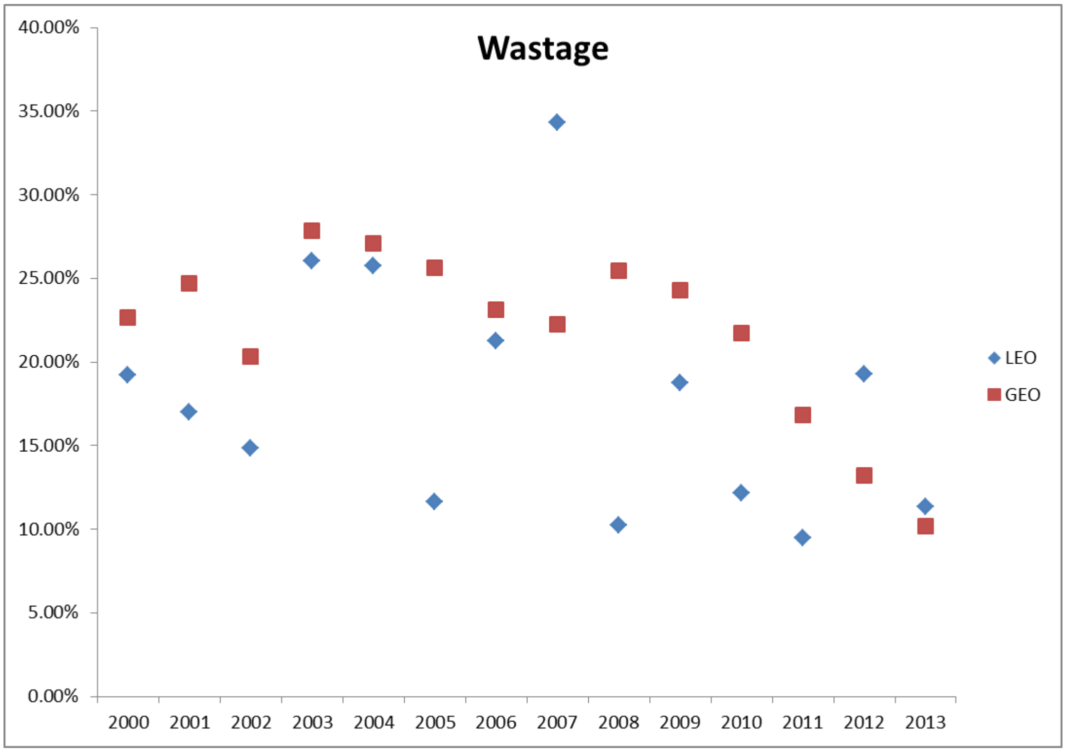

Figure 6.1: Wastage to LEO and GTO, 2000-2013

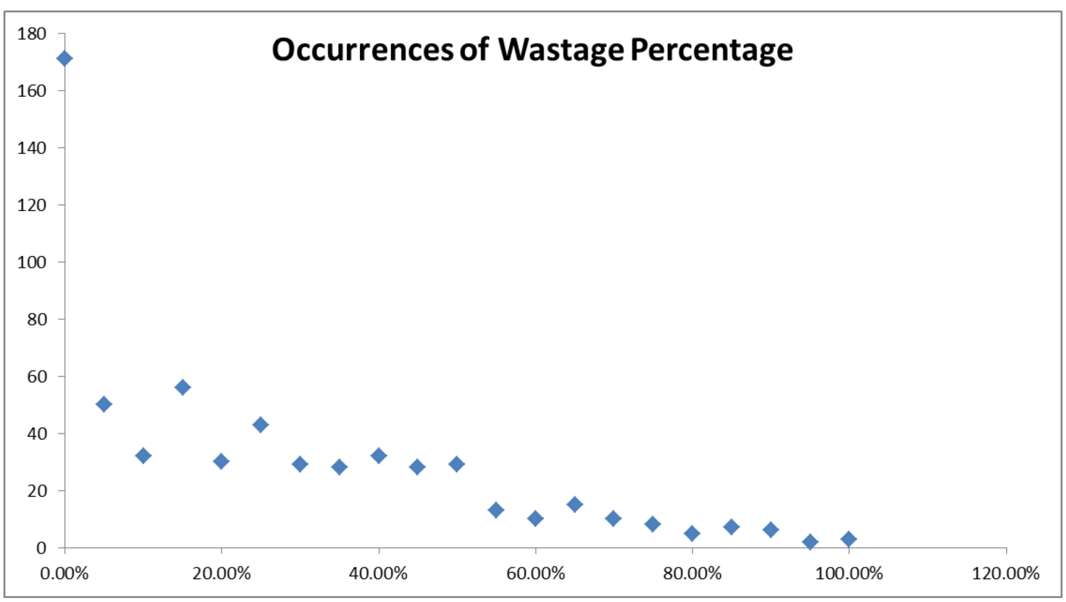

Figure 6.2: Number of Launches with Given Wastage Percentage, 2000-2013

possible factors include the launch vehicle used, its payload capacity to the desired orbit, and the owner of the payload. Tables 6.1 and 6.2 contain wastage data categorized by launch vehicle family for low Earth and geosynchronous orbits respectively.

Given that wastage is a function of launch vehicle choice and payload arrangement, both of which the customer controls to some degree, measuring wastage by payload owner can provide some measure of merit for the user's attempts to reduce wastage. Tables 6.3 and 6.4 contain wastage data categorized by the payload owner to LEO and GTO.

Chapter 8 examines the relationship between the maximum payload capacities of launch vehicles and the minimum possible wastage if operators arrange payloads in a way intended to reduce wastage as much as possible. The result obtained there is that the minimum wastage associated with launching a group of payloads on a given launch vehicle decreases with increasing maximum payload capacity. Data for real world wastage versus launch vehicle payload capacity are presented in Figures 6.3 and 6.4.

There appears to be little or no relationship between current real world wastage and payload capacity. This indicates that there is currently no concerted effort to reduce wastage, and that only individual users or launch vehicle enterprises are attempting to do so. While their efforts have the effect of reducing overall wastage over time and increasing the number of payloads per launch, this deviation from the wastage from ideally packed payloads, as explored in Chapter 8, indicates that much more improvement is possible.

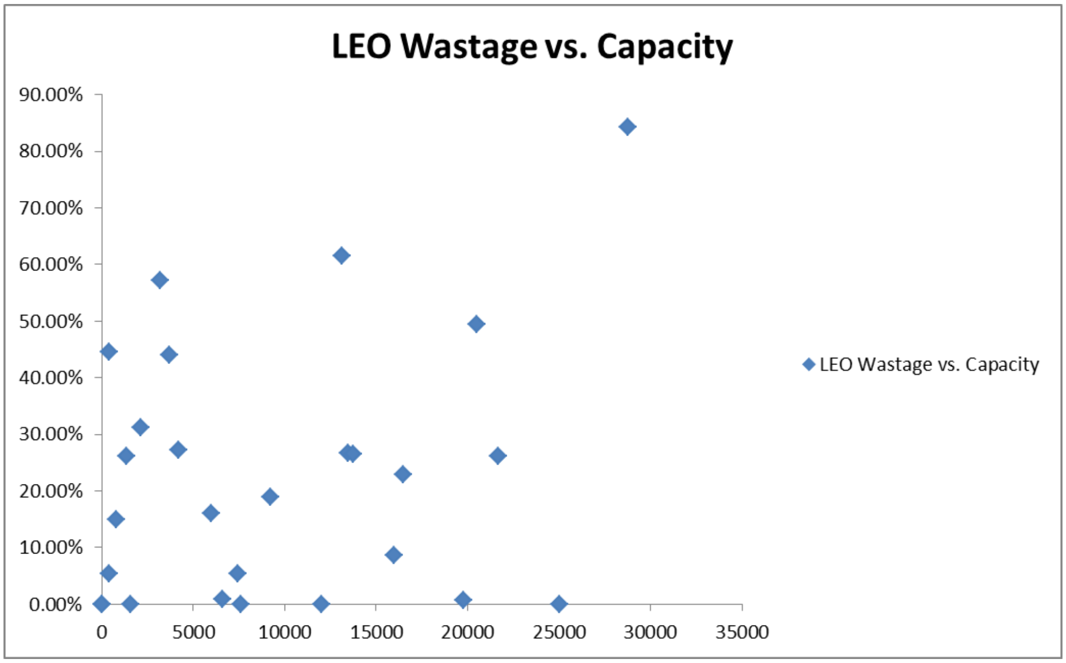

Figure 6.3: Overall Wastage Percentage versus Maximum Payload Capacity to LEO

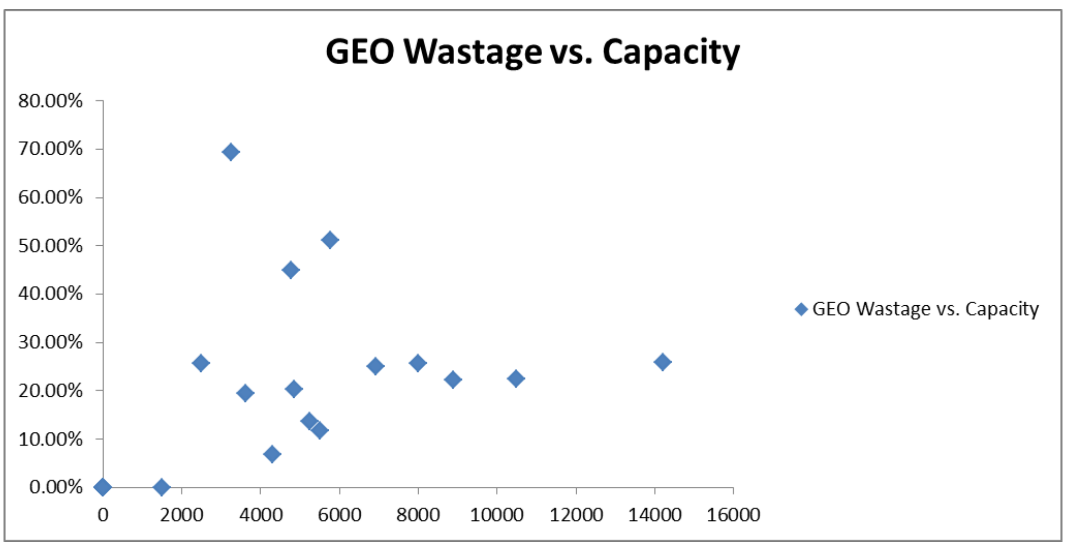

Figure 6.4: Overall Wastage Percentage versus Maximum Payload Capacity to GTO

Table 6.1: Wastage Percentage to Low Earth Orbit by Launch Vehicle and Year, 2000-2013

Wastage Percentage (LEO)															
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2000-2013
Ariane 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ariane 5	-	-	12.43%	-	51.75%	-	-	-	0.00%	32.26%	-	0.00%	0.00%	0.00%	8.65%
Atlas	0.83%	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83%
Atlas V	-	-	-	-	-	-	-	82.55%	-	82.86%	37.04%	15.34%	36.71%	-	49.35%
Delta II	14.02%	57.26%	0.84%	23.60%	34.86%	28.36%	24.27%	14.22%	32.74%	29.39%	10.29%	27.52%	-	-	26.76%
Delta IV	-	-	-	-	-	-	84.19%	-	-	-	-	-	-	-	84.19%
Proton	0.00%	-	0.00%	-	-	-	-	-	-	13.03%	-	-	-	-	0.77%
Soyuz	15.16%	2.59%	3.51%	1.74%	1.44%	1.58%	8.02%	16.06%	0.00%	0.00%	0.00%	6.32%	8.95%	0.00%	5.39%
PSLV	-	7.43%	-	0.00%	-	0.00%	-	67.76%	37.74%	71.17%	25.64%	25.90%	-	40.95%	44.08%
GSLV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long March 2	-	-	-	14.29%	43.35%	14.29%	0.00%	83.64%	-	-	-	3.13%	-	-	18.91%
Long March 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long March 4	46.43%	-	52.86%	42.86%	25.00%	-	3.57%	25.86%	50.00%	61.07%	15.19%	36.98%	3.04%	0.00%	27.25%
Zenit	18.89%	45.94%	-	-	36.00%	-	-	-	-	-	-	-	-	-	26.57%
STS	0.00%	0.00%	0.00%	0.00%	-	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-	-	0.00%
Titan	33.03%	23.20%	32.25%	72.66%	-	20.43%	-	-	-	-	-	-	-	-	26.22%
Kosmos	19.54%	0.00%	30.06%	17.10%	0.00%	14.19%	0.65%	0.43%	23.87%	-	0.00%	-	-	-	14.86%
Molniya	-	-	0.00%	0.00%	-	-	-	-	-	-	-	-	-	-	0.00%
Dnepr	95.94%	-	95.81%	-	70.06%	47.50%	48.68%	38.74%	23.45%	64.92%	26.88%	-	-	-	57.23%
H-II	-	-	23.67%	82.52%	-	-	52.22%	60.95%	-	13.92%	-	0.00%	8.44%	0.00%	22.80%
Rokot	6.14%	-	33.43%	51.85%	-	47.76%	41.96%	-	12.20%	27.59%	39.42%	12.50%	0.00%	44.91%	31.22%
Minotaur 1	54.68%	-	-	-	-	24.77%	25.68%	0.00%	-	37.85%	-	0.00%	-	-	26.16%
Minotaur V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pegasus	0.00%	-	0.00%	11.11%	-	0.00%	-	21.20%	0.00%	-	-	-	0.00%	0.00%	5.34%
Falcon 1	-	-	-	-	-	-	-	-	-	44.62%	-	-	-	-	44.62%
Falcon 9	-	-	-	-	-	-	-	-	-	-	61.68%	-	61.04%	61.72%	61.44%
Antares	-	-	-	-	-	-	-	-	-	-	-	-	-	16.07%	16.07%

Table 6.2: Wastage Percentage to Geosynchronous Orbit by Launch Vehicle and Year, 2000-2013

Wastage Percentage (GEO)															
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2000-2013
Ariane 4	7.72%	4.54%	8.87%	0.95%	-	-	-	-	-	-	-	-	-	-	6.91%
Ariane 5	22.80%	35.51%	30.74%	24.44%	12.50%	29.45%	21.66%	19.04%	20.81%	28.52%	26.08%	14.58%	20.23%	14.92%	22.51%
Atlas	18.91%	14.38%	24.03%	12.09%	20.97%	-	-	-	-	-	-	-	-	-	19.44%
Atlas V	-	-	-	30.80%	35.14%	22.61%	27.19%	14.66%	4.21%	30.97%	25.01%	0.00%	-	13.45%	21.83%
Delta II	-	-	-	-	-	-	45.02%	-	-	-	-	-	-	-	45.02%
Delta IV	-	-	40.19%	49.13%	-	-	39.64%	66.37%	-	15.43%	15.28%	0.00%	-	-	25.94%
Proton	31.06%	31.65%	17.78%	24.39%	33.51%	34.28%	37.11%	29.08%	37.91%	20.79%	21.45%	28.81%	9.65%	5.01%	25.11%
Soyuz	-	-	-	69.35%	-	-	-	-	-	-	-	-	-	-	69.35%
PSLV	-	-	0.00%	-	-	-	-	-	-	-	-	-	-	-	0.00%
GSLV	-	38.80%	-	27.00%	22.00%	-	-	14.80%	-	-	-	-	-	-	25.65%
Long March 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long March 3	22.12%	-	-	16.67%	48.89%	8.24%	3.90%	8.44%	24.41%	19.10%	10.39%	5.07%	10.80%	0.00%	11.71%
Long March 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zenit	16.50%	11.10%	7.62%	5.58%	7.40%	3.43%	14.45%	-	14.84%	33.68%	-	26.64%	0.00%	-	13.63%
STS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titan	58.68%	52.24%	49.44%	46.11%	58.68%	-	-	-	-	-	-	-	-	-	51.09%
Kosmos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Molniya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dnepr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H-II	-	-	-	-	-	37.14%	19.23%	-	46.00%	-	2.44%	-	-	-	25.66%
Rokot	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Minotaur 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Minotaur V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pegasus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Falcon 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Falcon 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Antares	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.3: Low Earth Orbit Wastage Percentage by Organization and Year, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Government - Civilian														
NASA	-	65.52%	18.86%	35.45%	34.86%	0.00%	38.50%	-	27.06%	59.18%	61.68%	-	61.04%	47.18%
Roscosmos	12.12%	6.00%	1.47%	0.23%	11.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
JAXA	-	-	-	-	-	47.50%	15.79%	-	-	13.92%	-	0.00%	0.00%	0.00%
ISRO	-	7.43%	-	-	-	0.00%	-	-	37.74%	71.17%	-	-	-	-
ESA	-	-	-	-	-	9.24%	85.52%	-	0.00%	16.81%	0.00%	0.00%	0.00%	0.00%
CNSA	-	-	-	-	25.00%	-	1.89%	-	-	-	-	4.76%	-	-
NOAA	32.20%	-	32.25%	-	-	28.36%	-	-	-	10.07%	-	-	-	-
Government - Military														
DOD	33.43%	-	-	45.39%	-	24.77%	80.62%	79.57%	0.00%	65.80%	37.04%	36.71%	36.71%	-
NRO	-	23.20%	-	-	-	20.43%	-	85.45%	-	-	-	-	-	-
Russian MoD	18.85%	39.74%	6.19%	3.87%	11.79%	0.00%	0.00%	0.00%	0.00%	5.66%	0.00%	-	-	-
French MoD	-	-	-	-	51.75%	-	-	-	-	32.26%	-	-	-	-
Private														
Eumetsat	-	-	20.89%	-	-	-	6.98%	-	-	-	-	-	-	-
Globalstar	23.44%	-	-	-	-	-	-	62.89%	-	-	-	-	-	-
Orbcomm	-	-	-	-	-	-	-	-	65.16%	-	-	-	-	-
Iridium	-	-	0.00%	-	-	-	-	-	-	-	-	-	-	-
Sirius XM	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SES	-	-	0.00%	-	-	-	-	-	-	-	-	-	-	-
Eutelsat	-	-	0.00%	-	-	-	-	-	-	-	-	-	-	-

Table 6.4: Geosynchronous Transfer Orbit Wastage Percentage by Organization and Year, 2000-2013

Government - Civilian

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
NASA	0.00%	-	0.00%	-	-	-	-	-	-	-	36.84%	-	-	- %
Roscosmos	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00%
JAXA	-	-	-	-	-	-	40.00%	-	46.00%	-	-	-	-	-
ISRO	-	-	0.00%	29.30%	22.00%	-	-	26.95%	-	-	-	-	-	-
CNSA	-	-	-	18.52%	-	-	-	15.38%	21.05%	-	42.11%	-	-	-
NOAA	27.05%	-	-	-	-	-	39.64%	-	-	-	49.30%	-	-	-

Government - Military

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
DOD	46.77%	42.09%	49.44%	44.22%	58.68%	-	45.02%	40.25%	-	-	17.48%	-	-	-
NRO	-	-	-	42.22%	-	-	-	-	-	0.00%	-	-	-	-
Russian MoD	44.83%	0.00%	-	0.00%	0.00%	-	-	41.54%	0.00%	0.00%	23.08%	-	-	-
Chinese MoD	11.54%	-	-	-	-	-	-	-	-	-	-	-	-	-

Private

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PanAmSat	18.00%	-	-	9.77%	-	-	-	-	-	-	-	-	-	-
Intelsat	0.00%	1.36%	0.35%	19.56%	19.44%	15.32%	-	-	23.57%	28.85%	36.62%	14.72%	13.85%	-
Echostar	-	-	40.49%	-	-	-	20.50%	-	0.00%	-	14.02%	-	22.76%	-
DirecTV	-	0.00%	17.17%	-	0.00%	26.37%	0.00%	14.84%	0.00%	14.74%	-	-	-	-
Sirius XM	12.64%	11.10%	-	-	-	10.42%	0.00%	-	-	13.64%	13.53%	-	-	-
SES	21.08%	14.30%	2.04%	5.75%	37.66%	27.75%	27.19%	24.24%	22.77%	27.73%	39.72%	17.20%	8.78%	13.29%
RSCC	43.78%	-	40.23%	40.23%	48.12%	-	-	-	62.73%	30.46%	-	-	-	-
Eutelsat	36.46%	26.78%	29.01%	31.74%	38.58%	28.02%	29.55%	15.38%	20.57%	9.34%	22.04%	8.06%	0.00%	11.56%

Chapter 7

Optimal Usage of Launch Vehicles

The wastage problem constitutes a considerable loss, both in direct financial terms and in terms of lost opportunities to launch useful space payloads. Yet there is little work dedicated to reducing it, or even computing the losses from it. While a detailed hardware or operational solution to wastage is beyond the scope of this work, examination of some means of combatting wastage is necessary to determine how much improvement is actually possible.

One obvious approach to the problem is to select different launch vehicles. One way of looking at wastage is that the payload's owner selected a larger launch vehicle to deploy it than was necessary. If a smaller launch vehicle launches the payload, then costs may be reduced. This is not a given, however. Since cost-effectiveness varies widely among different launch vehicle configurations, even an increase in wastage may actually reduce the cost per payload mass if there is a correspondingly greater improvement in launch vehicle price per payload mass.

This analysis may seem trivial at first glance, as it stands to reason that an organization making such an important decision would carefully research all the available alternatives and select the launch vehicle that best suited their needs. Given the looming financial considerations, one would expect most organizations to select the least expensive launch vehicle that has sufficient payload capacity for their mission. Since launch vehicle cost-effectiveness varies, it follows that there are situations where using a launch vehicle with higher wastage for the desired mission could actually be cheaper.

Other considerations can come into play when selecting a launch vehicle. Reliability is a consideration. Launch insurance is a significant cost, often costing as much as 15% or more of a single launch, and it is tied directly to launch vehicle reliability [1, 44]. This does not include the potential negative business repercussions of not having the payload on station when expected. Chapter 9 further investigates the effect of reliability on launch costs, but its role bears some brief mention here.

More important, however, are non-financial concerns. Many national security payloads are limited to launch on their own nation's launch vehicles, which prevents them from using the lowest cost launch vehicle that is suitable. For example, the least expensive launch vehicle capable of launching the US Air Force's X-37 OTV is Soyuz, which costs at most half as much as the Atlas V 501 commonly used to deliver it. It is highly unlikely, however, that the US Air Force would entrust one of its most secret spacecraft to its occasional adversaries. There may be contractual constraints as well, such as the Air Force's 'block buy' of Atlas V/Delta IV cores from ULA [25].

The lowest-cost scenario would be if customers selected the lowest cost launch vehicle available that is suitable for their mission. Table 7.1 contains yearly usage data for this case for LEO and GEO payloads combined.

There are some limitations to this comparison. Most important of these is that only the maximum listed launch vehicle payload capacities are used for this comparison. Payloads placed directly into geosynchronous orbits and payloads placed into low Earth orbits quite different from the orbit given for maximum payload capacity have the potential to skew the results. Since both of these factors create a tendency to overestimate wastage and potential cost savings, the results here represent a best-case scenario for possible savings.

The other limitation is that it is very difficult, given the complexities of laws such as the International Traffic in Arms Regulations (ITAR) and the difficulty of ascertaining what other circumstances constrain particular launch vehicle selections, to determine what the cheapest launch vehicle permissible to use was. Once again, this causes these results to present an idealized case.

It is possible to obtain some idea of the effect of these restrictions by performing the analysis again, but requiring that each payload use a launch vehicle sourced in its country of origin. This analysis excludes payloads owned by countries that do not have domestic launch vehicles, with the exception that it combines the European Union members into one country. If the previous analysis was optimistic, this will prove too pessimistic, as many payloads source launchers internationally to reduce cost. Some nations even use foreign launchers for their national security payloads: Germany uses Russian launchers for its reconnaissance satellites, and Israel uses Indian and Russian launchers in addition to their domestic Shavit launch vehicle. Table 7.2 contains the results of this analysis.

Usage patterns change considerably in these cases from actual utilization patterns as shown in Chapter 4. Proton and Soyuz were the most common launchers for the actual launches. The lowest cost option for the greatest number of launches was Dnepr, a launch vehicle conversion of SS-18 'Satan' ICBMs. Long March 3 ranked second, followed by Soyuz. Proton falls far behind, despite its relatively low overall cost. These changes in usage reduce the total cost for all LEO and GEO launches with complete data from $44.2B (2014$) to $24.9B, a 44% savings, while reducing wastage from 20% to 18%. While wastage is reduced, the benefit mostly comes from selection of more cost-effective launch vehicles.

The usage patterns for the nationality-restricted case much more closely resemble actual usage, with many more types of launch vehicles used. Some launch vehicles, such as Ariane 4, that are in overall terms not very cost-effective are the least expensive launch vehicle available to their respective nations for their own payloads. In some cases this is because nations only have one launcher, e.g. the European Union and Ariane 5 prior to the development of Vega.

How does real-world usage compare to this 'optimal' scenario? Table 7.3 shows how often each launch vehicle was the optimal choice if it was used, and contains data for how often the optimal choice was selected for each year and over the entire 2000-2013 period. Figure 7.1 graphically represents the rate at which launches used the minimum cost launch vehicle capable of accomplishing their mission.

18.45% of the time the lowest cost launch vehicle is selected for a given payload or set of payloads. While there are multiple possible reasons, such as those mentioned above, that the most cost-effective launch vehicle might not be selected for a particular mission, it is highly unlikely that they apply to nearly 82% of all space launches.

Table 7.3 can be inverted conceptually. That is, rather than asking "if a particular launch vehicle was used, was it the 'optimal' choice?" asking "if the launch vehicle was 'optimal', was it used?" Table 7.4 contains the results of this analysis.

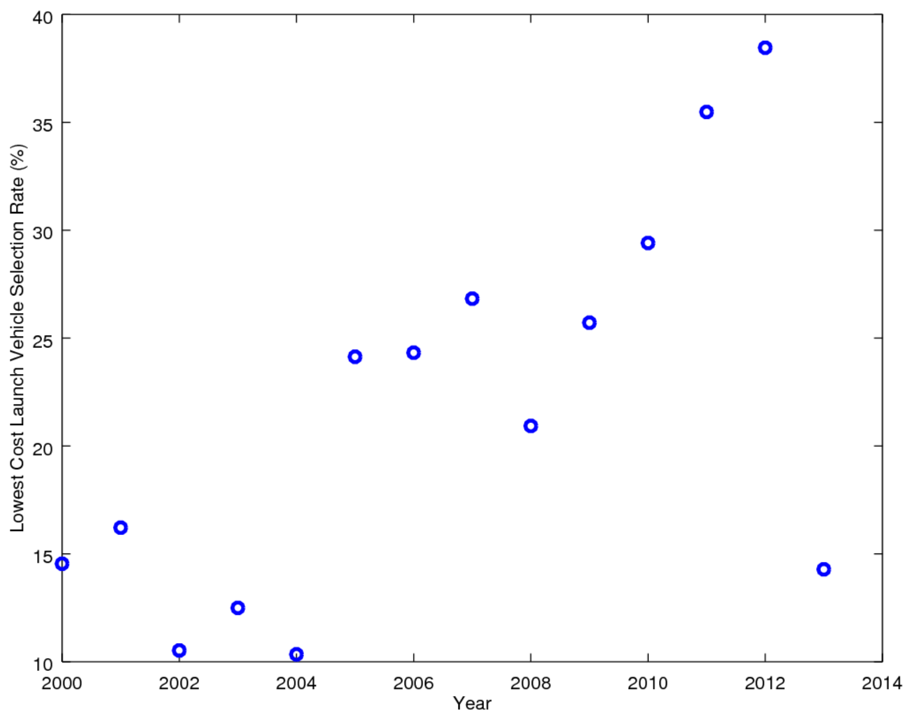

Figure 7.1: Minimum Cost Launch Vehicle Selection Rate, 2000-2013

Some interesting trends may be observed from Tables 7.3 and 7.4. The first is that there are some launch vehicles that are used commensurate with their cost effectiveness, but they are not used on the launches where they are optimal. For instance, Delta IV is the lowest cost option for some launches, but is literally never used over the 2000-2013 period when it is the cheapest option. Dnepr is probably the most underutilized launch vehicle in existence, never being used more than a quarter of the time that it is the cheapest option in any year, yet it is not the cheapest option for many of the payloads that actually do use it.

The second trend of interest is that over time launch vehicle selection is improving. In 2002, selection of the most cost-effective launch vehicle reached a minimum, with users only selecting the most cost-effective launch vehicle 9.52% of the time. Post 2004, there is a steep rise in this percentage.

The previous analyses show that usage of the minimum cost launch vehicle is relatively rare. It is also known, however, that there are limitations on launch vehicle selection that are difficult to evaluate quantitatively. Given such restrictions, a rational selector of a launch vehicle for a given mission would select the least expensive launch vehicle that did not violate any of them. This leads to the question of how highly ranked the actual choices are. Figure 7.2 is a histogram of the cost-effectiveness ranking of the launch vehicle actually chosen for both the minimum cost scenario and the minimum cost scenario where payloads must use their own nation's launch vehicles.

While relatively few customers select the most cost-effective launch vehicle for their application, a majority of them select one that is in the top four for their particular mission. Nearly 75% select one that is in the top ten. The tail of the distribution is rather long, however, with the 'worst' decision being 51st out of 74. This was launch 2000-065, with a single payload, 2000-065A, a geosynchronous

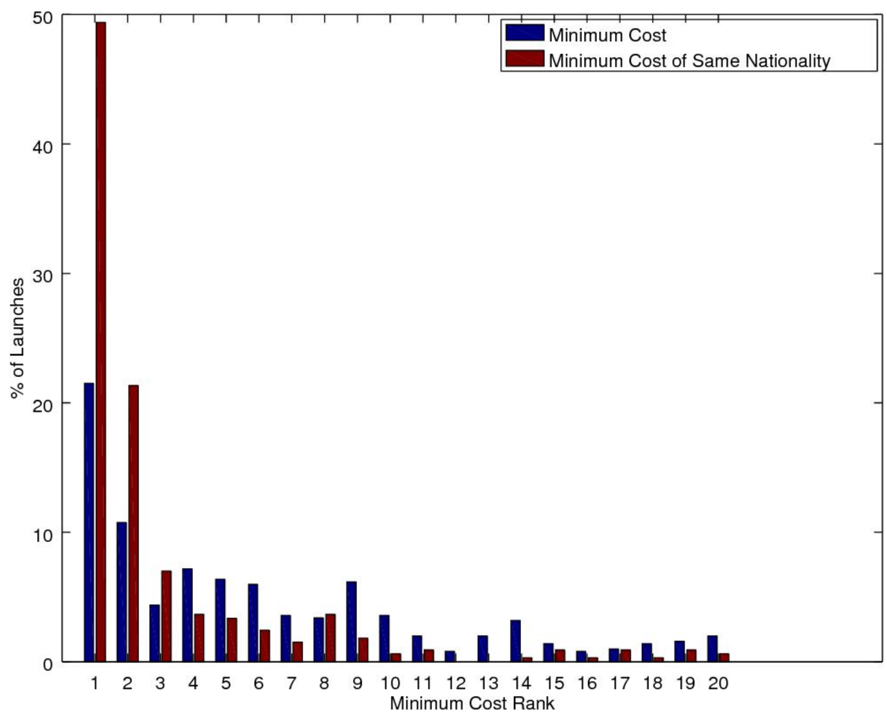

Figure 7.2: Minimum Cost Ranking for Launches

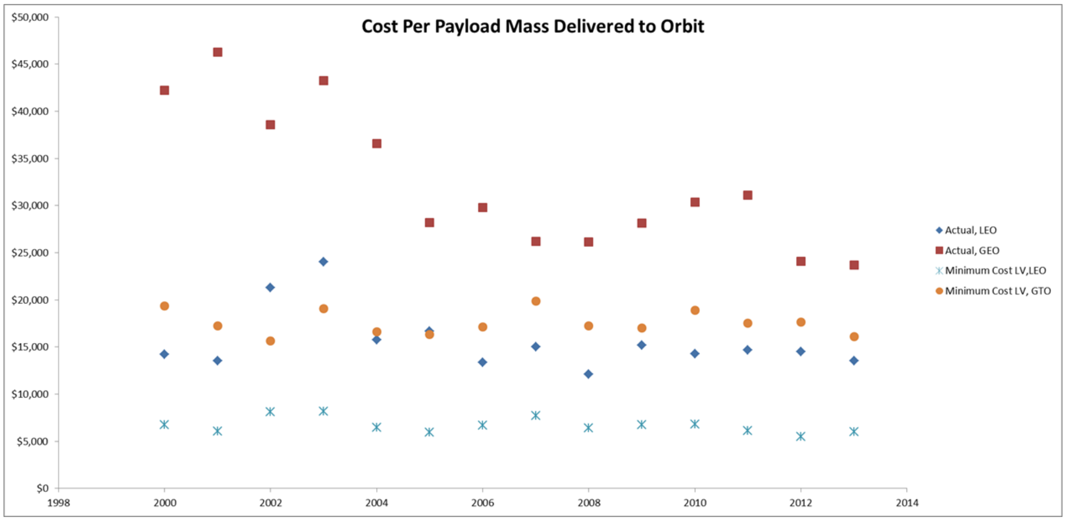

Figure 7.3: Average Cost Per Payload Mass Delivered to Orbit, 2000-2013

payload launched on Atlas IIA at 59.36% wastage. Since it was a US Department of Defense payload, it is probably a case where the requirement to use certain launch vehicles, no matter how poor of a financial decision it was, was a factor.

For the scenario where payloads must use a launcher from their own country, the results show a much greater number of first-ranked choices. Nearly 50% of launches of payloads owned by nations with their own launch vehicles selected the cheapest launch vehicle from their own nation that was capable of launching the payload. Coupled with the lower rate of selecting the lowest cost launch vehicle worldwide, this is a strong indication that launch vehicle nationality is a strong noneconomic consideration for launch vehicle decisions.

Figure 7.3 plots the average cost per kilogram of payload mass delivered to orbit for the actual and 'ideal' cases. Actual GEO costs have declined significantly, while LEO costs were relatively flat over the studied interval. Interestingly, costs for the 'ideal' cases are also relatively flat over the entire interval, despite the introduction of several new launch vehicle families. This is a possible indication of the relative importance of operational losses: it is possible to achieve nearly the same costs in 2013 as it was in 2000, despite the availability of superior launch vehicles.

The analyses conducted in this chapter show that while the majority of launch vehicle users select one of the best choices available to them for their mission, it is nonetheless possible to realize a savings in launch costs by improving the selection of launch vehicles. It is uncertain what savings is actually possible, since launch vehicle selection requires consideration of variables that are difficult to quantify.

Table 7.1: Lowest Cost Launch Vehicle, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ariane 5	0	0	0	0	0	0	1	1	1	0	1	0	1	1	6
Atlas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atlas V	0	0	0	0	0	1	3	3	4	3	2	2	1	2	21
Delta II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delta IV	0	0	0	3	2	3	2	1	6	6	8	2	0	1	34
Proton	5	1	0	0	0	2	0	0	1	1	0	2	2	2	16
Soyuz	7	8	6	4	3	6	5	6	5	7	7	6	5	1	76
PSLV	1	0	2	1	0	0	1	0	2	0	0	0	0	2	9
GSLV	0	0	0	1	0	0	0	1	1	1	0	0	0	0	4
Long March 2	1	0	2	1	1	0	0	0	0	0	2	0	2	1	10
Long March 3	27	19	15	15	13	7	10	8	10	6	5	8	0	0	143
Long March 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zenit	1	0	2	0	0	0	0	0	0	0	0	0	0	0	3

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Titan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kosmos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Molniya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dnepr	7	7	7	8	7	5	10	14	8	7	7	5	1	1	94
H-II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rokot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minotaur 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minotaur V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pegasus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Falcon 1	0	0	0	0	0	0	0	0	0	2	1	0	0	2	5
Falcon 9	0	0	0	0	0	0	0	0	0	0	1	2	0	1	4
Antares	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Start-1	6	1	4	7	3	4	3	5	5	1	0	1	1	0	41
Total	55	36	38	40	29	28	35	39	43	34	34	28	13	14	466

Table 7.2: Lowest Cost Launch Vehicle, Nationality of Choice Restricted, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	8	7	13	3	0	0	0	0	0	0	0	0	0	0	31
Ariane 5	2	0	0	0	8	4	5	9	10	13	11	9	11	6	88
Atlas	9	3	3	2	1	0	0	0	0	0	0	0	0	0	18
Atlas V	0	0	0	0	0	2	0	1	0	0	0	0	1	0	4
Delta II	5	1	5	2	3	1	3	4	2	3	0	0	0	0	29
Delta IV	0	0	0	4	1	4	5	3	6	5	6	2	1	0	37
Proton	5	3	1	3	2	0	0	1	2	2	1	1	3	0	24
Soyuz	7	7	5	4	3	6	6	6	6	7	6	5	4	3	75
PSLV	0	1	1	1	0	1	0	0	1	2	1	2	0	1	11
GSLV	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2
Long March 2	2	0	1	1	5	2	3	2	3	1	4	5	3	1	33
Long March 3	3	0	0	2	1	1	2	2	1	1	6	6	2	1	28
Long March 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zenit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Titan	3	5	3	0	0	0	0	0	0	0	0	0	0	0	11
Kosmos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dnepr	3	5	3	3	4	2	1	1	1	2	2	1	2	3	33
H-II	2	0	3	1	2	1	3	1	1	1	1	0	3	1	20
Rokot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minotaur 1	5	1	1	3	1	3	1	2	1	0	1	1	0	0	20
Minotaur V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pegasus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Falcon 1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	3
Falcon 9	0	0	0	0	0	0	0	0	0	0	5	5	3	6	19
Antares	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Start-1	1	0	1	2	1	0	1	0	0	0	0	0	0	0	6

Table 7.3: Launches Where LV Used was Lowest Cost, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	0/7	0/6	0/7	0/1	-	-	-	-	-	-	-	-	-	-	0/21
Ariane 5	0/4	0/2	0/3	0/3	-	0/2	1/5	1/4	1/6	0/5	1/5	0/3	1/3	1/4	6/49
Atlas	0/8	0/2	0/4	0/2	0/4	-	-	-	-	-	-	-	-	-	0/20
Atlas V	-	-	-	0/2	0/1	0/1	0/1	0/2	0/1	0/3	0/3	0/1	0/1	0/1	0/17
Delta II	0/1	0/1	0/1	0/2	0/3	0/1	0/2	0/1	0/3	0/2	0/1	0/1	-	-	0/19
Delta IV	-	-	-	0/2	-	-	0/1	0/1	-	-	-	-	-	-	0/4
Proton	0/8	0/5	0/4	0/3	0/5	0/4	0/3	0/4	0/8	0/8	0/8	0/5	-	0/1	0/66
Soyuz	7/8	5/7	3/4	4/5	3/3	6/6	5/5	6/9	5/5	7/7	6/6	5/5	4/4	1/1	67/75
PSLV	-	0/1	1/1	0/1	-	0/1	-	0/2	0/1	-	-	0/1	-	-	1/8
GSLV	-	0/1	-	1/1	0/1	-	-	0/1	-	-	-	-	-	-	1/4
Long March 2	-	-	-	-	0/1	0/1	0/1	0/1	-	-	-	-	-	-	0/4
Long March 3	0/3	-	-	0/2	0/1	1/1	1/2	2/4	2/3	1/1	1/1	6/6	-	-	14/24
Long March 4	-	-	0/1	0/1	0/1	-	0/2	0/1	0/2	-	0/1	0/2	-	-	0/11

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Zenit	0/4	0/3	0/1	0/2	0/4	0/3	0/4	-	0/5	0/1	-	0/1	-	-	0/28
Titan	0/3	0/3	0/2	0/3	0/1	0/2	-	-	-	-	-	-	-	-	0/14
Kosmos	0/3	0/1	0/4	0/3	0/2	0/2	0/1	0/3	0/3	-	0/1	-	-	-	0/23
Molniya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Dnepr	0/1	-	0/1	-	0/1	0/1	1/1	2/3	1/2	0/1	2/3	-	-	-	6/14
H-II	-	-	0/2	0/1	-	-	0/2	0/1	0/1	0/2	0/1	0/1	0/2	0/1	0/14
Rokot	0/1	-	0/2	0/2	-	0/1	0/1	-	0/1	0/2	0/2	0/1	-	0/1	0/14
Minotaur 1	0/2	-	-	-	-	0/2	0/2	0/1	-	0/1	-	0/1	-	-	0/9
Minotaur V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Pegasus	0/1	-	0/1	0/4	-	-	-	0/1	0/2	-	-	-	-	0/1	0/10
Falcon 1	-	-	-	-	-	-	-	-	-	1/1	-	-	-	-	1/1
Falcon 9	-	-	-	-	-	-	-	-	-	-	0/2	-	0/2	0/1	0/5
Antares	-	-	-	-	-	-	-	-	-	-	-	-	-	0/2	0/2
Start-1	1/1	1/1	-	-	-	-	1/1	-	-	-	-	-	-	-	3/3
Tsyklon	-	0/3	-	-	0/1	-	0/1	-	-	-	-	-	-	-	0/5
Vega	-	-	-	-	-	-	-	-	-	-	-	-	0/1	0/1	0/2
Total	8/55	6/37	4/38	5/40	3/29	7/29	9/37	11/41	9/43	9/35	10/34	11/31	5/13	2/14	99/466

Table 7.4: Launches Where Lowest Cost LV was Used, 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Ariane 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Ariane 5	-	-	-	-	-	-	1/1	1/1	1/1	-	1/1	-	1/1	1/1	6/6
Atlas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Atlas V	-	-	-	-	-	0/1	0/3	0/3	0/4	0/3	0/2	0/2	0/1	0/2	0/21
Delta II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Delta IV	-	-	-	0/3	0/2	0/3	0/2	0/1	0/6	0/6	0/8	0/2	-	0/1	0/34
Proton	0/5	0/1	-	-	-	0/2	-	-	0/1	0/1	-	0/2	0/2	0/2	0/16
Soyuz	7/7	5/8	3/6	4/4	3/3	6/6	5/5	6/6	5/5	7/7	6/7	5/6	4/5	1/1	67/76
PSLV	0/1	-	1/2	0/1	-	-	0/1	-	0/2	-	-	-	-	0/2	1/9
GSLV	-	-	-	1/1	-	-	-	0/1	0/1	0/1	-	-	-	-	1/4
Long March 2	0/1	-	0/2	0/1	0/1	-	-	-	-	-	0/2	-	0/2	0/1	0/10
Long March 3	0/27	0/19	0/15	0/15	0/13	1/7	1/10	2/8	2/10	1/6	1/5	6/8	-	-	14/143
Long March 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Zenit	0/1	-	0/2	-	-	-	-	-	-	-	-	-	-	-	0/3
Titan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Kosmos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Molniya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Dnepr	0/7	0/7	0/7	0/8	0/7	0/5	1/10	2/14	1/8	0/7	2/7	0/5	0/1	0/1	6/94
H-II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Rokot	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Minotaur 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Minotaur V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Pegasus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Falcon 1	-	-	-	-	-	-	-	-	-	1/2	0/1	-	-	0/2	1/5
Falcon 9	-	-	-	-	-	-	-	-	-	-	0/1	0/2	-	0/1	0/4
Antares	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Start-1	1/6	1/1	0/4	0/7	0/3	0/4	1/3	0/5	0/5	0/1	-	0/1	0/1	-	3/41
Tsyklon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0
Vega	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/0

Chapter 8

Optimal Arrangement of Payloads

The existence of launches with high percentages of wastage indicates that the least expensive launch vehicle capable of delivering a payload to the desired trajectory is not necessarily the one with the lowest wastage. The analysis in Chapter 7 confirms this, where it was shown that selecting the minimum cost launch vehicle capable of performing the mission for all real missions in the studied period results in little change in wastage despite a significant financial savings.

At the same time, wastage constitutes exactly what it says: a 'waste' of capacity. Nor is it required to arrange future payloads in a similar fashion to those launched in the past. If it is possible to control the arrangement of the payloads, how much reduction in wastage is possible? As discussed in Chapter 3, the number of payloads per launch has been rising slowly since 2000. This appears to indicate that actors in the market are already attempting to use improved payload arrangement strategies.

Finding an optimal arrangement of payloads and launch vehicles, in the simplest case, is an example of a bin packing problem. A case involving a single type of launch vehicle is a classical bin packing problem, which has been studied extensively, and has several algorithms dedicated to solving it [45]. In the case that multiple types of launch vehicles are available, the problem becomes a variable bin-packing problem with fixed costs, as described in Crainic et al [46]. As examined in that work, an approximate algorithm is available to solve this problem, albeit with less accuracy than for the classical bin-packing problem.

While there are algorithms that provide exact solutions to the classical bin packing problem [45, 47], a best fit descending, or BFD, algorithm was chosen instead for the sake of simplicity. This algorithm will provide a solution that uses no more than 11/9 the optimal number of bins, and in the majority of cases will return the optimal number of bins. Korf cites a problem of 90 elements, with elements ranging in size from zero to one million, and bin capacities of one million, where BFD returns the optimal solution 94.832% of the time [45].

The BFD algorithm requires that the elements (in this case, payloads) first be sorted in descending order. Then the algorithm assigns each payload to the fullest launch vehicle in which it can fit. If there are no launch vehicles with enough capacity remaining, another one is added. In the case where the payload is too large for the launch vehicle in question, it is not assigned, and is added to a 'NMC' (not mission capable) list.

The physical nature of the problem, however, introduces a few additional complications. The most important of these is that launch vehicle capacity depends on the payload's trajectory. For example, Pegasus XL can place 450 kg into a 200km altitude, 28.5 degree orbit, but only 120 kg into a 1400km 28.5 degree orbit [35]. This means that the launch vehicles cannot be treated as simple bins; there must be a mechanism to account for the payload's orbit.

Another complication follows from this. Two payloads in wildly different orbits cannot be launched together unless one or both of them is provided with a propulsion system. This introduces additional variables into the problem. Payloads are occasionally delivered to very different orbits by the same launch vehicle. For example, launch 2002-042, a H-IIA 2024, placed two USERS satellites into LEO and the Kodama satellite into GTO on September 10, 2002. However, this behavior is not common and in some cases imposes significant additional delta V requirements.

The variability of launch vehicle payload capacity and the need to roughly match payload orbits primarily affects payloads in low and medium Earth orbits. Since geosynchronous orbits are characterized by a specific orbital radius, they have very similar delta V requirements, making them much more amenable to the bin packing approach. While the delta V requirements may not be completely homogeneous owing to differences in the trajectory and/or amount of delta V provided by the payload, they will be assumed to have similar delta V requirements.

For these reasons, this portion of the work will only consider geosynchronous payloads. The algorithm is applied for this data set to all 63 launch vehicle configurations used during that period with geosynchronous transfer orbit capacity.

Launch times are an additional constraint. Some payloads must launch at certain times, such as payloads intended to function as part of a constellation. Others may be less time critical, such as many microsatellites or scientific payloads. It is difficult to determine the time schedule requirements for individual payloads. Therefore, two individual analyses examine the studied interval as a whole and sum the total results for individual years. For the most part, the results obtained are very similar.

Table 8.1: Payload Assignments for Falcon 9

Manifest 104:		
	2003-020A:	3440 kg
	2011-034A:	1410 kg
Manifest 105:		
	2008-034B:	3400 kg
	2013-034A:	1425 kg
Manifest 106:		
	2012-051B:	3400 kg
	2000-081A:	1414 kg
Manifest 107:		
	2012-043B:	3325 kg
	2003-043A:	1525 kg
Manifest 108:		
	2000-054A:	3320 kg
	2001-015A:	1530 kg
....		
NMC list:		
	2006-043A:	8180 kg
	2009-035A:	6910 kg
	2008-018A:	6740 kg
	2011-059A:	6740 kg
....		

The optimal arrangements to launch as many of the 358 payloads as possible were determined for each of the 97 launch vehicle configurations using the BFD algorithm. Table 8.1 contains an example of the results for an individual launch vehicle. This is an excerpt from the optimal payload arrangement for the Falcon 9 v1.1 launch vehicle.

Table 8.1 identifies payloads by their COSPAR identification numbers. Mass is also listed here for reference. As stated earlier, the NMC list is composed of payloads too heavy for the given launch vehicle to launch.

How much improvement is possible? Table 8.2 compares wastage and cost per payload mass delivered in actual geosynchronous service for selected launch vehicles with what is theoretically possible if the launch vehicle were to launch all geosynchronous payloads that it was capable of launching and they were packed optimally. As can be seen, many launch vehicles have much higher wastage than the minimum theoretically possible with all payloads from the data set. Note, however, that the entire data set may not be representative of what any individual launch vehicle is used for, and so it would be possible to have a lower wastage in actual service than this theoretical limit by the simple virtue of not launching payloads that are not a good fit for the given launch vehicle. Given the relative homogeneity of the GEO market, both in mass and in function, and the cost benefit obtained from larger launch vehicle production runs via the learning curve, this approach would be strategically unwise from a business perspective in most cases.

Most of this excess wastage is due to the difficulty of launching multiple payloads at once. The available adapters and other factors besides the raw mass of the payload limit the number and size of secondary payloads. These effects may be seen to the greatest effect in the case of Ariane 5ECA, which despite having a very low theoretically ideal wastage and a robust multi-payload capability still has in excess of 20% wastage in actual service.

As has been alluded to elsewhere in this work, historically there has been some debate about the sizing of launch vehicles. How does sizing affect costs in this 'ideally packed' scenario? Is there a relationship between payload capacity and cost per payload mass delivered? Figure 8.1 plots the maximum payload capacity of the launch vehicle against the cost per payload mass actually delivered to orbit if the payloads were ideally packed.

It is clear that there is a trend in this ideal case between maximum payload capacity and cost per unit payload mass delivered to orbit. However, it is some-

Table 8.2: Comparison of Real and All Payloads Optimally Packed Geosynchronous Wastage for Selected Launch Vehicles

	Wastage			Wastage	
LV	Actual	'Optimal'	LV	Actual	'Optimal'
Ariane 40	-	23.31%	Ariane 42L	18.93%	15.95%
Ariane 42P	-	13.88%	*Ariane 44L*	4.74%	9.30%
Ariane 44LP	0.33%	16.94%	*Ariane 44P*	4.43%	15.87%
Ariane 5ECA	11.37%	2.60%	Ariane 5G	14.22%	7.39%
Atlas IIA	16.63%	17.04%	*Atlas IIAS*	15.33%	18.14%
Atlas IIIA	9.62%	17.08%	Atlas IIIB	30.46%	15.93%
Atlas V 401	25.88%	10.31%	Atlas V 411	29.82%	9.34%
Atlas V 421	6.34%	6.86%	Atlas V 431	21.40%	3.05%
Atlas V 501	-	18.52%	Atlas V 511	-	7.51%
Atlas V 521	35.33%	8.28%	Atlas V 531	18.15%	3.66%
Atlas V 541	-	1.62%	*Atlas V* 551	0.92%	1.83%
Delta 7326-10	-	11.28%	Delta 7326-9.5	-	14.70%
Delta 7425-10	-	14.09%	Delta 7425-9.5	-	16.95%
Delta 7426-10	-	10.42%	Delta 7426-9.5	-	12.71%
Delta 7925-10	-	20.05%	Delta 7925-10L	-	19.69%
Delta 7925-9.5	15.00%	21.92%	Delta 7925H	-	16.10%
Delta 7925H-10	-	18.87%	Delta 7925H-10L	-	18.41%
Delta 7926-10	-	15.90%	Delta 7926-10L	-	15.74%
Delta 7926-9.5	-	19.28%	Delta 7926H	-	22.76%
Delta 7926H-10	-	24.65%	Delta 7926H-10L	-	23.95%
Delta IV Heavy	10.50%	1.30%	Delta IV Medium	60.02%	12.56%
Delta IV Medium+ (4,2)	30.58%	8.90%	Delta IV Medium+ (5,2)	-	8.49%
Delta IV Medium+ (5,4)	-	3.44%	Falcon 9	-	9.69%
GSLV	33.75%	23.31%	*H-IIA 202*	2.43%	15.54%
H-IIA 2024	28.66%	9.39%	H-IIB	-	1.87%
Long March 2C	-	13.07%	Long March 2E	-	16.71%
Long March 3A	17.93%	13.88%	*Long March 3B*	2.38%	8.61%
Long March 3C	17.48%	18.85%	*M-V*	0%	12.56%
Proton-K/DM-2	3.53%	10.42%	Proton-K/DM-2M	16.92%	10.42%
Proton-M/Briz-M	28.61%	8.12%	PSLV	-	12.21%
Soyuz FG	67.89%	19.28%	Soyuz U	-	19.28%
Titan 2G	-	11.62%	Titan 402B	60.35%	8.23%
Titan 401B	75.89%	8.23%	*Zenit 3SL*	6.77%	8.46%
Zenit 3SLB	34.24%	18.44%			

'-' indicates no actual geosynchronous usage. *Italics* indicate real wastage lower than optimal.

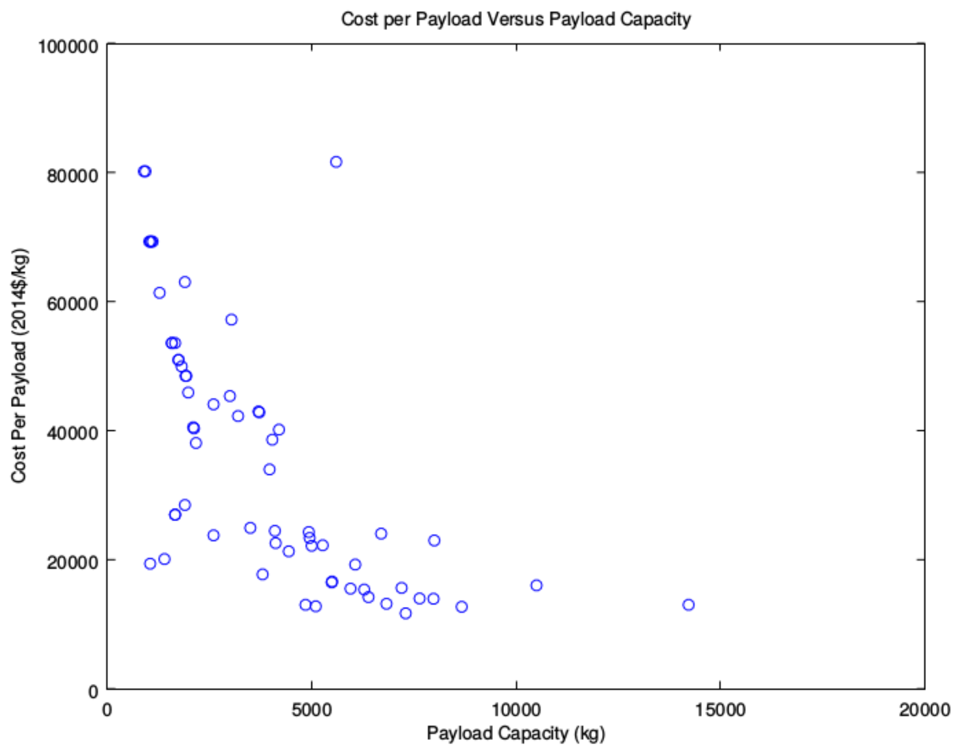

Figure 8.1: Cost Per Payload Mass Delivered versus Payload Capacity for Real Launch Vehicles with BFD Algorithm Applied to All Geosynchronous Payloads

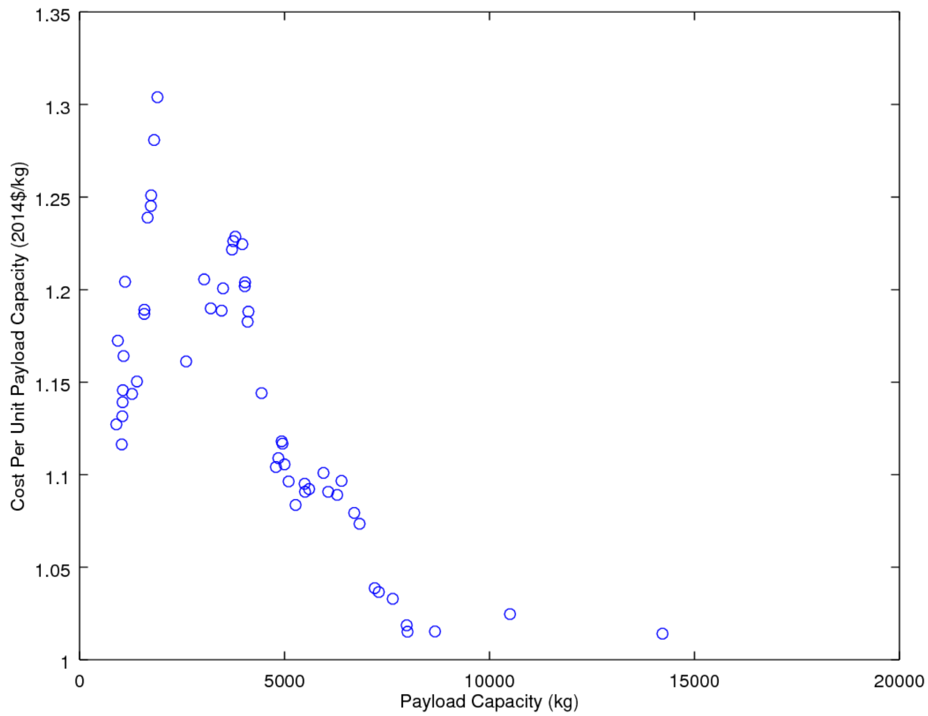

Figure 8.2: Cost Per Payload Mass Delivered versus Payload Capacity With Launch Vehicle Cost Per Unit Payload Mass Capacity Equalized

what obscured by variations in launch vehicle prices from other causes. A simple comparison demonstrates this: a Falcon 9 v1.1 has a maximum payload capacity of 4,850 kg to GTO, and costs $11,649 per kg of maximum payload capacity, while an Atlas V 401 has a maximum GTO payload capacity of 4,950 kg, yet costs $16,841 per kg of maximum payload capacity. In order to determine the effect of maximum payload capacity on cost per payload delivered to GTO, these variations must be removed, which requires only comparing launch vehicles with an identical cost per maximum payload capacity. Figure 8.2 shows the result of the analysis in Figure 8.1 if the cost per unit payload capacity for all launchers is set to 1.

Figure 8.2 shows that launch vehicles with payload capacities of 8,000 kg or more have a great advantage in price to geosynchronous orbit if optimally packed. This advantage tends to flatten out after this point, although it still slowly decreases. This makes intuitive sense: the larger individual launch capacity yields more potential configurations of the payloads, which provides more opportunities to reduce wastage.

It is interesting to compare this relationship between wastage and payload capacity to that shown for real launch vehicle usage in Figures 6.3 and 6.4 in Chapter 6. The results in these tables indicate that in current service there is no correlation between wastage and payload capacity. This indicates that currently there is no concerted effort to schedule payloads on any sort of scale. While individual operators may improve their practices over time, resulting in the decreasing trend seen in wastage and the increase in number of payloads per launch, the market is nowhere near a minimum wastage scenario.

It is clear that the use of larger launch vehicles reduces wastage in the ideally packed scenario with one type of launch vehicle. It is less certain, however, that this trend holds true if multiple types of launch vehicles are available, and if so, what the cost savings are. While the previous analysis provides a means for comparing individual launch vehicles, in order to determine the maximum possible savings, it is necessary to vary both the launch vehicle type and the arrangement of payloads.

Crainic et al provide a possible solution with their A-BFD algorithm, dedicated to solving this variable bin-packing problem with fixed costs. Figure 8.3 presents a flowchart of this algorithm. While subject to the same physical limitations on the problem as the BFD algorithm, A-BFD allows variation of the launch vehicle, both in number and type. This algorithm is very similar to BFD

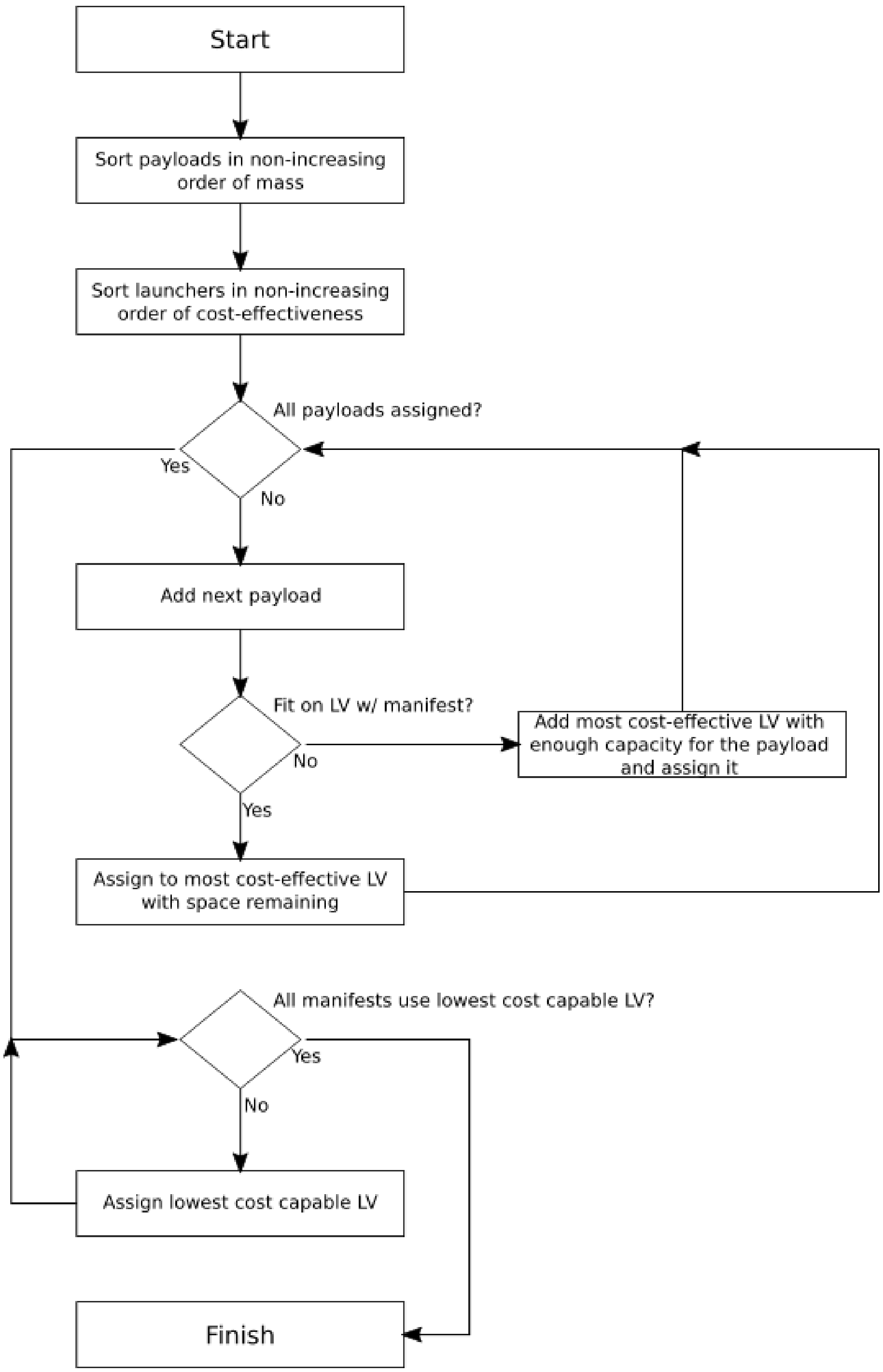

Figure 8.3: Flowchart of A-BFD Algorithm as Applied to Space Payload Scheduling

as used in the previous analysis, with two additional steps. The various bin types must be sorted in increasing order of the ratio $\frac{c}{V}$, where c is cost and V is volume. For this problem, this corresponds to the cost per maximum payload capacity. When a bin must be added, the bin with the best cost effectiveness capable of holding the object being evaluated is added if the object cannot fit in one of the existing bins. Bins of identical c/V must then be sorted in ascending order of capacity.

Given the fact that larger launch vehicles are generally more cost-effective than smaller launch vehicles, it may seem that this approach will cause excessive wastage, especially in the last few manifests assigned. Crainic addresses this issue by introducing a postprocessing step where the algorithm may swap each loaded bin with a new bin from the set of unused bins if the second bin is less expensive and has enough capacity to hold the contents of the first bin. For instance, if a very small payload is assigned to a very large capacity launcher by itself owing to this launchver's superior cost-effectiveness in the algorithm's first pass, the postprocessing step evaluates this situation and selects the cheapest launch vehicle capable of launching this payload, even if its cost-effectiveness is poor.

Table 8.3 presents launch vehicle usage for the A-BFD algorithm in the same case as the individual launch vehicle analyses. As would be expected, the results emphasize the most cost-effective launch vehicles, such as Falcon 9 and Long March 3B. The heaviest geosynchronous payload in the data set masses more than eight tons, far beyond the current capacity of either of these vehicles. This drives use of larger, more powerful, but less cost-effective launchers such as Atlas V 551. The end result is a total launch cost savings of 53% over the missions as actually launched, with a reduction in wastage from 21.8% to 9.66%.

Table 8.3: Launch Vehicle Usage for Worldwide Minimum Cost Scenario

Launch Vehicle	Number
Atlas V 421	22
Atlas V 551	2
Delta IV Medium+ (4,2)	46
Falcon 9	187
Long March 3B	18
Total	275

The results obtained using the variable bin-packing algorithm suggest that the 'optimal' solution for any given set of launch vehicles and payloads will maximize use of the least expensive launch vehicles, subject ot limitations in payload capacity. However, this presents an obvious real world problem: availability. Even if one launch vehicle is far superior in terms of cost-effectiveness than any other there is some limit as to how many could be produced. It is highly unlikely that all launch vehicle providers were producing at maximum capacity over this entire period, so some variance might not be of consequence, but the above solutions that only use one or two types of launch vehicles present a problem.

Table 8.4 presents launch vehicle usage if only the launch vehicles used in any given year are available for that year. This scenario limits the use of the most popular launchers in Table 8.3, especially Falcon 9, which was not actually used for any geosynchronous missions during the studied interval, and so offers lesser savings of 27.3% while reducing wastage to 4.73%.

Some missions are time-critical, such as space station resupply. While these constraints do not apply to all missions, it is necessary to investigate the effects of schedule constraints on the potential for scheduling to reduce costs. This may be done by running the algorithm on a single year's payloads at a time and then summing all years in the dataset, which has the end result of constraining all

Table 8.4: Launch Vehicle Usage for Worldwide Minimum Cost Scenario with Limited Launch Vehicle Availability

Launch Vehicle	Usage Minimum Cost	Usage Actual	Launch Vehicle	Usage Minimum Cost	Usage Actual
Ariane 42L	0	4	Ariane 44L	0	11
Ariane 44LP	0	4	Ariane 44P	1	3
Ariane 5ECA	38	38	Ariane 5G	10	10
Atlas IIA	0	7	Atlas IIAS	0	7
Atlas IIIA	2	2	Atlas IIIB	4	4
Atlas V 401	4	4	Atlas V 411	2	2
Atlas V 421	2	2	Atlas V 431	2	2
Atlas V 521	2	2	Atlas V 531	1	1
Atlas V 551	1	1	Delta 7925-9.5	0	1
Delta 7925H-10	0	0	Delta IV Heavy	1	1
Delta IV Medium	1	1	Delta IV Medium+ (4-2)	5	5
GSLV	0	4	H-IIA 202	1	1
H-IIA 2024	2	2	Long March 3A	12	12
Long March 3B	13	13	Long March 3C	4	4
Proton-K/DM-2	6	6	Proton-K/DM-2M	17	17
Proton-M/Briz-M	59	59	PSLV	0	1
Soyuz FG	0	1	Titan 401B	0	4
Titan 402B	0	3	Zenit 3SL	27	27
Zenit 3SLB	6	6	**Total**	223	272

payloads to be launched in the calendar year they were actually launched in. Tables 8.5 and 8.6 contain results for this case. For the case with unrestricted launch vehicle selection, this reduces the total cost savings to 43.7%. If launch vehicle selection is constrained, cost savings are reduced to 19.1%.

Table 8.5: Launch Vehicle Usage for Worldwide Minimum Cost Scenario with Time Constraints

Launch Vehicle	Number
Atlas V 421	18
Atlas V 551	2
Delta IV Medium+ (4,2)	50
Falcon 9	187
Long March 3A	6
Long March 3B	18
GSLV	2
PSLV	1
Total	284

Table 8.6: Launch Vehicle Usage for Worldwide Minimum Cost Scenario with Limited Launch Vehicle Availability and Time Constraints

	Usage By Year (Scenario/Actual)													
LV	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Ariane 42L	3/3	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Ariane 42P	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Ariane 44L	1/1	3/3	6/6	**0/1**	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Ariane 44LP	3/3	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Ariane 44P	1/1	2/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Ariane 5ECA	0/0	0/0	0/0	0/0	0/0	**0/2**	5/5	4/4	5/5	5/5	**4/5**	3/3	6/6	3/3
Ariane 5G	4/4	2/2	1/1	3/3	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas IIA	**2/4**	1/1	2/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas IIAS	2/2	1/1	1/1	0/0	3/3	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas IIIA	1/1	0/0	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas IIIB	0/0	0/0	2/2	2/2	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0

LV	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Atlas V 401	0/0	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	**0/1**	0/0	0/0	2/2
Atlas V 411	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	0/0	1/1	0/ 0	0/0	0/0	0/0
Atlas V 421	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	1/1	0/0	0/ 0	0/0	0/0	0/0
Atlas V 431	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/0	1/1	0/ 0	0/0	0/0	0/0
Atlas V 521	0/0	0/0	0/0	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas V 531	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/ 1	0/0	0/0	0/0
Atlas V 541	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Atlas V 551	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	1/1
Delta 7925-9.5	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Delta IV Heavy	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	0/0	0/ 0	0/0	0/0	0/0
Delta IV Medium	0/0	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Delta IV Medium+ (4,2)	0/0	0/0	1/1	1/1	0/0	0/0	1/1	0/0	0/0	1/1	1/ 1	0/0	0/0	0/0
GSLV	0/0	**0/1**	0/0	**0/1**	1/1	0/0	0/0	**0/1**	0/0	0/0	0/ 0	0/0	0/0	0/0
H-IIA 202	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	**0/1**	0/0	0/0	0/0
H-IIA 2024	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	**0/1**	0/0	0/ 0	0/0	0/0	0/0
Long March 3A	4/4	0/0	0/0	2/2	1/1	0/0	1/1	**0/2**	**0/1**	0/0	0/ 0	0/0	1/1	0/0
Long March 3B	0/0	0/0	0/0	0/0	0/0	**0/1**	1/1	2/2	1/1	1/1	0/ 0	5/5	1/1	1/1

LV	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Long March 3C	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	1/1	1/ 1	1/1	0/0	0/0
Proton-K/DM-2	1/1	2/2	0/0	1/1	1/1	0/0	0/0	0/0	0/0	0/1	0/ 0	0/0	0/0	0/0
Proton-K/DM-2M	7/7	2/2	4/4	2/2	1/1	0/0	0/0	0/0	**0/1**	0/0	0/ 0	0/0	0/0	0/0
Proton-M/Briz-M	0/0	1/1	0/0	0/0	4/4	**0/4**	3/3	4/4	7/7	7/7	10/10	6/6	9/9	4/4
PSLV	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Soyuz FG	0/0	0/0	0/0	**0/1**	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Titan 401B	0/0	**0/1**	1/1	**0/2**	0/0	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Titan 402B	**0/1**	**0/1**	0/0	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/ 0	0/0	0/0	0/0
Zenit 3SL	2/2	2/2	1/1	2/2	3/3	**0/3**	4/4	0/0	**3/5**	**0/1**	0/ 0	1/1	3/3	0/0
Zenit 3SLB	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	**0/1**	**0/3**	0/ 0	**1/2**	0/0	0/0

Several conclusions may be drawn from the results presented in this chapter. The first is that aside from their larger potential market share, large launch vehicles have another potential advantage over smaller ones. The current *raisons d'etre* for small launch vehicles are flexibility and launching small payloads, which as discussed in Chapter 3 are actually the majority of payloads to LEO. If payloads can be loaded without prejudice on large launch vehicles, however, their wastage is actually lower than that of small launch vehicles, increasing their already formidable cost advantage.

These results set a boundary for what a large launch vehicle is with regard to the capability to reduce wastage. Most of the potential reduction in wastage and thus cost is obtained at a GTO payload capacity of approximately 8000 kg. Beyond that, only small improvement from increasing size occurs. Since the development of ever-larger launch vehicles begins to increase the life-cycle cost per payload mass of the launch vehicle, it is clear that there is a point of diminishing returns. This figure is based on the assumption that payload masses remain relatively static over time. Historical data, as discussed in Chapter 3, indicates that average payloads are decreasing somewhat in mass over time. Thus, over time this optimum will have a tendency to decrease, barring some other change in the market that causes payload masses to increase.

Both the cost and price models show this point of diminishing returns to be near 8000 kg as well. Thus, given current market conditions, this represents an optimal payload capacity from a cost perspective. Only a single payload of the 337 in the data set masses more than 8000 kg, and the remainder can be launched at a wastage of 2.07%. Given that some sort of payload adapters would be required to attach the payloads to the launch vehicle, this probably represents a practical lower limit on wastage. As stated in Chapter 2, the SYLDA dual payload adapter for Ariane 5 masses slightly less than 5% of total GTO payload capacity.

In scenarios where multiple types of launch vehicle are available, several interesting trends are apparent. The first is that competition in these scenarios is very cutthroat. If launch vehicle selection and manifesting is completely free, the number of launch vehicle types used decreases from 37 to only 5. Limiting the launch vehicle availability to what was actually used still reduces the launch vehicle types used to 26. Investigation of Table 8.4 shows that usage is very much a binary decision: either a launch vehicle is cost effective enough to be used, in which case all of those available are used, or it is not, in which case none are used. The sole exception in that scenario is the single Ariane 44P launch. Adding the time constraint increases the number of types used. Only one launcher, Ariane 42P, is completely eliminated, although all launchers with poor cost-effectiveness suffer a reduction in numbers.

A significant savings in terms of launch cost is possible for most launch vehicles if multiple manifesting of payloads is increased in a systematic way. Assuming that each launch vehicle's individual market is similar to the geosynchronous market as a whole, many popular launch vehicles could reduce wastage and thus launch cost by up to 15% by arranging multiple manifests in a way designed to reduce wastage. This practice would also in theory promote additional savings because it enables the use of heavier launch vehicles that usually have lower costs per unit payload capacity. While there is a point of diminishing returns at approximately 8000 kg GTO capacity, below this, the higher the launch vehicle's capacity, the better. Reducing the use of cost inefficient small launch vehicles will result in additional savings.

If payloads' manifests could be arranged in the most cost-optimal way on the varied types of existing launch vehicles with no regard to time schedules or the number that can be produced, launch cost savings of up to 52% over existing costs are possible. Placing constraints such as time schedules or availability restrictions reduces this, but even in the most restrictive case, where launcher selection is restricted to the quantities actually produced and the payload must launch on a manifest in the same year that it actually launched in, a savings of up to 19% is possible over existing usage.

These results also give insights into which launch vehicle types have better cost-effectiveness for missions in the current market. Especially in the cases where availability is not restricted, entire classes of launch vehicles are not used owing to their inferior cost-effectiveness. In fact, if launcher selection were completely free over the studied interval, the lowest cost scenario only uses five distinct booster types. Even if launchers are restricted to the quantities actually used, eleven launch vehicle configurations are completely eliminated from use. It also seems that launcher utilization in this 'ideal' scenario is a binary proposition: either the complete quantity of available boosters is used or none are used.

Both wastage and low launch vehicle cost-effectiveness increase launch costs. These analyses show that launch vehicle cost-effectiveness is the primary driver behind high launch costs. If launch vehicle choice is unrestricted, wastage actually increases as costs are dramatically reduced. This is similar to the results in Chapter 7, where costs were reduced through changing launch vehicle selection for the as-launched manifests without significantly reducing wastage. However, if launch vehicle choice is restricted and scheduling constraints are imposed, reduction of wastage becomes more and more important. The most restrictive of the scenarios considered in this work actually retains a very cost-ineffective Titan IV launch while reducing usage of the much more cost-effective Ariane 5.

Chapter 9

Risk of Multiple Payload Launches

The results obtained in previous chapters suggest that significant savings are possible from rearrangement of payloads on launch vehicles. However, before proposing this as a future course of action to reduce launch costs, it is necessary to investigate any potential disadvantages this rearrangement may have. Most important of the potential disadvantages is the potential for increased risk of loss of some or all of the payloads in a launch. Buckley notes the effects of this risk [2], commenting that concern over this risk is a known barrier to combining payloads. Addressing this concern is critical to evaluation of the potential benefits of combining payloads.

Multiple payloads add complexity and failure points to individual launch events, reducing the chance that the entire launch and deployment of the on-board payloads will be successful. The additional risk to each payload from launching multiple payloads at once is dependent on the specific design of the payload adapters used to carry multiple payloads. Some adapters are configured such that a failure to separate one payload only causes the loss of that payload, while others, such as CubeSat launch tubes, may cause multiple payloads to be lost with a single separation failure [48].

This chapter will attempt to quantify the cost associated with this increased risk by estimating the cost to insure said risk. This approach is necessarily approximate, as any number of factors might affect real-life insurance costs. Different insurance policies also cover different types of losses; for instance, many launch insurance contracts also provide insurance on the payload itself for some specified period after reaching orbit, with one year being common [44]. However, at a minimum insurance has to charge enough to cover the occasional losses from launches and payload deployments, plus its own business costs and some amount of profit, and so that yields a floor on the minimum price of insurance over the long term.

It is important to note that this analysis is not intended to make definitive statements about actual insurance costs. First, some payloads, such as most United States government payloads, do not have insurance. This means that the 'insurer,' i.e. themselves, does not pass profit or overhead on to the end user. Second, past loss rates do not always drive future insurance costs. Insurers occasionally use other methods to determine their risk exposure, especially for newer, relatively untested launch vehicles [44], where the past launch data may be misleading. For example, failure on the first flight does not necessarily imply that a design really has 0% reliability. Notwithstanding these considerations, in the long run, the cost of the losses must be paid by someone, and estimating the insurance costs based on past loss rates can provide an idea of how much the additional risk adds to the final cost.

The cost of insurance is ideally a function of three variables: the value of the payload, the reliability of the launch vehicle and its subordinate systems, and the rate of profit of the insurance company. The rate of profit is not an engineering consideration. Strictly speaking, the value of the payload is not either, but cost analysis can provide some estimation of its value. Assuming relative homogeneity in payload value per mass, payload value should increase in proportion to the reduction in wastage. That is, reduction of wastage from 20% of maximum payload capacity to 10%, the value of the payload should increase by 12.5% (0.9/0.8-1).

The risk of a certain kind of loss comes from the risk of each potential cause. Separation events are a well-known cause of launch failures [44]. Depending on the design of the payload adapters, a payload separation failure may only cause the loss of the payload separating, or cause the loss of all payloads still attached to the upper stage. It is even conceivable that in the future the payload may not be lost at all; a launch vehicle with payload recovery capability such as the Space Shuttle could return payloads that failed to deploy, and the loss would be reduced to the payload's launch cost. The analysis done below will assume the worst-case scenario of all remaining payloads attached to the upper stage being total losses once a separation failure occurs.

A simple analysis of the worst-case scenario provides a way to quantify the cost effect of increased risk. A single payload, and thus a single separation event, is the baseline case. The chance of failure is $1 - R$, where R is the reliability of the separation system. For multiple payloads in this scenario, a failure of the first payload separation is a complete loss, so the chance of losing any of the subsequent payloads is at minimum $1-R$. It will be assumed that all separations have the same reliability R.

It follows that the chance of losing the Nth payload to a separation failure in this scenario is:

$$L = (1 - R) \prod_{i=1}^{N} R^{i-1} \tag{9.1}$$

Each individual payload requires insurance against its own replacement cost and the cost of launching this replacement. Again assuming homogeneity in value per payload mass, and further assuming that wastage on a subsequent flight would be the same, the additional insurance cost for the payloads is:

$$C_{IP} = \sum_{i=1}^{N} [(1 - R) \prod_{j=1}^{i} R^{j-1}] \frac{M_{Pi}}{M_P} (C_P + C_{LVe}) \tag{9.2}$$

This charges the risk for the first separation to the payload, rather than the launch vehicle.

There is a possibility that the launch vehicle itself will fail. While one would not expect delivery of multiple payloads to have an effect on launch vehicle reliability, it has an effect on the cost of insurance because it increases the value of the payload by reducing wastage. Launch insurance increases the cost of the launch vehicle by a factor of:

$$\frac{C_{LVe}}{C_{LV}} = 1 + (1 + \frac{C_P}{C_{LV}})(1 - R_{LV})(1 + P_I) \tag{9.3}$$

Adding the cost of insuring the payloads to this increased cost will give the total cost for the launch.

Data collected by Futron Corporation [49] suggest that separations have a historical failure rate of approximately .233%. Assuming operation at full load (i.e., negligible wastage), Table 9.1 displays the insurance costs for a given number of payloads as a percentage of launch vehicle cost, assuming 98% launch vehicle

Table 9.1: Loss Chance and Insurance Cost

		Number of Payloads on Launch									
Payload	% Loss	1	2	3	4	5	6	7	8	9	10
1	0.23%	0.95%	0.48%	0.32%	0.24%	0.19%	0.16%	0.14%	0.12%	0.11%	0.10%
2	0.47%		0.95%	0.64%	0.48%	0.38%	0.32%	0.27%	0.24%	0.21%	0.19%
3	0.70%			0.95%	0.71%	0.57%	0.48%	0.41%	0.36%	0.32%	0.29%
4	0.93%				0.95%	0.76%	0.63%	0.54%	0.48%	0.42%	0.38%
5	1.16%					0.95%	0.79%	0.68%	0.59%	0.53%	0.47%
6	1.39%						0.95%	0.81%	0.71%	0.63%	0.57%
7	1.62%							0.95%	0.83%	0.74%	0.66%
8	1.85%								0.95%	0.84%	0.76%
9	2.08%									0.95%	0.85%
10	2.31%										0.94%
Total		0.95%	1.43%	1.91%	2.38%	2.85%	3.33%	3.80%	4.27%	4.74%	5.21%
Increase		9.94%	14.90%	19.85%	24.80%	29.73%	34.66%	39.58%	44.49%	49.40%	54.30%

reliability and a $\frac{C_P}{C_{LV}}$ of 3. The additional insurance beyond that required for the launch vehicle for ten equally sized payloads with zero wastage launched simultaneously under this scheme reaches 5.2% of launch vehicle cost. This sets another floor on wastage: if the money saved from reducing wastage is immediately lost due to the cost of assuming increased risk, then nothing is gained.

This, however, is a worst-case scenario in several ways. First, even in the least constrained cases examined in Chapter 8 for the largest launch vehicles, it is seldom necessary to launch ten payloads at once. In the 'ideal' case, the largest number of simultaneous payloads for Ariane 5ECA is seven. For smaller launch vehicles, the maximum number of simultaneous payloads will be less.

Second, a multi-payload system where failure of any payload dooms all payloads that have not yet separated is pessimistic. Depending on the size of the subordinate payloads, there are several arrangements that could provide for separation of subsequent payloads even if a payload ahead of them in the queue fails to deploy. The existing ESPA ring for the EELVs falls into this category, as the payloads are arranged in parallel [31]. A detailed examination of payload geometries or arrangements and their effect on the rate of payload losses due to separation failure is beyond the scope of this work, but it is clear that even in current practice the assumption that a payload separation failure causes the loss of all subsequent payloads is conservative.

Finally, assuming that all payloads are of equal mass actually causes the insurance cost to increase. Both in actual service and in the 'ideal' case, there is a tendency to pair large payloads with small ones. Even if forced to adopt a physical configuration where a separation failure of a payload prevents subsequent payloads from deploying, ensuring that the largest and therefore usually most valuable payload deploys first will reduce the cost of insurance, since the first payload has the lowest chance of being lost to separation failure in this scenario.

Surprisingly, for highly reliable launch vehicles launching large numbers of individual payloads concurrently, there may be a higher chance of losing a payload to separation failure than of losing the launch vehicle. This carries a correspondingly higher insurance cost. However, the increased cost, even in the worst case, is far less (at least a factor of two) than average wastage for current launch vehicles. Further, this worst-case scenario is highly unlikely to occur, given that it requires making pessimistic assumptions about virtually all aspects of the launch manifest and payload separation system.

Increasing the number of payloads per launch vehicle is not without risk. The potential for reduced reliability and the requirement to pay launch insurance on an increased amount of payload value can reduce the potential savings. However, even in the most pessimistic scenario, these additional insurance costs will constitute no more than a 5% additional cost per launch.

Chapter 10

Conclusions

Operational losses constitute a significant expense in the deployment of spacecraft. Few commentators have remarked on this expense, even though it can be in excess of 20% from wastage alone. If the use of cost-ineffective launch vehicles, for whatever cause, is included, the expense can be as much as 53% of the total launch vehicle expenditure. Historically, the high cost of launch vehicles and until recently the requirement to expend them to reach space were the primary drivers behind the high cost of access to space. However, significant reductions in cost to the customer are possible if operational losses can be reduced, and these savings will continue even if launch vehicle technology is improved.

10.1 Review of Dissertation

Investigation of operational losses first requires data on launch vehicle usage and payload characteristics. Chapter 3 analyzed trends in the masses and orbit types of the space payloads in the data set, while Chapter 4 tabulated launch vehicle prices and historical usage while examining trends in launch vehicle pricing with multiple cost models. These analyses showed that the majority of individual payloads are small, but the majority of payload mass is contained in large payloads. Further analysis showed that at least among existing launch vehicles, larger size tends to be more cost-effective in terms of price per maximum payload capacity. This is an inherent conflict that expresses itself in both the wastage and launch vehicle selection problems.

Chapter 5 examined the capability of launch vehicles to launch payloads. The smallest launch vehicles, Pegasus and Falcon 1, are capable of launching approximately 33% of individual payloads, but this only translates to slightly more than 1% of payload mass. In combination with their inherently inferior cost-effectiveness, this makes small launch vehicles less attractive for the user. This drives the use of larger launch vehicles. Chapter 5 also studied the market share of launch vehicles, finding that single-digit shares of the payload mass that a launcher is capable of launching are typical.

Chapter 6 computed overall wastage and wastage of certain classes of payloads. The total wastage for all launches with complete data was 20.38% of total payload capacity. This results in a financial loss of no less than $8.72B (2014$). Given that the cost computations in this work purposely select optimistic (i.e. low) values for the prices of launch vehicles, the true financial loss could be twice this or more. It is important to note that wastage decreased sharply over the period 2009-2013, to the point that the wastage to low Earth and geosynchronous orbits for 2013 was less than half the average.

Chapter 7 investigated launch vehicle usage. The majority of launches do not use the cheapest launch vehicle capable of carrying out their mission. To some degree, this is inevitable, given the non-financial considerations highlighted in that chapter. Nonetheless, the percentage is low enough that making an attempt to improve it will yield significant savings. A savings of slightly less than 44% to low Earth and geosynchronous orbits is possible simply by changing launch vehicle selection among those available at the time for the existing payload manifests with no rearrangement at all.

The considerable amount of payload capacity wasted, coupled with the cost-inefficiency of small launch vehicles, represents a large increased cost imposed on the space launch industry. Analyses conducted in Chapters 7 and 8 of this work indicate that it is possible to reduce launch costs greatly by improving where possible the selection of launch vehicles and the manifesting of payloads.

The gains shown in these analyses are not fully possible in reality. As stated in the relevant chapters, real-world limitations place limits on the potential savings. Further, most of these real-world limitations, such as national security considerations, are not technical in nature and not amenable to technological or operational solutions. They are also difficult to quantify. It may be simple enough to determine the number of national security payloads and exempt them from the analysis performed in Chapters 7 and 8, but determining and quantifying all of the potential reasons to use a launch vehicle that appears to be uneconomical is not possible.

Nonetheless, it is clear that improvement is possible. The fact that over time the number of payloads per launch has gone up, as shown in Figure 3.7 while wastage has gone down as shown in Figure 6.1 is a strong indication of this. Individual users and launch vehicle producers are already working to increase the utilization of multiple payload launches [2].

Improved selection of launch vehicles offers a greater savings, but is more problematic than improved payload manifesting. If launch vehicle selection were completely open, a 43.7% savings over the current situation, even with identical manifests, is possible. Combining these approaches can result in radical improvement. As noted in Chapter 8, a total reduction in launch cost to geosynchronous orbit of nearly 52% is theoretically possible.

Merely proposing changes to launch scheduling is not a complete solution. The current array of payload adapters available for most launch vehicles is incapable of supporting much further increase in multiple payload launch, especially for payloads of larger size. Smaller satellites are somewhat better provided for in this regard, as the existing adapters are capable of carrying more payloads at once and new developments such as Spaceflight's SHERPA promise to carry considerably more [50]. Larger payloads, however, are still limited to single or double launches, and likely will remain so for the forseeable future.

While some 'containerized' satellite deployment systems exist, none operate in the same way that Earthbound containerized shipping systems do. The ISO container caused a revolution in international shipping and contributed to massive growth in the global economy [51]. No existing satellite transportation and deployment system matches its simplicity, scalability, and modularity. These traits enabled the ISO container to quickly become the world standard for the emerging intermodal transportation market.

The first requirement for a container is simplicity. Imposing a heavy additional mass or complexity requirement would eat up the savings the containers are intended to provide. The average wastage of 20% sets an upper limit beyond which containers would be of little use. As discussed in Chapter 2, container structural fractions of $\approx 5\%$ or less should be achievable, given that there are entire launch vehicle stages with similar structural fractions.

The second requirement is scalability. Some container ships carry thousands of containers of several different sizes. While the space payload market is not so extensive, it is equally diverse. The heaviest payloads (e.g. *Lacrosse*) and the lightest payloads (CubeSats) in the data set are four orders of magnitude apart in mass. Ideally packing payloads in the manner described in Chapter 8 can, depending on the payload set, result in scenarios where launching many payloads at once might be required. This is most often seen on the last few manifests with larger launch vehicles, where large numbers of smaller payloads left over from other manifests may be assigned. With current launch vehicles, this requirement could be up to three concurrent payloads for the geosynchronous scenario without launch vehicle selection or time constraints and up to 155 concurrent payloads for the low Earth orbit scenario with the same constraints. This may seem outlandish, but the Spaceflight SHERPA referenced above is designed to carry as many as 87 payloads concurrently [52].

The final requirement is modularity. Containers of multiple sizes must have some means to fit together. As briefly discussed in Chapter 9 attempts to reduce wastage by changing the arrangement of payloads tend to match a large payload with one or more smaller payloads. Most current payload adapters are very limited in this regard, only allowing a set number of payloads of given sizes. Some degree of modularity can be achieved by combining different sorts of adapters, such as the various types of smallsat dispensers designed to attach to ESPA ring interfaces [50], but this is limited.

ISO containers achieve modularity by establishing a universal 8 ft by 8 ft cross-section and allowing for varied container lengths. This approach is less likely to be successful with spacecraft because of the great variety of sizes of spacecraft. For ISO containers this is less of a problem because goods are often loosely packed or boxed inside them, and are typically much smaller than the 8 x 8 cross-section. Given the loads experienced during space launches and the need to deploy the payload once the launch vehicle has reached orbit, this approach cannot be used for a spaceborne container system.

Replication of the traits of the ISO container would provide many of the same benefits that containerization did for global trade. Containerization enabled ocean-going ships using much the same propulsion and guidance technology as their predecessors to greatly increase their utility and efficiency at moving goods from place to place. This resulted in rapid growth in the global economy due to increased trade, and the resulting 'globalization' still shapes the world today.

This approach stands in stark contrast to current efforts to reduce the cost of access to space that attempt to lower costs by making technological improvements to the launch vehicle. Until the recent successes of the reusable Falcon 9 program, these efforts, as epitomized by the Space Shuttle, the National Aerospace Plane, and the X-33 program, all failed to deliver the promised drastic reduction in launch costs due to spiraling costs brought on by the significant technical challenges each of these programs posed. In contrast, reduction of operational losses can, with a minimum of development of new hardware and the associated development costs, provide significant savings in the short term, and continue to provide benefits even if launch vehicle cost can be brought down significantly in the future.

10.2 Future Work

There are several possibilities for future work to support these goals. The first is to examine the non-economic considerations for space operations in more depth. The results displayed in Figure 7.2 demonstrate the large effect that non-economic considerations have on launch vehicle selection. While many of these effects are not amenable to quantification, some additional analysis will prove valuable, such as comparing launch vehicle selection behaviors among payload-owning organizations.

The subjects examined in this work touch on economic and business factors, but examination of such has been simplified, trying to reduce the total cost of launching payloads as much as possible. In real world space operations, other economic factors can play a role, as alluded to in Chapter 2 when discussing Greenberg's analysis of a notional launch vehicle selection business decision. As stated in that chapter, the information he relied on for this analysis is not widely available for most launch vehicles. However, examination of the effects of payment schedules and other economic factors in conjunction with the effects of operational losses noted in this paper would be useful from a conceptual perspective even if real world data on these factors are not available.

Finally, the amount of work done on launch vehicle cost modeling is limited, and much of it is dated. Koelle's work relies on an impressive collection of sources from the 1960s and 1970s. However, the business of developing and constructing launch vehicles has changed significantly since that time, and so this work requires updating. The rudimentary cost model developed in this work is a first step in this direction, but further work is necessary to confirm the trends observed in Chapter 4. Not only is this necessary for the uses in this work, it is important in design studies for future launch vehicles.

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Appendix A

Payload Database

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2000-001A	USA	US	2000/01/21	35780	35790	2610	GEO	Atlas IIA	3039	429	143766000
2000-002A	GALAXY	US	2000/01/25	35989	35937	1987	GEO	Ariane 42L	3590	1603	1.13533e+08
2000-003A	ZHONGXING-22	PRC	2000/01/25	36649	36620	2300	GEO	Long March 3A	2600	300	5.3593e+07
2000-004A	JAWSAT	US	2000/01/27	784	736	64	LEO	Minotaur 1	310	149	1.70124e+07
2000-004B	OCS	US	2000/01/27	239	200	22	LEO	Minotaur 1	0	0	0
2000-004C	OPAL	US	2000/01/27	798	744	13	LEO	Minotaur 1	0	0	0
2000-004D	FALCONSAT	US	2000/01/27	800	745	52	LEO	Minotaur 1	0	0	0
2000-004E	ASUSAT	US	2000/01/27	798	745	5	LEO	Minotaur 1	0	0	0
2000-004H	PICOSAT	US	2000/01/27	777	731	1	LEO	Minotaur 1	0	0	0
2000-004J	PICOSAT	US	2000/01/27	761	718	1	LEO	Minotaur 1	0	0	0
2000-004K	PICOSAT	US	2000/01/27	778	728	1	LEO	Minotaur 1	0	0	0
2000-004L	PICOSAT	US	2000/01/27	756	711	1	LEO	Minotaur 1	0	0	0
2000-004M	PICOSAT	US	2000/01/27	781	731	1	LEO	Minotaur 1	0	0	0
2000-005A	PROGRESS-M1	CIS	2000/02/01	333	7406.54	7150	LEO	Soyuz U	7200	50	3.57286e+07
2000-006A	COSMOS	CIS	2000/02/03	856	841	3200	LEO	Zenit 2	5000	1800	4.96707e+07
2000-007A	HISPASAT	SPN	2000/02/03	35798	35777	3112	GEO	Atlas IIAS	3630	518	1.27725e+08
2000-008A	GLOBALSTAR	GLOB	2000/02/08	1414	1413	450	LEO	Delta 7420-10L	2351	551	0
2000-008B	GLOBALSTAR	GLOB	2000/02/08	1495	1494	450	LEO	Delta 7420-10L	0	0	0
2000-008C	GLOBALSTAR	GLOB	2000/02/08	1606	1600	450	LEO	Delta 7420-10L	0	0	0
2000-008D	GLOBALSTAR	GLOB	2000/02/08	1415	1413	450	LEO	Delta 7420-10L	0	0	0
2000-009A	IRDT	CIS		613	580	110	LEO	Soyuz U	7200	7090	3.57286e+07
2000-010A	STS	US	2000/02/11	234	350	24400	LEO	STS	24400	0	491000000
2000-011A	GARUDA	INDO	2000/02/12	35798	35773	4500	GEO	Proton-K/DM-2M	4900	400	1.06437e+08
2000-012A	SUPERBIRD-B2	JPN	2000/02/18	35796	35777	4057	GEO	Ariane 44LP	4030	-27	1.27725e+08
2000-013A	EXPRESS-A2	CIS	2000/03/12	35918	35651	2600	GEO	Proton-K/DM-2M	4900	2300	1.06437e+08
2000-014A	MTI	US	2000/03/12	515	491	587	LEO	Taurus 1110	1320	733	0
2000-016A	ASIASTAR	US	2000/03/21	35805	35770	2778	GEO	Ariane 5G	6800	1244	1.48869e+08
2000-016B	INSAT-3B	IND	2000/03/21	35981	35935	2778	GEO	Ariane 5G	0	0	0
2000-017A	IMAGE	US	2000/03/25	45414	1458	494	HEO	Delta 7326-9.5	636	142	6.38623e+07
2000-018A	SOYUZ-TM	CIS	2000/04/04	378	7317.39	0	LEO	Soyuz U	7200	0	3.57286e+07
2000-019A	EUTELSAT	EUTE	2000/04/17	35798	35774	2500	GEO	Proton-K/DM-2M	4900	2400	1.06437e+08
2000-020A	GALAXY	US	2000/04/19	35939	35879	3668	GEO	Ariane 42L	3590	-78	1.13533e+08
2000-021A	PROGRESS-M1	CIS	2000/04/25	338	7287.67	7150	LEO	Soyuz U	7200	50	3.57286e+07
2000-022A	GOES	US	2000/05/03	36162	36106	2217	GEO	Atlas IIA	3039	822	143766000

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2000-023A	COSMOS 2370	CIS	2000/05/03	248	7257.96	6700	LEO	Soyuz U	7200	500	3.57286e+07
2000-024A	USA	US	2000/05/08	35780	35790	2380	GEO	Titan 402B/IUS	5760	3380	4.16834e+08
2000-025A	NAVSTAR	US	2000/05/11	20127	20235	2030	MEO	Delta 7925-9.5	0	0	7.09581e+07
2000-026A	SIMSAT	CIS	2000/05/16	528	517	657	LEO	Rokot	1400	86	1.42915e+07
2000-026B	SIMSAT	CIS	2000/05/16	524	516	657	LEO	Rokot	0	0	0
2000-027A	STS	US	2000/05/19	381	350	24400	LEO	STS	24400	0	491000000
2000-028A	EUTELSAT	EUTE	2000/05/24	35804	35769	3190	GEO	Atlas IIIA	4055	865	1.27725e+08
2000-029A	GORIZONT	CIS	2000/06/06	35780	35753	2125	GEO	Proton-K/Briz-M	4500	2375	0
2000-030A	TSX-5	US	2000/06/07	1470	408	247	LEO	Pegasus XL	190	-57	1.78643e+07
2000-031A	EXPRESS-A3	CIS	2000/06/24	36243	36185	2600	GEO	Proton-K/DM-2M	4350	1750	1.06437e+08
2000-032A	FENGYUN	PRC	2000/06/25	35839	35825	1400	GEO	Long March 3A	2600	1200	5.3593e+07
2000-033A	NADEZHDA	CIS	2000/06/28	687	666	825	LEO	Kosmos 3M	775	-106	1.70299e+07
2000-033B	TZINGHUA	PRC	2000/06/28	693	671	50	LEO	Kosmos 3M	0	0	0
2000-033C	SNAP	UK	2000/06/28	680	665	6	LEO	Kosmos 3M	0	0	0
2000-034A	TDRS	US	2000/06/30	35811	35763	3180	GEO	Atlas IIA	3039	-141	143766000
2000-035A	SIRIUS-1	US	2000/06/30	46994	24575	3800	error	Proton-K/DM-2M	4350	550	1.06437e+08
2000-036A	COSMOS	CIS	2000/07/04	35810	35769	2400	GEO	Proton-K/DM-2M	4350	1950	1.06437e+08
2000-037A	ZVEZDA	ISS	2000/07/12	365	372	20295	LEO	Proton-K	19760	-535	0
2000-038A	ECHOSTAR	US	2000/07/14	35797	35777	3700	GEO	Atlas IIAS	3630	-70	1.27725e+08
2000-039A	MITA-O	IT	2000/07/15	422	475	170	LEO	Kosmos 3M	775	46	1.70299e+07
2000-039B	CHAMP	GER	2000/07/15	409	464	522	LEO	Kosmos 3M	0	0	0
2000-039C	RUBIN	GER		411	463	37	LEO	Kosmos 3M	0	0	0
2000-040A	NAVSTAR	US	2000/07/16	20650	19673	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2000-041A	CLUSTER	ESA	2000/07/16	119319	167.398	1200	HEO	Soyuz U/Fregat	7200	0	0
2000-041B	CLUSTER	ESA	2000/07/16	119297	168.838	1200	HEO	Soyuz U/Fregat	0	0	0
2000-042A	MIGHTYSAT	US	2000/07/19	547	581	120	LEO	Minotaur 1	310	190	1.70124e+07
2000-043A	INTELSAT	US	2000/07/28	35796	35778	3659	GEO	Zenit 3SL	5250	1591	1.06437e+08
2000-044A	PROGRESS-M1	CIS	2000/08/06	388	350	7150	LEO	Soyuz U	7200	50	3.57286e+07
2000-045A	CLUSTER	ESA	2000/08/09	119265	171.719	1200	HEO	Soyuz U/Fregat	7200	0	0
2000-045B	CLUSTER	ESA	2000/08/09	122506	173.159	1200	HEO	Soyuz U/Fregat	0	0	0
2000-046A	BRASILSAT	BRAZ	2000/08/17	35798	35776	1757	GEO	Ariane 44LP	4030	446	1.27725e+08
2000-046B	NILESAT	EGYP	2000/08/17	35804	35768	1827	GEO	Ariane 44LP	0	0	0
2000-047A	USA	US	2000/08/17	689	695	14500	LEO	Titan 403B	21680	7180	4.16834e+08
2000-049A	RADUGA-1	CIS	2000/08/28	35792	35767	2400	GEO	Proton-K/DM-2	4350	1950	1.06437e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2000-050A	JB-3	PRC	2000/09/01	422	417	1500	LEO	Long March 4B	2800	1300	2.97739e+07
2000-051A	SIRIUS-2	US	2000/09/05	47083	24487	3800	error	Proton-K/DM-2M	4350	550	1.06437e+08
2000-052A	EUROBIRD	EUTE	2000/09/06	36425	36342	3250	GEO	Ariane 44P	3465	215	1.13533e+08
2000-053A	STS	US	2000/09/08	387	350	24400	LEO	STS	24400	0	491000000
2000-054A	ASTRA	SES	2000/09/14	35795	35777	3320	GEO	Ariane 5G	6800	1545	1.48869e+08
2000-054B	AMC-7	SES	2000/09/14	35797	35776	1935	GEO	Ariane 5G	0	0	0
2000-055A	NOAA	US	2000/09/21	858	841	1476	LEO	Titan 2G	2177	701	70850000
2000-056A	COSMOS 2372	CIS	2000/09/25	211	343	12000	LEO	Zenit 2	13740	1740	4.96707e+07
2000-057A	SAUDISAT	SAUD	2000/09/26	655	589	50	LEO	Dnepr	3200	3070	1.31005e+07
2000-057B	MEGSAT-1	IT	2000/09/26	633	583	50	LEO	Dnepr	0	0	0
2000-057C	UNISAT	IT	2000/09/26	649	576	10	LEO	Dnepr	0	0	0
2000-057D	TIUNGSAT-1	MALA	2000/09/26	639	583	10	LEO	Dnepr	0	0	0
2000-057E	SAUDISAT	SAUD	2000/09/26	662	589	10	LEO	Dnepr	0	0	0
2000-058A	COSMOS 2373	CIS	2000/09/29	268	14.7119	6600	LEO	Soyuz U	7200	600	3.57286e+07
2000-059A	NSS-11	SES	2000/10/01	35794	35780	3593	GEO	Proton-K/DM-2M	4350	757	1.06437e+08
2000-060A	N-SAT-110	JPN	2000/10/06	35789	35786	3531	GEO	Ariane 42L	3590	59	1.13533e+08
2000-061A	HETE-2	US	2000/10/09	580	551	130	LEO	Pegasus H	350	0	0
2000-062A	STS	US	2000/10/11	390	350	24400	LEO	STS	24400	0	491000000
2000-063A	[GLONASS]	CIS	2000/10/13	19143	9724.38	1370	MEO	Proton-K/DM-2	4350	195	1.06437e+08
2000-063B	COSMOS 2376	CIS	2000/10/13	19135	9694.67	1415	MEO	Proton-K/DM-2	0	0	0
2000-063C	[GLONASS]	CIS	2000/10/13	19287	9664.95	1370	MEO	Proton-K/DM-2	0	0	0
2000-064A	PROGRESS-M	CIS	2000/10/16	271	280	6860	LEO	Soyuz U	7200	340	3.57286e+07
2000-065A	USA	US	2000/10/20	35780	35790	1235	GEO	Atlas IIA	3039	1804	143766000
2000-066A	THURAYA-1	UAE	2000/10/21	36167	36135	5108	GEO	Zenit 3SL	5250	142	1.06437e+08
2000-067A	AMC-6	SES	2000/10/21	35800	35774	3909	GEO	Proton-K/DM-2M	4350	441	1.06437e+08
2000-068A	INTELSAT	ITSO	2000/10/29	35797	35797	4167	GEO	Ariane 44LP	4030	-137	1.27725e+08
2000-069A	BEIDOU	PRC	2000/10/30	36236	36111	2200	GEO	Long March 3A	2600	400	5.3593e+07
2000-070A	SOYUZ-TM	CIS	2000/10/31	378	385	0	LEO	Soyuz U	0	0	3.57286e+07
2000-071A	NAVSTAR	US	2000/11/10	20000	19979	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2000-072A	INTELSAT	US	2000/11/16	35781	35793	4758	GEO	Ariane 5G	6800	1455	1.48869e+08
2000-072B	PHASE	GER	2000/11/16	1167	1106	397	LEO	Ariane 5G	0	0	0
2000-072C	STRV	UK	2000/11/16	39207	650	95	HEO	Ariane 5G	0	0	0
2000-072D	STRV	UK	2000/11/16	39232	649	95	HEO	Ariane 5G	0	0	0
2000-073A	PROGRESS-M1	CIS	2000/11/16	378	385	7150	LEO	Soyuz U	7200	50	3.57286e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2000-074A	QUICKBIRD	US	2000/11/20	610	610	950	LEO	Kosmos 3M	1500	550	1.70299e+07
2000-075A	EO-1	US	2000/11/21	691	676	566	LEO	Delta 7320-10	1579	-45	6.38623e+07
2000-075B	SAC-C	ARGN	2000/11/21	703	701	529	LEO	Delta 7320-10	0	0	0
2000-075C	MUNIN	SWED	2000/11/21	1790	704	529	LEO	Delta 7320-10	0	0	0
2000-076A	ANIK	CA	2000/11/21	35799	35774	4711	GEO	Ariane 44L	4790	79	1.41916e+08
2000-077A	SIRIUS-3	US	2000/11/30	47116	24452	3800	error	Proton-K/DM-2M	4350	0	1.06437e+08
2000-078A	STS	US	2000/12/01	365	350	24400	LEO	STS	24400	0	491000000
2000-078B	FLOATING	US	2000/12/01	325	325	0	LEO	STS	0	0	0
2000-079A	EROS	ISRA	2000/12/05	533	519	240	LEO	Start-1	500	260	1.07186e+07
2000-080A	USA	US	2000/12/06	270	37490	3600	LEO	Atlas IIAS	3630	30	1.27725e+08
2000-081A	ASTRA	SES	2000/12/20	35789	35784	1414	GEO	Ariane 5G	6800	1957	1.48869e+08
2000-081B	AMC-8	SES	2000/12/20	35799	35775	2015	GEO	Ariane 5G	0	0	0
2000-081C	LDREX	JPN	2000/12/20	261	30257	1414	LEO	Ariane 5G	0	0	0
2000-082A	BEIDOU	PRC	2000/12/20	36419	35732	2200	GEO	Long March 3A	2600	400	5.3593e+07
2001-001A	SHENZHOU	PRC	2001/01/09	330	345	0	LEO	Long March 2F	0	0	0
2001-002A	TURKSAT	TURK	2001/01/10	35801	35773	3535	GEO	Ariane 44P	3465	-70	1.13533e+08
2001-003A	PROGRESS-M1	CIS	2001/01/24	151	215	7300	LEO	Soyuz U	7200	-100	3.57286e+07
2001-004A	NAVSTAR	US	2001/01/30	19790	184	2032	HEO	Delta 7925-9.5	0	0	7.09581e+07
2001-005A	SICRAL	IT	2001/02/07	35803	35771	2596	GEO	Ariane 44L	4790	705	1.41916e+08
2001-005B	SKYNET	UK	2001/02/07	35801	35773	1489	GEO	Ariane 44L	0	0	0
2001-006A	STS	US	2001/02/07	386	350	24400	LEO	STS	24400	0	491000000
2001-006B	DESTINY	ISS	2001/02/07	386	350	0	LEO	STS	0	0	0
2001-007A	ODIN	SWED	2001/02/20	569	565	250	LEO	Start-1	500	250	1.07186e+07
2001-008A	PROGRESS-M	CIS	2001/02/26	373	393	7250	LEO	Soyuz U	7200	-50	3.57286e+07
2001-009A	USA	US	2001/02/27	35764	35768	4670	GEO	Titan 401B	9000	4330	4.16834e+08
2001-010A	STS	US	2001/03/08	379	350	24400	LEO	STS	24400	0	491000000
2001-011A	EUTELSAT	EUTE	2001/03/08	35809	35765	3050	GEO	Ariane 5G	6800	2433	1.48869e+08
2001-011B	BSAT-2A	JPN	2001/03/08	36124	36066	1317	GEO	Ariane 5G	0	0	0
2001-012A	XM-2	US	2001/03/18	35801	35772	4667	GEO	Zenit 3SL	5250	583	1.06437e+08
2001-013A	MARS	US	2001/04/07	0	0	725	Mars	Delta 7925-9.5	1265	540	7.09581e+07
2001-014A	EKRAN	CIS	2001/04/07	36094	35862	1970	GEO	Proton-M/Briz-M	6920	4950	8.33668e+07
2001-015A	GSAT-1	IND	2001/04/18	35787	33853	1530	GEO	GSLV	2500	970	4.16834e+07
2001-016A	STS	US	2001/04/19	404	350	24400	LEO	STS	24400	0	491000000
2001-017A	SOYUZ-TM	CIS	2001/04/28	385	397	0	LEO	Soyuz U	0	0	3.57286e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2001-018A	XM-1	US	2001/05/08	35803	35770	4667	GEO	Zenit 3SL	5250	583	1.06437e+08
2001-019A	INTELSAT	US	2001/05/15	35777	35795	3712	GEO	Proton-K/DM-2M	4350	638	1.06437e+08
2001-020A	USA 158	US	2001/05/18	35700	179	1800	HEO	Delta 7925-9.5	0	0	7.09581e+07
2001-021A	PROGRESS-M1	CIS	2001/05/20	402	391	7250	LEO	Soyuz FG	7420	170	3.57286e+07
2001-022A	COSMOS 2377	CIS	2001/05/29	261	170	6500	LEO	Soyuz U	7200	700	3.57286e+07
2001-023A	COSMOS2378	CIS	2001/06/08	1010	962	825	LEO	Kosmos 3M	775	-50	1.70299e+07
2001-024A	INTELSAT	ITSO	2001/06/09	35800	35773	4725	GEO	Ariane 44L	4790	65	1.41916e+08
2001-025A	ASTRA	SES	2001/06/16	35790	35783	3728	GEO	Proton-K/DM-2M	4350	622	1.06437e+08
2001-026A	ICO	NICO	2001/06/19	10627	10572	2750	MEO	Atlas IIAS	3630	880	1.27725e+08
2001-027A	WMAP	US	2001/06/30	0	0	840	Solar	Delta 7425-10	1073	233	6.38623e+07
2001-028A	STS	US	2001/07/12	395	350	24400	LEO	STS	24400	0	491000000
2001-029A	ARTEMIS	ESA	2001/07/12	35803	35772	3105	GEO	Ariane 5G	6800	2397	1.48869e+08
2001-029B	BSAT-2B	JPN	2001/07/12	5118	134	1298	HEO	Ariane 5G	0	0	0
2001-030A	MOLNIYA	CIS	2001/07/20	39729	150	1900	HEO	Molniya ML	1800	-100	0
2001-031A	GOES	US	2001/07/23	36133	36084	2105	GEO	Atlas IIA	3033	928	143766000
2001-032A	CORONAS	CIS	2001/07/31	529	486	2260	LEO	Tsyklon 3	4100	1840	2.38191e+07
2001-033A	USA	US	2001/08/06	35780	35780	2380	GEO	Titan 402B/IUS	5760	3380	4.16834e+08
2001-034A	GENESIS	US	2001/08/08	0	0	494	Solar	Delta 7326-9.5	629	135	6.38623e+07
2001-035A	STS	US	2001/08/10	402	350	24400	LEO	STS	24400	0	491000000
2001-036A	PROGRESS-M	CIS	2001/08/21	389	376	7250	LEO	Soyuz U	7200	-50	3.57286e+07
2001-037A	COSMOS	CIS	2001/08/24	35788	35734	2155	GEO	Proton-K/DM-2	2000	-155	1.06437e+08
2001-038A	LRE	JPN	2001/08/29	33918	220	3500	HEO	H-IIA 202	4100	600	8.33668e+07
2001-039A	INTELSAT	ITSO	2001/08/30	35798	35775	4725	GEO	Ariane 44L	4790	65	1.41916e+08
2001-040A	USA	US	2001/09/08	1100	1100	5000	LEO	Atlas IIAS	0	0	1.27725e+08
2001-041A	PROGRESS-DC	CIS	2001/09/14	335	329	6900	LEO	Soyuz U	7200	300	3.57286e+07
2001-042A	EUTELSAT	EUTE	2001/09/25	35804	35767	3149	GEO	Ariane 44P	3465	316	1.13533e+08
2001-043A	STARSHINE 3	US	2001/09/30	799	783	90	LEO	Athena-1	360	177	0
2001-043B	PICOSAT	US	2001/09/30	799	783	67	LEO	Athena-1	0	0	0
2001-043C	PCSAT	US	2001/09/30	797	787	10	LEO	Athena-1	0	0	0
2001-043D	SAPPHIRE	US	2001/09/30	799	786	16	LEO	Athena-1	0	0	0
2001-044A	USA	US	2001/10/05	1050	150	16650	LEO	Titan 404B	21680	5030	4.16834e+08
2001-045A	RADUGA-1	CIS	2001/10/06	36592	36428	2000	GEO	Proton-K/DM-2	2000	0	1.06437e+08
2001-046A	USA	US	2001/10/11	36000	36000	3600	GEO	Atlas IIAS	3630	30	1.27725e+08
2001-047A	QUICKBIRD	US	2001/10/18	429	427	980	LEO	Delta 7320-10	1579	599	6.38623e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2001-048A	SOYUZ-TM	CIS	2001/10/21	397	386	0	LEO	Soyuz U	0	0	3.57286e+07
2001-049A	TES	IND	2001/10/22	591	527	1108	LEO	PSLV	1400	104	1.78643e+07
2001-049B	PROBA-1	ESA	2001/10/22	654	542	94	LEO	PSLV	0	0	0
2001-049C	BIRD	GER	2001/10/22	515	495	94	LEO	PSLV	0	0	0
2001-050A	MOLNIYA	CIS	2001/10/25	40658	646	1900	HEO	Molniya ML	1800	-100	0
2001-051A	PROGRESS-M1	CIS	2001/11/26	392	384	7250	LEO	Soyuz FG	7420	149	3.57286e+07
2001-051C	KOLIBRI-2000	CIS	2001/11/26	175	163	21	LEO	Soyuz FG	0	0	0
2001-052A	DIRECTV	US	2001/11/27	35794	35780	4245	GEO	Ariane 44LP	4030	-215	1.27725e+08
2001-053A	COSMOS 2382	CIS	2001/12/01	19146	9575.8	1415	MEO	Proton-K/DM-2	0	0	1.06437e+08
2001-053B	[GLONASS]	CIS	2001/12/01	19211	9546.09	1370	MEO	Proton-K/DM-2	0	0	0
2001-053C	COSMOS 2380	CIS	2001/12/01	19138	9516.37	1480	MEO	Proton-K/DM-2	0	0	0
2001-054A	STS	US	2001/12/05	377	350	24400	LEO	STS	24400	0	491000000
2001-054B	STARSHINE	US	2001/12/05	136	0	0	LEO	STS	0	0	0
2001-055A	JASON	US	2001/12/07	1333	1319	485	LEO	Delta 7920-X	2984	2014	0
2001-055B	TIMED	US	2001/12/07	612	611	485	LEO	Delta 7920-X	0	0	0
2001-056A	METEOR-3M	CIS	2001/12/10	1014	994	2500	LEO	Zenit 2	5000	2297	4.96707e+07
2001-056B	KOMPASS	CIS	2001/12/10	1013	985	80	LEO	Zenit 2	0	0	0
2001-056C	BADR-B	PAKI	2001/12/10	1014	984	70	LEO	Zenit 2	0	0	0
2001-056D	MAROC-TUBSAT	GER	2001/12/10	1014	985	45	LEO	Zenit 2	0	0	0
2001-056E	REFLECTOR	CIS	2001/12/10	1011	985	8	LEO	Zenit 2	0	0	0
2001-057A	COSMOS 2383	CIS	2001/12/21	155	5088.29	3150	LEO	Tsyklon 2	2820	-330	2.38191e+07
2001-058A	COSMOS2384	CIS	2001/12/28	1430	1417	225	LEO	Tsyklon 3	4100	2750	2.38191e+07
2001-058B	COSMOS2385	CIS	2001/12/28	1425	1417	225	LEO	Tsyklon 3	0	0	0
2001-058C	COSMOS2386	CIS	2001/12/28	1419	1415	225	LEO	Tsyklon 3	0	0	0
2001-058D	GONETS-D1	CIS	2001/12/28	1418	1411	225	LEO	Tsyklon 3	0	0	0
2001-058E	GONETS-D1	CIS	2001/12/28	1417	1417	225	LEO	Tsyklon 3	0	0	0
2001-058F	GONETS-D1	CIS	2001/12/28	1418	1404	225	LEO	Tsyklon 3	0	0	0
2002-001A	USA	US	2002/01/14	35800	35773	4550	GEO	Titan Centaur 401B	9000	4450	4.16834e+08
2002-002A	INSAT-3C	IND	2002/01/23	35809	35764	2750	GEO	Ariane 42L	3590	840	1.13533e+08
2002-003A	TSUBASA	JPN	2002/02/04	18823	222	304	HEO	H-IIA 2024	5000	4626	9.97277e+07
2002-003B	DASH & VEP 3	JPN	2002/02/04	35231	352	70	HEO	H-IIA 2024	0	0	0
2002-004A	RHESSI	US	2002/02/05	543	527	449	LEO	Pegasus XL	443	-6	1.78643e+07
2002-005A	IRIDIUM	US	2002/02/11	778	777	690	LEO	Delta 7920-10L	2984	-466	7.09581e+07
2002-005B	IRIDIUM	US	2002/02/11	752	745	690	LEO	Delta 7920-10L	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2002-005C	IRIDIUM	US	2002/02/11	782	774	690	LEO	Delta 7920-10L	0	0	0
2002-005D	IRIDIUM	US	2002/02/11	779	776	690	LEO	Delta 7920-10L	0	0	0
2002-005E	IRIDIUM	US	2002/02/11	782	774	690	LEO	Delta 7920-10L	0	0	0
2002-006A	ECHOSTAR	US	2002/02/21	35790	35783	690	GEO	Atlas IIIB	4119	3429	7.74121e+07
2002-007A	INTELSAT	ITSO	2002/02/23	35799	35774	4680	GEO	Ariane 44L	4730	50	1.41916e+08
2002-008A	COSMOS 2387	CIS	2002/02/25	297	4540.65	6500	LEO	Soyuz U	7200	700	3.57286e+07
2002-009A	ENVISAT	ESA	2002/03/01	767	765	7911	LEO	Ariane 5G	10000	2089	1.48869e+08
2002-010A	STS	US	2002/03/01	578	350	24400	LEO	STS	24400	0	491000000
2002-011A	TDRS	US	2002/03/08	35837	35737	3192	GEO	Atlas IIA	3039	-153	143766000
2002-012A	GRACE-1	US	2002/03/17	443	423	432	LEO	Rokot	1800	936	1.42915e+07
2002-012B	GRACE-2	US	2002/03/17	443	422	432	LEO	Rokot	0	0	0
2002-013A	PROGRESS-M1	CIS	2002/03/21	398	379	7150	LEO	Soyuz U	7200	50	3.57286e+07
2002-014A	SHENZHOU	PRC	2002/03/25	339	339	0	LEO	Long March 4B	0	0	2.97739e+07
2002-015A	JCSAT-2A	JPN	2002/03/29	35795	35778	1495	GEO	Ariane 44L	4730	1740	1.41916e+08
2002-015B	ASTRA	SES	2002/03/29	36012	35954	1495	GEO	Ariane 44L	0	0	0
2002-016A	INTELSAT	ITSO	2002/03/30	35798	35776	4726	GEO	Proton-K/DM-2M	4350	-376	1.06437e+08
2002-017A	COSMOS 2388	CIS	2002/04/01	314	1802.43	1900	LEO	Molniya 2BL	1800	-100	0
2002-018A	STS	US	2002/04/08	402	350	24400	LEO	STS	24400	0	491000000
2002-019A	NSS-7	SES	2002/04/16	35796	35778	4692	GEO	Ariane 44L	4730	38	1.41916e+08
2002-020A	SOYUZ-TM	CIS	2002/04/25	397	386	0	LEO	Soyuz U	0	0	3.57286e+07
2002-021A	SPOT	FR	2002/05/04	826	824	3000	LEO	Ariane 42P	0	0	9.93413e+07
2002-021B	IDEFIX	FR	2002/05/04	804	787	12	LEO	Ariane 42P	0	0	0
2002-022A	AQUA	US	2002/05/04	703	702	2934	LEO	Delta 7920-10L	2984	50	7.09581e+07
2002-023A	DIRECTV	US	2002/05/07	35802	35771	3640	GEO	Proton-K/DM-2M	5000	1360	1.06437e+08
2002-024A	HAIYANG-1A	PRC	2002/05/15	798	784	360	LEO	Long March 4B	2800	1480	2.97739e+07
2002-024B	FENGYUN	PRC	2002/05/15	872	851	960	LEO	Long March 4B	0	0	0
2002-025A	OFEQ	ISRA	2002/05/28	565	529	300	LEO	Shavit 1	225	-75	0
2002-026A	COSMOS 2389	CIS	2002/05/28	1016	948	825	LEO	Kosmos 3M	775	-50	1.70299e+07
2002-027A	INTELSAT	ITSO	2002/06/05	35798	35776	4723	GEO	Ariane 44L	4730	7	1.41916e+08
2002-028A	STS	US	2002/06/05	387	350	24400	LEO	STS	24400	0	491000000
2002-029A	EXPRESS-A4	CIS	2002/06/10	35807	35767	2600	GEO	Proton-K/DM-2M	4350	1750	1.06437e+08
2002-030A	GALAXY	US	2002/06/15	35788	35786	4850	GEO	Zenit 3SL	5250	400	1.06437e+08
2002-031A	IRIDIUM	US	2002/06/20	778	777	690	LEO	Rokot	1000	-380	1.42915e+07
2002-031B	IRIDIUM	US	2002/06/20	749	748	690	LEO	Rokot	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2002-032A	NOAA	US	2002/06/24	819	801	1475	LEO	Titan 2G	2177	702	70850000
2002-033A	PROGRESS-M	CIS	2002/06/26	398	388.141	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2002-034A	CONTOUR	US	2002/07/03	0	0	1005	Solar	Delta 7425-10	0	0	6.38623e+07
2002-035A	EUTELSAT	EUTE	2002/07/05	197.647	35763	4050	LEO	Ariane 5G	6800	-1300	1.48869e+08
2002-035B	N-STAR	JPN	2002/07/05	35799	35776	4050	GEO	Ariane 5G	0	0	0
2002-036A	COSMOS2390	CIS	2002/07/08	1506	1469	225	LEO	Kosmos 3M	775	325	1.70299e+07
2002-036B	COSMOS2391	CIS	2002/07/08	1505	1467	225	LEO	Kosmos 3M	0	0	0
2002-037A	COSMOS 2392	CIS	2002/07/25	1958	1343	6000	LEO	Proton-K/DM-5	6000	0	0
2002-038A	EUTELSAT	EUTE	2002/08/21	35763	35767	3905	GEO	Atlas IIIB	4500	595	7.74121e+07
2002-039A	ECHOSTAR	US	2002/08/22	35799	35775	4660	GEO	Proton-K/DM-2M	4350	-310	1.06437e+08
2002-040A	EUTELSAT	EUTE	2002/08/28	35770	35770	2700	GEO	Ariane 5G	6800	2090	1.48869e+08
2002-040B	METEOSAT-8	EUME	2002/08/28	35794	35777	2010	GEO	Ariane 5G	0	0	0
2002-041A	INTELSAT	ITSO	2002/09/06	35801	35772	4723	GEO	Ariane 44L	4730	7	1.41916e+08
2002-042A	USERS	JPN	2002/09/10	497	508	1726	LEO	H-IIA 2024	11730	3435.2	9.97277e+07
2002-042B	KODAMA	JPN	2002/09/10	35796	35777	2800	GEO	H-IIA 2024	0	0	0
2002-042H	USERS	JPN	2002/09/10	497	508	0	LEO	H-IIA 2024	0	0	0
2002-043A	KALPANA-1	IND	2002/09/12	35831	35742	1000	GEO	PSLV	800	-200	1.78643e+07
2002-044A	HISPASAT	SPN	2002/09/18	35803	35770	3250	GEO	Atlas IIAS	3630	380	1.27725e+08
2002-045A	PROGRESS-M1	CIS	2002/09/25	391	392	7150	LEO	Soyuz FG	7420	270	3.57286e+07
2002-046A	NADEZHDA	CIS	2002/09/26	1016	964	825	LEO	Kosmos 3M	775	-50	1.70299e+07
2002-047A	STS	US	2002/10/07	405	350	24400	LEO	STS	24400	0	491000000
2002-048A	INTEGRAL	ESA	2002/10/17	156562	6118	4100	HEO	Proton-K/DM-5	0	0	0
2002-049A	JB-3	PRC	2002/10/27	428	425	1500	LEO	Long March 4B	0	0	2.97739e+07
2002-050A	SOYUZ-TM	CIS	2002/10/30	395	392	0	LEO	Soyuz FG	0	0	3.57286e+07
2002-051A	EUTELSAT	EUTE	2002/11/20	35801	35773	3170	GEO	Delta IV Medium+ (4-2)	5300	2130	8.21287e+07
2002-052A	STS	US	2002/11/24	398	350	24400	LEO	STS	24400	0	491000000
2002-052B	MEPSI	US	2002/11/24	51.6	192	2	LEO	STS	0	0	0
2002-053A	ASTRA	LUXE	2002/11/25	352	27185.6	5250	LEO	Proton-K/DM-2M	4350	-900	1.06437e+08
2002-054A	ALSAT 1	ALG	2002/11/28	675	644	88	LEO	Kosmos 3M	775	607	1.70299e+07
2002-054B	MOZHAYETS	CIS	2002/11/28	735	676	80	LEO	Kosmos 3M	0	0	0
2002-055A	TDRS	US	2002/12/05	35827	35747	3190	GEO	Atlas IIA	3039	-151	143766000
2002-056A	MIDORI	JPN	2002/12/14	804	803	3730	LEO	H-IIA 202	4250	347	8.33668e+07
2002-056B	FEDSAT	AUS	2002/12/14	803	792	65	LEO	H-IIA 202	0	0	0
2002-056C	WEOS	JPN	2002/12/14	802	789	58	LEO	H-IIA 202	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2002-056D	MICRO	JPN	2002/12/14	802	787	50	LEO	H-IIA 202	0	0	0
2002-056F	RITE TARGET	JPN	2002/12/14	796	783	0	LEO	H-IIA 202	0	0	0
2002-056G	RITE TARGET	JPN	2002/12/14	796	782	0	LEO	H-IIA 202	0	0	0
2002-057A	NSS-6	SES	2002/12/17	35801	35776	4575	GEO	Ariane 44L	4730	155	1.41916e+08
2002-058A	RUBIN-2	GER	2002/12/20	673	626	45	LEO	Dnepr	3200	3066	1.31005e+07
2002-058B	LATINSAT	ARGN	2002/12/20	690	628	12	LEO	Dnepr	0	0	0
2002-058C	SAUDISAT	SAUD	2002/12/20	675	628	10	LEO	Dnepr	0	0	0
2002-058D	UNISAT	IT	2002/12/20	654	631	10	LEO	Dnepr	0	0	0
2002-058E	TRAILBLAZER	US	2002/12/20	644	631	45	LEO	Dnepr	0	0	0
2002-058H	LATINSAT	ARGN	2002/12/20	644	631	12	LEO	Dnepr	0	0	0
2002-059A	COSMOS	CIS	2002/12/24	40089	149	1900	HEO	Molniya 2BL	1600	-300	0
2002-060A	[GLONASS]	CIS	2002/12/25	19132	9486.66	1370	MEO	Proton-K/DM-2M	0	0	1.06437e+08
2002-060B	[GLONASS]	CIS	2002/12/25	19167	9456.94	1370	MEO	Proton-K/DM-2M	0	0	0
2002-060C	[GLONASS]	CIS	2002/12/25	19147	9427.22	1370	MEO	Proton-K/DM-2M	0	0	0
2002-061A	SHENZHOU	PRC	2002/12/29	331	331	0	LEO	Long March 4B	0	0	2.97739e+07
2002-062A	NIMIQ	CA	2002/12/29	35307	35304	3600	GEO	Proton-K/Briz-M	4500	900	0
2003-001A	CORIOLIS	US	2003/01/06	840	820	828	LEO	Titan 2G	3028	2200	70850000
2003-002A	ICESAT	US	2003/01/13	155	133	1000	LEO	Delta 7320-10	1982	897	6.38623e+07
2003-002B	CHIPSAT	US	2003/01/13	571	556	85	LEO	Delta 7320-10	0	0	0
2003-003A	STS	US	2003/01/16	276	350	24400	LEO	STS	24400	0	491000000
2003-004A	SORCE	US	2003/01/25	633	595	268	LEO	Pegasus XL	268	0	1.78643e+07
2003-005A	NAVSTAR	US	2003/01/29	101.846	19995	2032	LEO	Delta 7925-9.5	1819	-241	7.09581e+07
2003-005B	XSS-10	US	2003/01/29	777	513	28	LEO	Delta 7925-9.5	0	0	0
2003-006A	PROGRESS-M	CIS	2003/02/02	387	19819.9	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2003-007A	INTELSAT	ITSO	2003/02/15	35800	35774	4685	GEO	Ariane 44L	4730	45	1.41916e+08
2003-008A	USA	US	2003/03/11	35800	35774	2733	GEO	Delta IV Medium+ (4-2)	3900	1167	8.21287e+07
2003-009A	IGS	JPN	2009/03/28	495	483	850	LEO	H-IIA 2024	11730	9680	9.97277e+07
2003-009B	IGS	JPN	2003/03/28	500	489	1200	LEO	H-IIA 2024	0	0	0
2003-010A	NAVSTAR	US	2003/03/31	19630	19630	2032	MEO	Delta 7925-9.5	1819	-213	7.09581e+07
2003-011A	MOLNIYA	CIS	2003/04/02	671	1900	1660	LEO	Molniya ML	1600	-60	0
2003-012A	USA	US	2003/04/08	35811	35762	4500	GEO	Titan Centaur 401B	9000	4500	4.16834e+08
2003-013A	INSAT-3A	IND	2003/04/09	35813	35760	2958	GEO	Ariane 5G	6800	2050	1.48869e+08
2003-013B	GALAXY	US	2003/04/09	35794	35760	1792	GEO	Ariane 5G	0	0	0
2003-014A	ASIASAT	AC	2003/04/12	35789	35786	4042	GEO	Atlas IIIB	4119	77	7.74121e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2003-015A	COSMOS	CIS	2003/04/24	35893	35562	2155	GEO	Proton-K/DM-2	2000	-155	1.06437e+08
2003-016A	SOYUZ-TMA	CIS	2003/04/26	382	24730.3	0	LEO	Soyuz FG	0	0	3.57286e+07
2003-017A	GALEX	US	2003/04/28	693	688	280	LEO	Pegasus XL	280	0	1.78643e+07
2003-018A	GSAT-2	IND	2003/05/08	35910	35898	1825	GEO	GSLV	2500	675	4.16834e+07
2003-019A	HAYABUSA	JPN	2003/05/09	0	0	500	Solar	M-V	500	0	6.78844e+07
2003-020A	HELLAS-SAT	GREC	2003/05/13	35804	35771	3440	GEO	Atlas V 401	4950	1510	8.33668e+07
2003-021A	BEIDOU	PRC	2003/05/24	35948	35908	2200	GEO	Long March 3A	2700	500	5.3593e+07
2003-022A	MARS	ESA	2003/06/02	0	0	1120	Mars	Soyuz FG	2100	980	3.57286e+07
2003-023A	COSMOS2398	CIS	2003/06/04	1015	970	820	LEO	Kosmos 3M	775	-45	1.70299e+07
2003-024A	AMC-9	SES	2003/06/06	35798	35776	4100	GEO	Proton-K/Briz-M	4350	250	0
2003-025A	PROGRESS-M1	CIS	2003/06/08	341	23807.7	7150	LEO	Soyuz U	7200	50	3.57286e+07
2003-026A	THURAYA-2	UAE	2003/06/10	35807	35765	5177	GEO	Zenit 3SL	5250	73	1.06437e+08
2003-027A	MARS	US	2003/06/10	0	0	1063	Mars	Delta 7925-9.5	1265	202	7.09581e+07
2003-028A	BSAT-2C	JPN	2003/06/11	36110	36067	1298	GEO	Ariane 5G	6800	777	1.48869e+08
2003-028B	OPTUS	AUS	2003/06/11	35806	35768	4725	GEO	Ariane 5G	0	0	0
2003-029A	MOLNIYA	CIS	2003/06/19	389	22885	1600	LEO	Molniya ML	1600	0	0
2003-030A	ORBVIEW	US	2003/06/26	294	22423.7	304	LEO	Pegasus XL	443	139	1.78643e+07
2003-031B	MIMOSA	CZCH	2003/06/30	146	129	51	LEO	Rokot	1000	877	1.42915e+07
2003-031C	DTUSAT	DEN	2003/06/30	826	814	1	LEO	Rokot	0	0	0
2003-031D	MOST	CA	2003/06/30	831	818	66	LEO	Rokot	0	0	0
2003-031E	CUTE-1	JPN	2003/06/30	827	815	1	LEO	Rokot	0	0	0
2003-031F	QUAKESAT	US	2003/06/30	827	816	1	LEO	Rokot	0	0	0
2003-031G	AAU	DEN	2003/06/30	826	814	1	LEO	Rokot	0	0	0
2003-031H	CANX-1	CA	2003/06/30	827	814	1	LEO	Rokot	0	0	0
2003-031J	CUBESAT	JPN	2003/06/30	828	816	1	LEO	Rokot	0	0	0
2003-032A	MARS	US	2003/07/08	0	0	1063	Mars	Delta 7925-9.5	1265	202	7.09581e+07
2003-033A	ECHOSTAR	US	2003/07/17	35793	35780	4328	GEO	Atlas V 521	6485	2157	8.7995e+07
2003-034A	GALAXY	US	2003/08/08	35809	35764	4737	GEO	Zenit 3SL	5250	513	1.06437e+08
2003-035A	COSMOS 2399	CIS	2003/08/12	247	180	6750	LEO	Soyuz U	7200	450	3.57286e+07
2003-036A	SCISAT	CA	2003/08/13	649	637	260	LEO	Pegasus XL	260	0	1.78643e+07
2003-037A	COSMOS2400	CIS	2003/08/19	1503	1467	225	LEO	Kosmos 3M	450	0	1.70299e+07
2003-037B	COSMOS2401	CIS	2003/08/19	1502	1465	225	LEO	Kosmos 3M	0	0	0
2003-038A	SPITZER	US	2003/08/25	0	0	923	Solar	Delta 7920H	923	0	0
2003-039A	PROGRESS-M	CIS	2003/08/29	374	20578.4	7450	LEO	Soyuz U	7200	-250	3.57286e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2003-040A	USA	US	2003/08/29	35790	35780	1235	GEO	Delta IV Medium	3900	2665	8.21287e+07
2003-041A	USA	US	2003/09/09	35790	35780	5200	GEO	Titan Centaur 401B	9000	3800	4.16834e+08
2003-042A	MOZHAYETS	CIS	2003/09/27	688	669	100	LEO	Kosmos 3M	775	342	1.70299e+07
2003-042C	NIGERIASAT-1	NIG	2003/09/27	667	597	80	LEO	Kosmos 3M	0	0	0
2003-042D	UK-DMC	UK	2003/09/27	686	593	80	LEO	Kosmos 3M	0	0	0
2003-042E	BILSAT	TURK	2003/09/27	690	674	64	LEO	Kosmos 3M	0	0	0
2003-042F	LARETS	CIS	2003/09/27	693	675	64	LEO	Kosmos 3M	0	0	0
2003-042G	STSAT-1	SKOR	2003/09/27	690	672	45	LEO	Kosmos 3M	0	0	0
2003-043A	EUTELSAT	EUTE	2003/09/27	35792	35782	1525	GEO	Ariane 5G	6800	2158.5	1.48869e+08
2003-043C	SMART-1	ESA	2003/09/27	0	0	366.5	Moon	Ariane 5G	0	0	0
2003-043E	INSAT-3E	IND	2003/09/27	35815	35758	2750	GEO	Ariane 5G	0	0	0
2003-044A	GALAXY	US	2003/10/01	35793	128.362	4060	HEO	Zenit 3SL	5250	1190	1.06437e+08
2003-045A	SHENZHOU	PRC	2003/10/15	19655.8	332	0	HEO	Long March 4B	0	0	2.97739e+07
2003-046A	IRS-P6	IND	2003/10/17	822	818	1360	LEO	PSLV	1200	-160	1.78643e+07
2003-047A	SOYUZ-TMA	CIS	2003/10/18	369	18733.2	0	LEO	Soyuz FG	0	0	3.57286e+07
2003-048A	DMSP	US	2003/10/18	853	842	1154	LEO	Titan 2G	0	0	70850000
2003-049A	CBERS	CHBZ	2003/10/21	775	774	1500	LEO	Long March 4B	2800	1200	2.97739e+07
2003-049B	CHUANGXIN	PRC	2003/10/21	748	728	100	LEO	Long March 4B	0	0	0
2003-050A	SERVIS	JPN	2003/10/30	1009	979	840	LEO	Rokot	1000	160	1.42915e+07
2003-051A	FSW-3	PRC	2003/11/03	165	18271.8	3000	LEO	Long March 2D	3500	500	0
2003-052A	ZHONGXING-20	PRC	2003/11/14	35806	35766	2300	GEO	Long March 3A	2700	400	5.3593e+07
2003-053A	YAMAL	CIS	2003/11/24	35799	35776	1360	GEO	Proton-K/DM-2M	4350	1670	1.06437e+08
2003-053B	YAMAL	CIS	2003/11/24	35800	35773	1320	GEO	Proton-K/DM-2M	0	0	0
2003-054A	USA	US	2003/12/02	1210	1010	0	LEO	Atlas IIAS	0	0	1.27725e+08
2003-056A	COSMOS 2401	CIS	2003/12/10	19224	9338.08	1415	MEO	Proton-K/Briz-M	0	0	0
2003-056B	[GLONASS]	CIS	2003/12/10	19218	9308.36	1370	MEO	Proton-K/Briz-M	0	0	0
2003-056C	[GLONASS]	CIS	2003/12/10	19224	9278.64	1370	MEO	Proton-K/Briz-M	0	0	0
2003-057A	UFO	US	2003/12/18	35800	35774	3200	GEO	Atlas IIIB	4119	919	7.74121e+07
2003-058A	NAVSTAR	US	2003/12/21	132.15	19998	2032	LEO	Delta 7925-9.5	0	0	7.09581e+07
2003-059A	AMOS-2	ISRA	2003/12/27	35801	35773	996	GEO	Soyuz FG	3250	2254	3.57286e+07
2003-060A	EXPRESS-AM22	CIS	2003/12/28	35789	35783	2600	GEO	Proton-K/DM-2M	4350	1750	1.06437e+08
2003-061A	DOUBLESTAR	PRC	2003/12/29	11947	17810.5	270	MEO	Long March 2C	0	0	2.38191e+07
2004-001A	ESTRELA	USBZ	2004/01/11	36203	36203	4694	GEO	Zenit 3SL	5250	556	1.06437e+08
2004-002A	PROGRESS-M1	CIS	2004/01/29	363	17349.2	7150	LEO	Soyuz U	7450	300	3.57286e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2004-003A	AMC-10	SES	2004/02/05	35799	35774	2340	GEO	Atlas IIAS	3630	1290	1.27725e+08
2004-004A	USA	US	2004/02/14	36105	35852	2380	GEO	Titan 402B/IUS	5760	3380	4.16834e+08
2004-005A	MOLNIYA	CIS	2004/02/18	39278	1082	1900	HEO	Proton-K/DM-2	0	0	1.06437e+08
2004-006A	ROSETTA	ESA	2004/03/02	0	0	2900	Solar	Ariane 5Gp	0	0	0
2004-007A	MBSAT	JPN	2004/03/13	35793	35779	4143	GEO	Atlas IIIA	4055	-88	1.27725e+08
2004-008A	EUTELSAT	EUTE	2004/03/15	35804	35768	4250	GEO	Proton-M/Briz-M	6920	2670	8.33668e+07
2004-009A	NAVSTAR	US	2004/03/20	20268	20100	2032	MEO	Delta 7925-9.5	1819	-213	7.09581e+07
2004-010A	RADUGA-1	CIS	2004/03/27	35799	35763	2000	GEO	Proton-K/DM-2	2000	0	1.06437e+08
2004-011A	SUPERBIRD-A2	JPN	2004/04/16	36117	35917	3100	GEO	Atlas IIAS	3630	530	1.27725e+08
2004-012A	TANSUO	PRC	2004/04/18	147.302	583	204	LEO	Long March 2C	2200	1971	2.38191e+07
2004-012B	NAXING 1	PRC	2004/04/18	605	590	25	LEO	Long March 2C	0	0	0
2004-013A	SOYUZ-TMA	CIS	2004/04/19	366	16887.9	0	LEO	Soyuz FG	0	0	3.57286e+07
2004-014A	GP-B	US	2004/04/20	640	637	3145	LEO	Delta 7920-10L	3599	454	7.09581e+07
2004-015A	EXPRESS-AM11	CIS	2004/04/26	36106	36052	2542	GEO	Proton-K/DM-2M	4900	2358	1.06437e+08
2004-016A	DIRECTV	US	2004/05/04	35833	35740	5483	GEO	Zenit 3SL	5250	-233	1.06437e+08
2004-017A	AMC-11	SES	2004/05/19	35797	35776	2316	GEO	Atlas IIAS	3630	1314	1.27725e+08
2004-018A	FORMOSAT-2	ROC	2004/05/20	892	890	760	LEO	Taurus 3210	912	152	0
2004-019A	PROGRESS-M	CIS	2004/05/25	367	16426.6	7450	LEO	Soyuz U	0	0	3.57286e+07
2004-020A	COSMOS 2405	CIS	2004/05/28	417	405	3150	LEO	Tsyklon 2	2820	-330	2.38191e+07
2004-021A	COSMOS 2406	CIS	2004/06/10	867	843	3200	LEO	Zenit 2	5000	1800	4.96707e+07
2004-022A	INTELSAT	ITSO	2004/06/16	35790	35783	5575	GEO	Proton-M/Briz-M	6920	1345	8.33668e+07
2004-023A	NAVSTAR	US	2004/06/23	20413	20273	2032	MEO	Delta 7925-9.5	1819	-213	7.09581e+07
2004-024A	APSTAR	PRC	2004/06/29	35797	35777	4640	GEO	Zenit 3SL	5250	610	1.06437e+08
2004-025A	APRIZESAT	US	2004/06/29	850	693	12	LEO	Dnepr	775	543	1.31005e+07
2004-025C	DEMETER	FR	2004/06/29	655	654	125	LEO	Dnepr	0	0	0
2004-025D	SAUDICOMSAT	SAUD	2004/06/29	745	697	12	LEO	Dnepr	0	0	0
2004-025E	SAUDICOMSAT	SAUD	2004/06/29	778	697	12	LEO	Dnepr	0	0	0
2004-025F	SAUDISAT	SAUD	2004/06/29	733	696	35	LEO	Dnepr	0	0	0
2004-025G	APRIZESAT	US	2004/06/29	762	697	12	LEO	Dnepr	0	0	0
2004-025H	UNISAT	IT	2004/06/29	794	695	12	LEO	Dnepr	0	0	0
2004-025K	ECHO	US	2004/06/29	814	695	12	LEO	Dnepr	0	0	0
2004-026A	AURA	US	2004/07/15	704	701	2967	LEO	Delta 7920-10L	2984	17	7.09581e+07
2004-027A	ANIK	CA	2004/07/18	35788	35785	5950	GEO	Ariane 5Gp	6800	850	0
2004-028A	COSMOS2407	CIS	2004/07/22	1006	950	820	LEO	Kosmos 3M	775	-45	1.70299e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2004-029A	DOUBLESTAR	PRC	2004/07/25	37474	230	270	HEO	Long March 2C	0	0	2.38191e+07
2004-030A	MESSENGER	US	2004/08/03	0	0	1100	Mercury	Delta 7925H	0	0	7.09581e+07
2004-031A	AMAZONAS	SPN	2004/08/04	35791	35782	4605	GEO	Proton-M/Briz-M	6920	2315	8.33668e+07
2004-032A	PROGRESS-M	CIS	2004/08/11	357	15503.9	7450	LEO	Soyuz U	0	0	3.57286e+07
2004-033A	FSW-3	PRC	2004/08/29	547	168	2100	LEO	Long March 2C	0	0	2.38191e+07
2004-034A	USA	US	2004/08/31	0	0	3600	Unknown	Atlas IIAS	0	0	1.27725e+08
2004-035A	SJ-6A	PRC	2004/09/08	604	578	2700	LEO	Long March 4B	2800	100	2.97739e+07
2004-035B	SJ-6B	PRC	2004/09/08	597	586	0	LEO	Long March 4B	0	0	0
2004-036A	GSAT-3	IND	2004/09/20	36088	36052	1950	GEO	GSLV	2500	550	4.16834e+07
2004-037A	COSMOS2408	CIS	2004/09/23	1495	1471	225	LEO	Kosmos 3M	450	0	1.70299e+07
2004-037B	COSMOS2409	CIS	2004/09/23	1494	1474	225	LEO	Kosmos 3M	0	0	0
2004-038A	COSMOS 2410	CIS	2005/01/09	348	208	6700	LEO	Soyuz U	6220	-480	3.57286e+07
2004-039A	FSW-3	PRC	2004/09/27	297	205	3000	LEO	Long March 2D	3500	500	0
2004-040A	SOYUZ-TMA	CIS	2004/10/14	360	5605.12	0	LEO	Soyuz U	0	0	3.57286e+07
2004-041A	AMC-15	SES	2004/10/14	35796	35776	4021	GEO	Proton-M/Briz-M	6920	2899	8.33668e+07
2004-042A	FENGYUN	PRC	2004/10/19	35794	35785	1380	GEO	Long March 3A	2700	1320	5.3593e+07
2004-043A	EXPRESS-AM1	CIS	2004/10/29	36113	36066	2542	GEO	Proton-K/DM-2M	0	0	1.06437e+08
2004-044A	JB-3	PRC	2004/11/06	602	552	1500	LEO	Long March 4B	2800	1300	2.97739e+07
2004-045A	NAVSTAR	US	2004/11/06	19810	20413	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2004-046A	TANSUO	PRC	2004/11/18	8357.45	689	300	HEO	Long March 2C	0	0	2.38191e+07
2004-047A	SWIFT	US	2004/11/20	586	568	1331	LEO	Delta 7320-10	4844	3513	6.38623e+07
2004-048A	AMC-16	SES	2004/12/17	35797	35777	4200	GEO	Atlas V 521	6485	2285	8.7995e+07
2004-049A	HELIOS	FR	2004/12/18	690	688	4200	LEO	Ariane 5Gp	10000	5175	0
2004-049B	NANOSAT-1	SPN	2004/12/18	658	653	20	LEO	Ariane 5Gp	0	0	0
2004-049C	ESSAIM-1	FR	2004/12/18	673	663	120	LEO	Ariane 5Gp	0	0	0
2004-049D	ESSAIM-2	FR	2004/12/18	673	663	120	LEO	Ariane 5Gp	0	0	0
2004-049E	ESSAIM-3	FR	2004/12/18	673	663	120	LEO	Ariane 5Gp	0	0	0
2004-049F	ESSAIM-4	FR	2004/12/18	673	663	120	LEO	Ariane 5Gp	0	0	0
2004-049G	PARASOL	FR	2004/12/18	694	691	125	LEO	Ariane 5Gp	0	0	0
2004-051A	PROGRESS-M	CIS	2004/12/23	355	5539.36	7450	LEO	Soyuz U	7150	-300	3.57286e+07
2004-052A	SICH-1M	CIS	2004/12/24	145	137	2263	LEO	Tsiklon-3	4100	1771	0
2004-052C	MK-1TS	CIS	2004/12/24	151	144	66	LEO	Tsiklon-3	0	0	0
2004-053A	[GLONASS]	CIS	2004/12/26	19156	9159.78	1370	MEO	Proton-K/DM-2	0	0	1.06437e+08
2004-053B	COSMOS 2413	CIS	2004/12/26	19143	311.127	1415	HEO	Proton-K/DM-2	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2004-053C	[GLONASS]	CIS	2004/12/26	19138	9130.07	1370	MEO	Proton-K/DM-2	0	0	0
2005-001A	EPOXI	US	2005/01/12	0	0	601	Solar		0	0	0
2005-002A	COSMOS2414	CIS	2005/01/20	967	909	820	LEO	Kosmos 3M	775	-75	1.70299e+07
2005-002C	TATIANA	CIS	2005/01/20	966	911	30	LEO	Kosmos 3M	0	0	0
2005-003A	NSS-10	SES	2005/02/03	35799	35774	5000	GEO	Proton-M/Briz-M	6920	1920	8.33668e+07
2005-004A	USA	US	2005/02/03	1209	1011	5000	LEO	Atlas IIIB	0	0	7.74121e+07
2005-005A	XTAR-EUR	US	2005/02/12	35797	35776	3631	GEO	Ariane 5ECA	10500	6742	1.64257e+08
2005-005C	SLOSHSAT	ESA	2005/02/12	34034	279	127	HEO	Ariane 5ECA	0	0	0
2005-006A	HIMAWARI-6	JPN	2005/02/26	35796	35777	3300	GEO	H-IIA 2022	5250	1950	0
2005-007A	PROGRESS-M	CIS	2005/02/28	353	5342.07	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2005-007C	TNS-0	CIS	2005/02/28	145	132	5	LEO	Soyuz U	0	0	0
2005-008A	XM-3	US	2005/03/01	35789	35786	4703	GEO	Zenit 3SL	5250	547	1.06437e+08
2005-009A	INMARSAT	IM	2005/03/11	35803	35771	5959	GEO	Atlas V 431	7800	1841	103000000
2005-010A	EXPRESS-AM2	CIS	2005/03/29	35789	35785	2600	GEO	Proton-K/DM-2M	0	0	1.06437e+08
2005-011A	XSS-11	US	2005/04/11	596	363	145	LEO	Minotaur 1	310	165	1.70124e+07
2005-012A	APSTAR	PRC	2005/04/12	35794	35779	4680	GEO	Long March 3B	5100	420	5.95477e+07
2005-013A	SOYUZ-TMA	CIS	2005/04/15	349	5210.54	0	LEO	Soyuz U	0	0	3.57286e+07
2005-014A	DART	US	2005/04/15	618	368	360	LEO	Pegasus XL/HAPS	350	-10	0
2005-015A	SPACEWAY	US	2005/04/26	35788	35785	6080	GEO	Zenit 3SL	5250	-830	1.06437e+08
2005-016A	USA	US	2005/04/30	705	481	14500	LEO	Titan 403B	21680	7180	4.16834e+08
2005-017A	IRS-P5	IND	2005/05/05	620	617	1560	LEO	PSLV	1400	-202	1.78643e+07
2005-017B	HAMSAT	IND	2005/05/05	633	599	42	LEO	PSLV	0	0	0
2005-018A	NOAA	US	2005/05/20	863	843	1420	LEO	Delta 7320-10	1982	562	6.38623e+07
2005-019A	DIRECTV	US	2005/05/22	35802	35772	3711	GEO	Proton-M/Briz-M	6920	3209	8.33668e+07
2005-020A	FOTON-M	ESA	2005/05/31	304	262	6535	LEO	Soyuz U	7200	665	3.57286e+07
2005-021A	PROGRESS-M	CIS	2005/06/16	353	5079.01	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2005-022A	GALAXY	ITSO	2005/06/23	35801	173.818	5500	HEO	Zenit 3SL	5450	-50	1.06437e+08
2005-023A	EXPRESS-AM3	CIS	2005/06/24	35793	35783	2600	GEO	Proton-K/DM-2M	0	0	1.06437e+08
2005-024A	SJ-7	PRC	2005/07/05	612	563	0	LEO	Long March 2D	0	0	0
2005-025A	SUZAKU	JPN	2005/07/10	552	544	1680	LEO	M-V	0	0	6.78844e+07
2005-026A	STS	US	2005/07/26	350	350	24400	LEO	STS	24400	0	491000000
2005-027A	FSW-3	PRC	2005/08/02	259	153	3000	LEO	Long March 2C	3500	500	2.38191e+07
2005-028A	THAICOM	THAI	2005/08/11	35797	35777	6486	GEO	Ariane 5GS	6800	314	0
2005-029A	MRO	US	2005/08/12	0	0	2180	Mars	Atlas V 401	0	0	8.33668e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2005-030A	GALAXY	US	2005/08/13	35799	35775	2087	GEO	Soyuz FG	0	0	3.57286e+07
2005-031A	KIRARI	JPN	2005/08/23	595	569	570	LEO	Dnepr	1200	570	1.31005e+07
2005-031B	REIMEI	JPN	2005/08/23	634	592	60	LEO	Dnepr	0	0	0
2005-032A	MONITOR-E	CIS	2005/08/26	502	493	700	LEO	Rokot	1340	640	1.42915e+07
2005-033A	FSW-3	PRC	2005/08/29	130	4881.72	3000	LEO	Long March 2D	0	0	0
2005-034A	COSMOS 2415	CIS	2005/09/02	272	205	6600	LEO	Soyuz U	6200	-400	3.57286e+07
2005-035A	PROGRESS-M	CIS	2005/09/08	353	4750.2	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2005-035C	SUITSAT	CIS	2005/09/08	147	4684.43	0	LEO	none	6920	0	0
2005-036A	ANIK	CA	2005/09/08	35801	35772	4500	GEO	Proton-M/Briz-M	6920	2420	8.33668e+07
2005-037A	STP-R1	US	2005/09/23	318	295	417	LEO	Minotaur 1	437	20	1.70124e+07
2005-038A	NAVSTAR	US	2005/09/26	20187	20006	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2005-039A	SOYUZ-TMA	CIS	2005/10/01	348	4552.91	0	LEO	Soyuz U	0	0	3.57286e+07
2005-040A	SHENZHOU	PRC	2005/10/12	4487.14	331	0	HEO	Long March 4B	0	0	2.97739e+07
2005-041A	GALAXY	ITSO	2005/10/13	35796	35776	2033	GEO	Ariane 5GS	6800	1042	0
2005-041B	SYRACUSE	FR	2005/10/13	35802	35772	3725	GEO	Ariane 5GS	0	0	0
2005-042A	USA	US	2005/10/19	1050	264	20000	LEO	Titan 404B	21680	1680	4.16834e+08
2005-043A	BEIJING	PRC	2005/10/27	703	680	140	LEO	Kosmos 3M	775	220	1.70299e+07
2005-043B	TOPSAT	UK	2005/10/27	705	679	108	LEO	Kosmos 3M	0	0	0
2005-043C	UWE-1	GER	2005/10/27	702	676	1	LEO	Kosmos 3M	0	0	0
2005-043D	SINAH	IRAN	2005/10/27	703	680	160	LEO	Kosmos 3M	0	0	0
2005-043E	SSETI	ESA	2005/10/27	705	679	80	LEO	Kosmos 3M	0	0	0
2005-043F	CUBESAT	JPN	2005/10/27	702	676	1	LEO	Kosmos 3M	0	0	0
2005-043G	MOZHAYETS	GER	2005/10/27	711	681	64	LEO	Kosmos 3M	0	0	0
2005-043H	NCUBE-2	ESA	2005/10/27	701	675	1	LEO	Kosmos 3M	0	0	0
2005-044A	INMARSAT	IM	2005/11/08	35799	35774	5958	GEO	Zenit 3SL	5450	-508	1.06437e+08
2005-045A	VENUS	ESA	2005/11/09	0	0	1270	Venus	Soyuz FG	0	0	3.57286e+07
2005-046A	TELKOM	INDO	2005/11/16	35793	35780	1975	GEO	Ariane 5ECA	10500	2409	1.64257e+08
2005-046B	SPACEWAY	US	2005/11/16	35788	35785	6116	GEO	Ariane 5ECA	0	0	0
2005-047A	PROGRESS-M	CIS	2005/12/21	349	336	7250	LEO	Soyuz U	7200	-50	3.57286e+07
2005-048A	COSMOS2416	CIS	2005/12/21	1448	1436	225	LEO	Kosmos 3M	0	0	1.70299e+07
2005-048B	GONETS-D1M	CIS	2005/12/21	1449	1438	225	LEO	Kosmos 3M	0	0	0
2005-049A	INSAT-4A	IND	2005/12/21	35815	35758	3081	GEO	Ariane 5GS	6800	1685	0
2005-049B	METEOSAT-9	EUME	2005/12/21	35789	35785	2034	GEO	Ariane 5GS	0	0	0
2005-050A	COSMOS 2419	CIS	2005/12/25	19168	19089	1415	MEO	Proton-K/DM-2	0	0	1.06437e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2005-050B	[GLONASS-M]	CIS	2005/12/25	19168	19087	1450	MEO	Proton-K/DM-2	0	0	0
2005-050C	[GLONASS]	CIS	2005/12/25	19170	19094	1370	MEO	Proton-K/DM-2	0	0	0
2005-051A	GIOVE-A	ESA	2005/12/28	23360	23330	600	MEO	Soyuz FG	0	0	3.57286e+07
2005-052A	EUTELSAT	EUTE	2005/12/29	35797	35775	4981	GEO	Proton-M/Briz-M	6920	1939	8.33668e+07
2006-001A	NEW HORIZONS	US	2006/01/19	0	0	478	Pluto	Atlas V 551	0	0	1.08527e+08
2006-002A	ALOS	JPN	2006/01/24	692	691	4000	LEO	H-IIA 2022	4750	750	0
2006-003A	ECHOSTAR	US	2006/02/15	35792	35781	4333	GEO	Zenit 3SL	5450	1117	1.06437e+08
2006-004A	MTSAT-2	JPN	2006/02/18	35800	35774	3000	GEO	H-IIA 2024	5000	2000	9.97277e+07
2006-005A	AKARI	JPN	2006/02/21	664	434	955	LEO	M-V	0	0	6.78844e+07
2006-005C	CUTE-1.7+APD	JPN	2006/02/21	155	4289.85	1	LEO	M-V	0	0	0
2006-006A	ARABSAT-4A	AB	2006/02/28	14684	497	3341	HEO	Proton-M/Briz-M	6920	3579	8.33668e+07
2006-007A	SPAINSAT	SPN	2006/03/11	35811	35762	3683	GEO	Ariane 5ECA	10500	2717	1.64257e+08
2006-007B	EUTELSAT	EUTE	2006/03/11	35809	35765	4100	GEO	Ariane 5ECA	0	0	0
2006-008A	ST5-A	US	2006/03/22	4122	307	22	HEO	Pegasus XL	66	0	1.78643e+07
2006-008B	ST5-B	US	2006/03/22	3661	271	22	HEO	Pegasus XL	0	0	0
2006-008C	ST5-C	US	2006/03/22	3818	280	22	HEO	Pegasus XL	0	0	0
2006-009A	SOYUZ-TMA	CIS	2006/03/30	348	4158.32	0	LEO	Soyuz FG	0	0	3.57286e+07
2006-010A	JCSAT-5A	JPN	2006/04/12	35797	35776	4401	GEO	Zenit 3SL	5450	1049	1.06437e+08
2006-011A	FORMOSAT-3	ROC	2006/04/15	538	496	70	LEO	Minotaur 1	250	-170	1.70124e+07
2006-011B	FORMOSAT-3	ROC	2006/04/15	541	500	70	LEO	Minotaur 1	0	0	0
2006-011C	FORMOSAT-3	ROC	2006/04/15	681	567	70	LEO	Minotaur 1	0	0	0
2006-011D	FORMOSAT-3	ROC	2006/04/15	538	496	70	LEO	Minotaur 1	0	0	0
2006-011E	FORMOSAT-3	ROC	2006/04/15	538	496	70	LEO	Minotaur 1	0	0	0
2006-011F	FORMOSAT-3	ROC	2006/04/15	542	497	70	LEO	Minotaur 1	0	0	0
2006-012A	ASTRA	SES	2006/04/20	35808	35768	4332	GEO	Atlas V 411	6075	1743	8.33668e+07
2006-013A	PROGRESS-M	CIS	2006/04/24	350	350	7450	LEO	Soyuz U	7450	0	3.57286e+07
2006-014A	EROS	ISRA	2006/04/25	522	502	350	LEO	Start-1	350	0	1.07186e+07
2006-015A	RSS-1	PRC	2006/04/26	626	624	2700	LEO	Long March 4B	2800	100	2.97739e+07
2006-016A	CLOUDSAT	US	2006/04/28	703	702	848	LEO	Delta 7420-10	1895	460	6.38623e+07
2006-016B	CALIPSO	US	2006/04/28	704	701	587	LEO	Delta 7420-10	0	0	0
2006-017A	COSMOS 2420	CIS	2006/05/03	349	178	6700	LEO	Soyuz U	6220	-480	3.57286e+07
2006-018A	GOES	US	2006/05/24	35800	35772	3199	GEO	Delta IV Medium+ (4-2)	5300	2101	8.21287e+07
2006-019A	KOMPAS-2	CIS	2006/05/26	492	402	80	LEO	Shtil-1/1N	300	220	0
2006-020A	SATMEX	MEX	2006/05/27	35796	35776	5465	GEO	Ariane 5ECA	10500	2269	1.64257e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2006-020B	THAICOM	THAI	2006/05/27	35802	35772	2766	GEO	Ariane 5ECA	0	0	0
2006-021A	RESURS-DK	CIS	2006/06/15	585	355	7250	LEO	Soyuz U	7200	-50	3.57286e+07
2006-022A	KAZSAT	CIS	2006/06/17	36106	36052	1380	GEO	Proton-K/DM-2M	0	0	1.06437e+08
2006-023A	GALAXY	US	2006/06/18	35800	35773	4640	GEO	Proton-K/DM-2M	0	0	1.06437e+08
2006-024A	USA	US	2006/06/21	35800	35773	225	GEO	Delta 7925-9.5	1819	819	7.09581e+07
2006-024B	USA	US	2006/06/21	35800	35773	225	GEO	Delta 7925-9.5	0	0	0
2006-024C	USA	US	2006/06/21	35800	35773	550	GEO	Delta 7925-9.5	0	0	0
2006-025A	PROGRESS-M	CIS	2006/06/24	357	357	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2006-026A	COSMOS	CIS	2006/06/25	414	384	3150	LEO	Tsyklon 2	2820	-330	2.38191e+07
2006-027A	USA	US	2006/06/28	0	0	4500	HEO	Delta IV Medium+ (4-2)	0	0	8.21287e+07
2006-028A	STS	US	2006/07/04	351	350	24400	LEO	STS	24400	0	491000000
2006-029A	GENESIS	US	2006/07/12	547	536	1360	LEO	Dnepr	2650	1290	1.31005e+07
2006-030A	COSMOS2422	CIS	2006/07/21	38956	1358	1750	HEO	Proton-K/DM-2M	0	0	1.06437e+08
2006-031A	ARIRANG-2	SKOR	2006/07/28	696	676	798	LEO	Rokot	1375	577	1.42915e+07
2006-032A	EUTELSAT	EUTE	2006/08/04	35817	35770	4875	GEO	Proton-M/Briz-M	6920	2045	8.33668e+07
2006-033A	JCSAT-3A	JPN	2006/08/11	35796	35778	4048	GEO	Ariane 5ECA	10500	2702	1.64257e+08
2006-033B	SYRACUSE	FR	2006/08/11	35801	35772	3750	GEO	Ariane 5ECA	0	0	0
2006-034A	KOREASAT	SKOR	2006/08/22	35793	35782	4465	GEO	Zenit 3SL	5450	985	1.06437e+08
2006-035A	SJ-8	PRC	2006/09/09	336	173	3000	LEO	Long March 2C	2500	-500	2.38191e+07
2006-036A	STS	US	2006/09/09	350	350	24400	LEO	STS	24400	0	491000000
2006-037A	IGS	JPN	2006/09/11	490	486	850	LEO	H-IIA 202	5400	4550	8.33668e+07
2006-038A	ZHONGXING-22A	PRC	2006/09/12	35808	35765	2300	GEO	Long March 3A	2600	300	5.3593e+07
2006-039A	COSMOS 2423	CIS	2006/09/14	284	3566.45	6750	LEO	Soyuz U	6220	-530	3.57286e+07
2006-040A	SOYUZ-TMA	CIS	2006/09/18	344	3500.69	0	LEO	Soyuz FG	0	0	3.57286e+07
2006-041A	HINODE	JPN	2006/09/22	696	669	870	LEO	M-V	0	0	6.78844e+07
2006-041F	HIT-SAT	JPN	2006/09/22	145	3434.92	1	LEO	M-V	0	0	0
2006-042A	NAVSTAR	US	2006/09/25	20342	20020	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2006-043A	DIRECTV	US	2006/10/13	35807	35767	8180	GEO	Ariane 5ECA	10500	-30	1.64257e+08
2006-043B	OPTUS	AUS	2006/10/13	35801	35772	2350	GEO	Ariane 5ECA	0	0	0
2006-043C	LDREX-2	JPN	2006/10/13	427	119	0	LEO	Ariane 5ECA	0	0	0
2006-044A	METOP-A	EUME	2006/10/19	822	819	4093	LEO	Soyuz ST	4400	307	0
2006-045A	PROGRESS-M	CIS	2006/10/23	346	3303.4	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2006-046A	SJ-6C	PRC	2006/10/23	592	590	1350	LEO	Long March 4B	2800	100	2.97739e+07
2006-046B	SJ-6D	PRC	2006/10/23	594	593	1350	LEO	Long March 4B	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2006-047A	STEREO	US	2006/10/26	0	0	620	Solar	Delta 7925-10L	1207	-33	7.09581e+07
2006-047B	STEREO	US	2006/10/26	0	0	620	Solar	Delta 7925-10L	0	0	0
2006-048A	SINOSAT	PRC	2006/10/28	38174	37829	5100	GEO	Long March 3B	5100	0	5.95477e+07
2006-049A	XM-4	US	2006/10/30	35787	35786	6100	GEO	Zenit 3SL	5450	-650	1.06437e+08
2006-050A	DMSP	US	2006/11/04	855	839	1154	LEO	Delta IV Medium	7300	6146	8.21287e+07
2006-051A	BADR-4	AB	2006/11/08	35801	35773	3280	GEO	Proton-M/Briz-M	6920	3640	8.33668e+07
2006-052A	NAVSTAR	US	2006/11/17	20367	20206	2032	MEO	Delta 7925-9.5	0	0	7.09581e+07
2006-053A	FENGYUN	PRC	2006/12/08	35789	35784	1400	GEO	Long March 3A	0	0	5.3593e+07
2006-054A	WILDBLUE-1	US	2006/12/08	35792	35781	4735	GEO	Ariane 5ECA	10500	3684	1.64257e+08
2006-054B	AMC-18	SES	2006/12/08	35797	35776	2081	GEO	Ariane 5ECA	0	0	0
2006-055A	STS	US	2006/12/10	339	350	24400	LEO	STS	24400	0	491000000
2006-055B	MEPSI	US	2006/12/10	144	135	3.5	LEO	STS	0	0	0
2006-055C	RAFT	US	2006/12/10	139	129	4	LEO	STS	0	0	0
2006-055D	MARSCOM	US	2006/12/10	148	142	3	LEO	STS	0	0	0
2006-055F	ANDE	US	2006/12/10	137	133	75	LEO	STS	0	0	0
2006-055J	ANDE	US	2006/12/10	136	124	50	LEO	STS	0	0	0
2006-056A	MEASAT-3	MALA	2006/12/11	35796	35778	4900	GEO	Proton-M/Briz-M	6920	2020	8.33668e+07
2006-057A	USA	US	2006/12/14	376	354	0	LEO	Delta 7920-10C	0	0	0
2006-058A	TACSAT-2	US	2006/12/16	163	161	370	LEO	Minotaur 1	591	216	1.70124e+07
2006-058C	GENESAT-1	US	2006/12/16	156	150	5	LEO	Minotaur 1	0	0	0
2006-059A	KIKU-8	JPN	2006/12/18	35812	35763	5817	GEO	H-IIA 204	5400	-417	0
2006-060A	SAR-LUPE	GER	2006/12/19	495	473	770	LEO	Kosmos 3M	775	5	1.70299e+07
2006-061A	MERIDIAN	CIS	2006/12/24	38005	1264	2000	HEO	Soyuz ST	0	0	0
2006-062A	[GLONASS-M]	CIS	2006/12/25	19181	14995.8	1450	MEO	Proton-K/DM-2	0	0	1.06437e+08
2006-062B	[GLONASS-M]	CIS	2006/12/25	19178	14834.5	1450	MEO	Proton-K/DM-2	0	0	0
2006-062C	[GLONASS-M]	CIS	2006/12/25	19176	14673.1	1450	MEO	Proton-K/DM-2	0	0	0
2006-063A	COROT	FR	2006/12/27	903	896	630	LEO	Soyuz-2-1B	4350	3720	0
2007-001A	LAPAN-TUBSAT	INDO	2007/01/10	635	617	56	LEO	PSLV	1400	108	1.78643e+07
2007-001B	CARTOSAT-2	IND	2007/01/10	635	632	680	LEO	PSLV	0	0	0
2007-001C	SRE-1	IND	2007/01/10	643	486	550	LEO	PSLV	0	0	0
2007-001D	PEHUENSAT	ARGN	2007/01/10	608	590	6	LEO	PSLV	0	0	0
2007-002A	PROGRESS-M	CIS	2007/01/18	347	2908.82	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2007-003A	BEIDOU	PRC	2007/02/02	36356	35850	2200	GEO	Long March 3A	2600	400	5.3593e+07
2007-004A	THEMIS	US	2007/02/17	87254	1003	125	HEO	Delta 7925-10C	1143	518	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2007-004B	THEMIS	US	2007/02/17	87114	1004	125	HEO	Delta 7925-10C	0	0	0
2007-004C	THEMIS	US	2007/02/17	87792	736	125	HEO	Delta 7925-10C	0	0	0
2007-004D	THEMIS	US	2007/02/17	66598	909	125	HEO	Delta 7925-10C	0	0	0
2007-004E	THEMIS	US	2007/02/17	67300	892	125	HEO	Delta 7925-10C	0	0	0
2007-005A	IGS	JPN	2007/02/24	496	488	1200	LEO	H-IIA 2024	5250	3200	9.97277e+07
2007-005B	IGS	JPN	2007/02/24	488	484	850	LEO	H-IIA 2024	0	0	0
2007-006A	OE	US	2007/03/09	282	266	1090	LEO	Atlas V 401	9000	7161	8.33668e+07
2007-006B	MIDSTAR-1	US	2007/03/09	478	467	120	LEO	Atlas V 401	0	0	0
2007-006C	OE	US	2007/03/09	507	494	250	LEO	Atlas V 401	0	0	0
2007-006D	STPSAT-1	US	2007/03/09	538	533	170	LEO	Atlas V 401	0	0	0
2007-006E	FALCONSAT-3	US	2007/03/09	533	529	50	LEO	Atlas V 401	0	0	0
2007-006F	CFESAT	US	2007/03/09	536	530	159	LEO	Atlas V 401	0	0	0
2007-007A	INSAT-4B	IND	2007/03/11	35805	35769	3035	GEO	Ariane 5ECA	10500	2830	1.64257e+08
2007-007B	SKYNET	UK	2007/03/11	35801	35772	4635	GEO	Ariane 5ECA	0	0	0
2007-008A	SOYUZ-TMA	CIS	2007/04/07	344	2843.05	0	LEO	Soyuz FG	0	0	3.57286e+07
2007-009A	ANIK	CA	2007/04/09	35793	35779	4634	GEO	Proton-M/Briz-M	6920	2286	8.33668e+07
2007-010A	HAIYANG-1B	PRC	2007/04/11	804	780	360	LEO	Long March 2C	2200	1840	2.38191e+07
2007-011A	BEIDOU	PRC	2007/04/13	22450	22447	2200	MEO	Long March 3A	0	0	5.3593e+07
2007-012A	EGYPTSAT	EGYP	2007/04/17	661	654	100	LEO	Dnepr	800	596	1.31005e+07
2007-012B	SAUDISAT	SAUD	2007/04/17	676	656	35	LEO	Dnepr	0	0	0
2007-012C	SAUDICOMSAT	SAUD	2007/04/17	735	650	12	LEO	Dnepr	0	0	0
2007-012E	SAUDICOMSAT	SAUD	2007/04/17	758	647	12	LEO	Dnepr	0	0	0
2007-012F	CSTB1	US	2007/04/17	761	643	1	LEO	Dnepr	0	0	0
2007-012H	SAUDICOMSAT	SAUD	2007/04/17	723	651	12	LEO	Dnepr	0	0	0
2007-012J	SAUDICOMSAT	SAUD	2007/04/17	712	651	12	LEO	Dnepr	0	0	0
2007-012K	MAST	US	2007/04/17	777	644	3	LEO	Dnepr	0	0	0
2007-012L	SAUDICOMSAT	SAUD	2007/04/17	746	648	12	LEO	Dnepr	0	0	0
2007-012M	LIBERTAD-1	COL	2007/04/17	786	642	1	LEO	Dnepr	0	0	0
2007-012N	POLYSAT	US	2007/04/17	785	642	1	LEO	Dnepr	0	0	0
2007-012P	CAPE1	US	2007/04/17	786	642	1	LEO	Dnepr	0	0	0
2007-012Q	POLYSAT	US	2007/04/17	763	645	1	LEO	Dnepr	0	0	0
2007-012R	AEROCUBE	US	2007/04/17	763	645	1	LEO	Dnepr	0	0	0
2007-013A	AGILE	IT	2007/04/23	528	504	352	LEO	PSLV	3700	3348	1.78643e+07
2007-014A	NFIRE	US	2007/04/24	407	399	494	LEO	Minotaur 1	436	-58	1.70124e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2007-015A	AIM	US	2007/04/25	577	562	197	LEO	Pegasus XL	250	53	1.78643e+07
2007-016A	ASTRA	SES	2007/05/04	35807	35766	4497	GEO	Ariane 5ECA	10500	1903	1.64257e+08
2007-016B	GALAXY	US	2007/05/04	35804	35769	4100	GEO	Ariane 5ECA	0	0	0
2007-017A	PROGRESS-M	CIS	2007/05/12	345	2777.29	7450	LEO	Soyuz U	7200	0	3.57286e+07
2007-018A	NIGCOMSAT	NIG	2007/05/13	35797	35748	5150	GEO	Long March 3B	5100	-50	5.95477e+07
2007-019A	YAOGAN	PRC	2007/05/25	661	631	2700	LEO	Long March 2D	0	0	0
2007-020A	GLOBALSTAR	GLOB	2007/05/29	1415	1412	450	LEO	Soyuz FG	4850	3050	3.57286e+07
2007-020C	GLOBALSTAR	GLOB	2007/05/29	1415	1412	450	LEO	Soyuz FG	0	0	0
2007-020D	GLOBALSTAR	GLOB	2007/05/29	1414	1413	450	LEO	Soyuz FG	0	0	0
2007-020F	GLOBALSTAR	GLOB	2007/05/29	1414	1413	450	LEO	Soyuz FG	0	0	0
2007-021A	EUTELSAT	EUTE	2007/05/31	35801	35775	2200	GEO	Long March 3A	2600	400	5.3593e+07
2007-022A	COSMOS 2427	CIS	2007/06/07	347	167	6700	LEO	Soyuz U	6200	-500	3.57286e+07
2007-023A	COSMO-SKYMED	IT	2007/06/08	624	621	1700	LEO	Delta 7420-10C	1966	266	0
2007-024A	STS	US	2007/06/08	354	350	24400	LEO	STS	24400	0	491000000
2007-025A	OFEQ	ISRA	2007/06/10	580	453	300	LEO	Shavit 1	225	-75	0
2007-026A	TERRASAR-X	GER	2007/06/15	510	507	1346	LEO	Dnepr	1750	404	1.31005e+07
2007-027A	USA	US	2007/06/15	1246	776	1346	LEO	Atlas V 401	9250	7904	8.33668e+07
2007-028A	GENESIS	US	2007/06/28	569	516	1360	LEO	Dnepr	2200	840	1.31005e+07
2007-029A	COSMOS	CIS	2007/06/29	857	846	3200	LEO	Zenit 2SB	0	0	0
2007-030A	SAR-LUPE	GER	2007/07/02	491	478	770	LEO	Kosmos 3M	775	5	1.70299e+07
2007-031A	ZHONGXING-6B	PRC	2007/07/05	35798	35776	4600	GEO	Long March 3B	5100	500	5.95477e+07
2007-032A	DIRECTV	US	2007/07/07	35788	35785	5893	GEO	Proton-M/Briz-M	6920	1027	8.33668e+07
2007-033A	PROGRESS-M	CIS	2007/08/02	335	2580	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2007-034A	PHOENIX	US	2007/08/04	0	0	680	Mars	Delta 7925	0	0	0
2007-035A	STS	US	2007/08/08	348	337	24400	LEO	STS	24400	0	491000000
2007-036A	SPACEWAY	US	2007/08/14	35788	35785	6075	GEO	Ariane 5ECA	10500	2458	1.64257e+08
2007-036B	BSAT-3A	JPN	2007/08/14	35808	35766	1967	GEO	Ariane 5ECA	0	0	0
2007-037A	INSAT-4CR	IND	2007/09/02	35802	35772	2130	GEO	GSLV	2500	370	4.16834e+07
2007-038A	COSMOS2429	CIS	2007/09/11	1010	954	825	LEO	Kosmos 3M	775	-50	1.70299e+07
2007-039A	KAGUYA	JPN	2007/09/14	0	0	2900	Moon	H-IIA 2022	0	0	0
2007-040A	FOTON-M	CIS	2007/09/14	280	258	6500	LEO	Soyuz U	7200	700	3.57286e+07
2007-041A	WORLDVIEW-1	US	2007/09/18	492	492	2500	LEO	Delta 7920-10C	3017	517	0
2007-042A	CBERS	CHBZ	2007/09/19	784	739	1452	LEO	Long March 4B	2800	1348	2.97739e+07
2007-043A	DAWN	US	2007/09/27	0	0	1218	Solar	Delta 7925H	0	0	7.09581e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2007-044A	OPTUS	AUS	2007/10/05	35801	35772	2400	GEO	Ariane 5GS	6200	1400	0
2007-044B	INTELSAT	ITSO	2007/10/05	35802	35773	2400	GEO	Ariane 5GS	0	0	0
2007-045A	SOYUZ-TMA	CIS	2007/10/10	338	336	0	LEO	Soyuz FG	0	0	3.57286e+07
2007-046A	WGS	US	2007/10/11	35001	35001	5990	GEO	Atlas V 421	7000	1010	8.33668e+07
2007-047A	NAVSTAR	US	2007/10/17	20213	20049	2032	MEO	Delta 7925-H	0	0	0
2007-048A	GLOBALSTAR	GLOB	2007/10/20	1414	1413	450	LEO	Soyuz FG	4850	3050	3.57286e+07
2007-048B	GLOBALSTAR	GLOB	2007/10/20	1415	1412	450	LEO	Soyuz FG	0	0	0
2007-048C	GLOBALSTAR	GLOB	2007/10/20	1414	1413	450	LEO	Soyuz FG	0	0	0
2007-048D	GLOBALSTAR	GLOB	2007/10/20	1413	1411	450	LEO	Soyuz FG	0	0	0
2007-049A	COSMOS 2430	CIS	2007/10/23	38581	1767	1900	HEO	Molniya 2BL	0	0	0
2007-050A	STS	US	2007/10/23	339	234	24400	LEO	STS	24400	0	491000000
2007-051A	CHANG'E-1	PRC	2007/10/24	0	0	2300	Moon	Long March 3A	0	0	5.3593e+07
2007-052A	[GLONASS-M]	CIS	2007/10/26	19134	12253	1450	MEO	Proton-K/DM-2	0	0	1.06437e+08
2007-052B	COSMOS 2432	CIS	2007/10/26	19157	12091.6	1415	MEO	Proton-K/DM-2	0	0	0
2007-052C	[GLONASS-M]	CIS	2007/10/26	19168	8773.47	1450	MEO	Proton-K/DM-2	0	0	0
2007-053A	SAR-LUPE	GER	2007/11/01	490	479	770	LEO	Kosmos 3M	775	5	1.70299e+07
2007-054A	USA	US	2007/11/11	36325	35800	2270	GEO	Delta IV Heavy	6750	4480	1.81856e+08
2007-055A	YAOGAN	PRC	2007/11/11	626	624	2700	LEO	Long March 4C	2800	100	0
2007-056A	STAR	BRAZ	2007/11/14	35794	35779	4100	GEO	Ariane 5ECA	10500	1765	1.64257e+08
2007-056B	SKYNET	UK	2007/11/14	35804	35769	4635	GEO	Ariane 5ECA	0	0	0
2007-057A	ASTRA	SES	2007/11/17	35796	35776	4600	GEO	Proton-M/Briz-M	6920	2320	8.33668e+07
2007-058A	RADUGA-1M	CIS	2007/12/09	36041	36028	1900	GEO	Proton-M/Briz-M	3250	1350	8.33668e+07
2007-059A	COSMO-SKYMED	IT	2007/12/09	623	622	1700	LEO	Delta 7420-10	1895	195	6.38623e+07
2007-060A	USA	US	2007/12/10	39705	515	0	HEO	Atlas V 401	0	0	8.33668e+07
2007-061A	RADARSAT-2	CA	2007/12/14	793	791	2200	LEO	Soyuz FG	4450	2250	3.57286e+07
2007-062A	NAVSTAR	US	2007/12/20	20283	20082	2032	MEO	Delta 7925	0	0	0
2007-063A	RASCOM-QAF	RASC	2007/12/21	36168	36088	4579	GEO	Ariane 5GS	6200	-729	0
2007-063B	HORIZONS-2	ITSO	2007/12/21	35798	35775	2350	GEO	Ariane 5GS	0	0	0
2007-064A	PROGRESS-M	CIS	2007/12/23	339	326	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2007-065A	[GLONASS-M]	CIS	2007/12/25	19179	19081	1450	MEO	Proton-M/DM-2	0	0	0
2007-065B	[GLONASS-M]	CIS	2007/12/25	19150	19100	1450	MEO	Proton-M/DM-2	0	0	0
2007-065C	[GLONASS-M]	CIS	2007/12/25	19137	19133	1450	MEO	Proton-M/DM-2	0	0	0
2008-001A	THURAYA-3	UAE	2008/01/15	35809	35765	5173	GEO	Zenit 3SL	5450	277	1.06437e+08
2008-002A	TECSAR	ISRA	2008/01/21	504	397	260	LEO	PSLV C	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2008-003A	EXPRESS-AM33	CIS	2008/01/28	35788	35786	2579	GEO	Proton-M/Briz-M	6920	4341	8.33668e+07
2008-004A	PROGRESS-M	CIS	2008/02/05	339	338	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2008-005A	STS	US	2008/02/07	343	329	24400	LEO	STS	24400	0	491000000
2008-006A	THOR	NOR	2008/02/11	35797	35776	1940	GEO	Proton-M/Briz-M	6920	4980	8.33668e+07
2008-007A	KIZUNA	JPN	2008/02/23	35798	35776	2700	GEO	H-IIA 2024	5000	2300	9.97277e+07
2008-008A	ATV-1	ESA	2008/03/09	338	323	19357	LEO	Ariane 5ES	16000	-3357	1.66734e+08
2008-009A	STS	US	2008/03/11	346	341	24400	LEO	STS	24400	0	491000000
2008-010A	USA	US	2008/03/13	35780	1112	0	HEO	Atlas V 411	0	0	8.33668e+07
2008-011A	AMC-14	US	2008/03/14	35988	35585	4140	GEO	Proton-M/Briz-M	6920	2780	8.33668e+07
2008-012A	NAVSTAR	US	2008/03/15	20223	20142	2032	MEO	Delta 7925	0	0	0
2008-013A	DIRECTV	US	2008/03/19	35787	35787	5920	GEO	Zenit 3SL	5450	-470	1.06437e+08
2008-014A	SAR-LUPE	GER	2008/03/27	496	472	730	LEO	Kosmos 3M	775	45	1.70299e+07
2008-015A	SOYUZ-TMA	CIS	2008/04/08	354	350	0	LEO	Soyuz FG	0	0	3.57286e+07
2008-016A	ICO	US	2008/04/14	35802	35772	6600	GEO	Atlas V 421	6890	290	8.33668e+07
2008-017A	C/NOFS	US	2008/04/16	695	389	395	LEO	Pegasus XL	275	-120	1.78643e+07
2008-018A	VINASAT-1	VTNM	2008/04/18	35796	35778	6740	GEO	Ariane 5ECA	10500	-340	1.64257e+08
2008-018B	STAR	BRAZ	2008/04/18	35796	35779	4100	GEO	Ariane 5ECA	0	0	0
2008-019A	TIANLIAN	PRC	2008/04/25	35933	35640	3000	GEO	Long March 3C	3800	800	5.3593e+07
2008-020A	GIOVE-B	ESA	2008/04/27	23830	23818	530	MEO	Soyuz FG	1645	1115	3.57286e+07
2008-021A	CARTOSAT-2A	IND	2008/04/28	643	624	768	LEO	PSLV	1350	509.5	1.78643e+07
2008-021B	NTS	CA	2008/04/28	629	609	6.5	LEO	PSLV	0	0	0
2008-021C	CUTE-1.7+APD	JPN	2008/04/28	625	607	1	LEO	PSLV	0	0	0
2008-021D	IMS-1	IND	2008/04/28	634	618	60	LEO	PSLV	0	0	0
2008-021E	COMPASS-1	GER	2008/04/28	620	601	1	LEO	PSLV	0	0	0
2008-021F	AAUSAT-II	DEN	2008/04/28	618	600	1	LEO	PSLV	0	0	0
2008-021G	DELFI-C3	NETH	2008/04/28	608	591	1	LEO	PSLV	0	0	0
2008-021H	CANX-2	CA	2008/04/28	626	607	1	LEO	PSLV	0	0	0
2008-021J	SEEDS	JPN	2008/04/28	623	604	1	LEO	PSLV	0	0	0
2008-022A	AMOS-3	ISRA	2008/04/28	35796	35777	996	GEO	Zenit 3SLB	3750	2754	1.06437e+08
2008-023A	PROGRESS-M	CIS	2008/05/14	362	340	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2008-024A	GALAXY	US	2008/05/21	35798	35775	4642	GEO	Zenit 3SL	5450	808	1.06437e+08
2008-025A	YUBILEINY	CIS	2008/05/23	1508	1480	225	LEO	Rokot	1025	125	1.42915e+07
2008-025B	COSMOS2437	CIS	2008/05/23	1511	1480	225	LEO	Rokot	0	0	0
2008-025C	COSMOS2438	CIS	2008/05/23	1508	1477	225	LEO	Rokot	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2008-025D	COSMOS2439	CIS	2008/05/23	1510	1479	225	LEO	Rokot	0	0	0
2008-026A	FENGYUN	PRC	2008/05/27	834	821	0	LEO	Long March 4C	0	0	0
2008-027A	STS	US	2008/05/31	351	338	24400	LEO	STS	24400	0	491000000
2008-028A	CHINASAT	PRC	2008/06/09	35804	35770	0	GEO	Long March 3B	0	0	5.95477e+07
2008-029A	FGRST	US	2008/06/11	554	535	4303	LEO	Delta 7920H	5899	1596	0
2008-030A	SKYNET	UK	2008/06/12	35802	35771	4635	GEO	Ariane 5ECA	10500	2765	1.64257e+08
2008-030B	TURKSAT	TURK	2008/06/12	35807	35765	3100	GEO	Ariane 5ECA	0	0	0
2008-031A	ORBCOMM	ORB	2008/06/19	664	654	45	LEO	Kosmos 3M	775	505	1.70299e+07
2008-031B	ORBCOMM	ORB	2008/06/19	664	655	45	LEO	Kosmos 3M	0	0	0
2008-031C	ORBCOMM	ORB	2008/06/19	666	654	45	LEO	Kosmos 3M	0	0	0
2008-031D	ORBCOMM	ORB	2008/06/19	668	654	45	LEO	Kosmos 3M	0	0	0
2008-031E	ORBCOMM	ORB	2008/06/19	666	655	45	LEO	Kosmos 3M	0	0	0
2008-031F	ORBCOMM	ORB	2008/06/19	667	654	45	LEO	Kosmos 3M	0	0	0
2008-032A	JASON	FR	2008/06/20	1344	1332	485	LEO	Delta 7320-10	2703	2218	6.38623e+07
2008-033A	COSMOS	CIS	2008/06/27	35800	35768	2154	GEO	Proton-K/DM-2M	1880	-274	1.06437e+08
2008-034A	INTELSAT	ITSO	2008/07/07	35799	35775	4100	GEO	Ariane 5ECA	10500	3000	1.64257e+08
2008-034B	BADR-6	AB	2008/07/07	35793	35779	3400	GEO	Ariane 5ECA	0	0	0
2008-035A	ECHOSTAR	US	2008/07/16	35798	35775	5511	GEO	Zenit 3SL	5450	-61	1.06437e+08
2008-036A	SAR-LUPE	GER	2008/07/22	496	473	770	LEO	Kosmos 3M	775	5	1.70299e+07
2008-037A	COSMOS	CIS	2008/07/26	732	711	6700	LEO	Soyuz 2-1B	6600	-100	0
2008-038A	SUPERBIRD-C2	JPN	2008/08/14	35789	35785	5000	GEO	Ariane 5ECA	10500	3000	1.64257e+08
2008-038B	AMC-21	SES	2008/08/14	35798	35775	2500	GEO	Ariane 5ECA	0	0	0
2008-039A	INMARSAT	IM	2008/08/18	35799	35775	4960	GEO	Proton-M/Briz-M	6920	1960	8.33668e+07
2008-040A	RAPIDEYE	GER	2008/08/29	639	620	152	LEO	Dnepr	1100	340	1.31005e+07
2008-040B	RAPIDEYE	GER	2008/08/29	641	618	152	LEO	Dnepr	0	0	0
2008-040C	RAPIDEYE	GER	2008/08/29	648	611	152	LEO	Dnepr	0	0	0
2008-040D	RAPIDEYE	GER	2008/08/29	638	621	152	LEO	Dnepr	0	0	0
2008-040E	RAPIDEYE	GER	2008/08/29	637	622	152	LEO	Dnepr	0	0	0
2008-041A	HUANJING	PRC	2008/09/06	665	626	700	LEO	Long March 2C	0	0	2.38191e+07
2008-041B	HUANJING	PRC	2008/09/06	672	618	700	LEO	Long March 2C	0	0	0
2008-042A	GEOEYE	US	2008/09/06	686	671	1923	LEO	Delta 7420-10	1895	-28	6.38623e+07
2008-043A	PROGRESS-M	CIS	2008/09/10	364	351	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2008-044A	NIMIQ	CA	2008/09/19	35798	35777	4800	GEO	Proton-M/Briz-M	6920	2120	8.33668e+07
2008-045A	GALAXY	US	2008/09/24	35800	35774	4690	GEO	Zenit 3SL	5450	760	1.06437e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2008-046A	[GLONASS-M]	CIS	2008/09/25	19185	10155.5	1450	MEO	Proton-M/DM-2	0	0	0
2008-046B	[GLONASS-M]	CIS	2008/09/25	19182	9994.21	1450	MEO	Proton-M/DM-2	0	0	0
2008-046C	[GLONASS-M]	CIS	2008/09/25	19187	293.389	1450	HEO	Proton-M/DM-2	0	0	0
2008-047A	SHENZHOU	PRC	2008/09/25	301.791	329	0	LEO	Long March 2F	0	0	0
2008-047G	BX-1	PRC	2008/09/25	148	144	40	LEO	Long March 2F	0	0	0
2008-049A	THEOS	THAI	2008/10/01	826	824	715	LEO	Dnepr	350	-365	1.31005e+07
2008-050A	SOYUZ-TMA	CIS	2008/10/12	358	345	0	LEO	Soyuz FG	0	0	3.57286e+07
2008-051A	IBEX	US	2008/10/19	298742	81392	107	GEO	Pegasus XL	0	0	1.78643e+07
2008-052A	CHANDRAYAAN-1	IND	2008/10/22	0	0	1380	Moon	PSLV	0	0	1.78643e+07
2008-053A	SJ-6E	PRC	2008/10/25	606	579	300	LEO	Long March 4B	2800	2200	2.97739e+07
2008-053B	SJ-6F	PRC	2008/10/25	602	577	300	LEO	Long March 4B	0	0	0
2008-054A	COSMO-SKYMED	IT	2008/10/25	623	622	1700	LEO	Delta 7420-10	1966	266	6.38623e+07
2008-055A	VENESAT-1	VENZ	2008/10/29	35795	35778	5100	GEO	Long March 3B	5100	0	5.95477e+07
2008-056A	SHIYAN	PRC	2008/11/05	805	785	0	LEO	Long March 2D	0	0	0
2008-056B	CHUANGXIN	PRC	2008/11/05	806	784	0	LEO	Long March 2C	0	0	2.38191e+07
2008-057A	ASTRA	SES	2008/11/05	35808	35764	5344	GEO	Proton-M/Briz-M	6920	1576	8.33668e+07
2008-058A	COSMOS	CIS	2008/11/14	277	188	6600	LEO	Soyuz U	6200	-400	3.57286e+07
2008-059A	STS	US	2008/11/15	352	344	24400	LEO	STS	24400	0	491000000
2008-059B	PSSC	US	2008/11/15	150	146	4	LEO	STS	0	0	0
2008-060A	PROGRESS-M	CIS	2008/11/26	357	259	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2008-061A	YAOGAN	PRC	2008/12/01	657	634	0	LEO	Long March 2D	0	0	0
2008-062A	COSMOS2446	CIS	2008/12/02	38772	1592	1900	HEO	Molniya 2BL	0	0	0
2008-063A	CIEL-2	CA	2008/12/10	35797	35776	5600	GEO	Proton-M/Briz-M	6920	1320	8.33668e+07
2008-064A	YAOGAN	PRC	2008/12/15	421	410	2200	LEO	Long March 4B	2800	600	2.97739e+07
2008-065A	EUTELSAT	EUTE	2008/12/20	35798	35764	4880	GEO	Ariane 5ECA	10500	2160	1.64257e+08
2008-065B	EUTELSAT	EUTE	2008/12/20	35798	35773	3460	GEO	Ariane 5ECA	0	0	0
2008-066A	FENGYUN	PRC	2008/12/23	35796	35781	593	GEO	Long March 3A	2600	2007	5.3593e+07
2008-067A	COSMOS 2447	CIS	2008/12/25	19143	292.455	1415	HEO	Proton-M/DM-2	0	0	0
2008-067B	[GLONASS-M]	CIS	2008/12/25	19187	9026.16	1450	MEO	Proton-M/DM-2	0	0	0
2008-067C	[GLONASS-M]	CIS	2008/12/25	19145	8864.82	1450	MEO	Proton-M/DM-2	0	0	0
2009-001A	USA	US	2009/01/18	38077	35943	0	GEO	Delta IV Heavy	14220	0	1.81856e+08
2009-002A	GOSAT	JPN	2009/01/23	670	668	1750	LEO	H-IIA 202	4900	2909	8.33668e+07
2009-002B	PRISM	JPN	2009/01/23	621	595	5	LEO	H-IIA 202	0	0	0
2009-002C	SPRITE-SAT	JPN	2009/01/23	663	660	100	LEO	H-IIA 202	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2009-002D	KAGAYAKI	JPN	2009/01/23	663	653	50	LEO	H-IIA 202	0	0	0
2009-002E	SOHLA-1	JPN	2009/01/23	664	656	50	LEO	H-IIA 202	0	0	0
2009-002F	SDS-1	JPN	2009/01/23	667	663	28	LEO	H-IIA 202	0	0	0
2009-002G	STARS	JPN	2009/01/23	656	640	5	LEO	H-IIA 202	0	0	0
2009-002H	KKS-1	JPN	2009/01/23	659	647	3	LEO	H-IIA 202	0	0	0
2009-003A	KORONAS-FOTON	CIS	2009/01/30	555	523	1900	LEO	Tsyklon 2	0	0	2.38191e+07
2009-004A	OMID	IRAN	2009/02/02	155	140	25	LEO	Safir-2	25	0	0
2009-005A	NOAA	US	2009/02/06	865	843	1420	LEO	Delta 7320-10C	1579	159	0
2009-006A	PROGRESS-M	CIS	2009/02/10	357	342	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2009-007A	EXPRESS-AM44	CIS	2009/02/11	35790	35783	3672	GEO	Proton-M/Briz-M	6920	2108	8.33668e+07
2009-007B	EXPRESS-MD1	CIS	2009/02/11	36135	36095	1140	GEO	Proton-M/Briz-M	0	0	0
2009-008A	NSS-9	SES	2009/02/12	35796	35777	2400	GEO	Ariane 5ECA	10500	2991	1.64257e+08
2009-008B	EUTELSAT	EUTE	2009/02/12	35796	35773	4875	GEO	Ariane 5ECA	0	0	0
2009-008C	SPIRALE	FR	2009/02/12	18159	226	117	HEO	Ariane 5ECA	0	0	0
2009-008D	SPIRALE	FR	2009/02/12	33042	257	117	HEO	Ariane 5ECA	0	0	0
2009-009A	TELSTAR	CA	2009/02/26	35803	35772	4012	GEO	Zenit 3SLB	5000	988	1.06437e+08
2009-010A	RADUGA-1	CIS	2009/02/28	35792	35788	2300	GEO	Proton-K/DM-2	1880	-420	1.06437e+08
2009-011A	KEPLER	US	2009/03/07	0	0	1050	Solar	Delta 7920-10L	0	0	7.09581e+07
2009-012A	STS	US	2009/03/15	353	335	24400	LEO	STS	24400	0	491000000
2009-013A	GOCE	ESA	2009/03/17	232	223	1100	LEO	Rokot	1600	500	1.42915e+07
2009-014A	NAVSTAR	US	2009/03/24	8654.61	20019	2032	MEO	Delta 7925	0	0	0
2009-015A	SOYUZ-TMA	CIS	2009/03/26	351	340	0	LEO	Soyuz FG	0	0	3.57286e+07
2009-016A	EUTELSAT	EUTE	2009/04/03	35807	35766	5900	GEO	Proton-M/Briz-M	6920	0	8.33668e+07
2009-017A	WGS	US	2009/04/04	35452	35784	0	GEO	Atlas V 421	0	0	8.33668e+07
2009-018A	BEIDOU	PRC	2009/04/14	36028	35511	3100	GEO	Long March 3C	3800	700	5.3593e+07
2009-019A	RISAT	IND	2009/04/20	438	418	340	LEO	PSLV CA	3700	3320	0
2009-019B	ANUSAT	IND	2009/04/20	182	176	40	LEO	PSLV CA	0	0	0
2009-020A	SICRAL	IT	2009/04/20	35808	35762	3038	GEO	Zenit 3SL	5450	2412	1.06437e+08
2009-021A	YAOGAN	PRC	2009/04/22	514	513	0	LEO	Long March 2C	0	0	2.38191e+07
2009-022A	COSMOS 2450	CIS	2009/04/29	282	180	6700	LEO	Soyuz U	6200	-500	3.57286e+07
2009-023A	STSS	US	2009/05/05	892	792	2000	LEO	Delta 7920-10	0	0	7.09581e+07
2009-024A	PROGRESS-M	CIS	2009/05/07	348	337	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2009-025A	STS	US	2009/05/11	566	302	24400	LEO	STS	24400	0	491000000
2009-026A	HERSCHEL	ESA	2009/05/14	0	0	3300	Solar	Ariane 5ECA	0	0	1.64257e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2009-026B	PLANCK	ESA	2009/05/14	0	0	1900	Solar	Ariane 5ECA	0	0	0
2009-027A	SES-7	SES	2009/05/16	35799	35781	4000	GEO	Proton-M/Briz-M	6920	2920	8.33668e+07
2009-028A	TACSAT	US	2009/05/19	157	147	400	LEO	Minotaur 1	650	246	1.70124e+07
2009-028B	PHARMASAT	US	2009/05/19	176	160	1	LEO	Minotaur 1	0	0	0
2009-028C	POLYSAT	US	2009/05/19	176	169	1	LEO	Minotaur 1	0	0	0
2009-028D	HAWKSAT	US	2009/05/19	165	161	1	LEO	Minotaur 1	0	0	0
2009-028E	AEROCUBE	US	2009/05/19	185	151	1	LEO	Minotaur 1	0	0	0
2009-029A	MERIDIAN	CIS	2009/05/21	35523	999	2000	HEO	Soyuz 2	0	0	0
2009-030A	SOYUZ-TMA	CIS	2009/05/27	349	333	0	LEO	Soyuz FG	0	0	3.57286e+07
2009-031A	LRO	US	2009/06/18	0	0	1846	Moon	Atlas V 401	0	0	8.33668e+07
2009-032A	MEASAT-3A	MALA	2009/06/21	35800	35774	2370	GEO	Zenit 3SLB	3750	1380	1.06437e+08
2009-033A	GOES	US	2009/06/27	35824	35749	3210	GEO	Delta IV Medium+ (4-2)	6390	3180	8.21287e+07
2009-034A	SIRIUS	US	2009/06/30	35795	35779	5976	GEO	Proton-M/Briz-M	6920	944	8.33668e+07
2009-035A	TERRESTAR-1	US	2009/07/01	35799	35774	6910	GEO	Ariane 5ECA	10500	3590	1.64257e+08
2009-036A	COSMOS 2451	CIS	2009/07/06	1508	1498	225	LEO	Rokot	1375	700	1.42915e+07
2009-036B	COSMOS2452	CIS	2009/07/06	1507	1482	225	LEO	Rokot	0	0	0
2009-036C	COSMOS 2453	CIS	2009/07/06	1506	1495	225	LEO	Rokot	0	0	0
2009-037A	RAZAKSAT	MALA	2009/07/14	687	663	180	LEO	Falcon 1	325	145	7.14573e+06
2009-038A	STS	US	2009/07/15	336	328	24400	LEO	STS	24400	0	491000000
2009-038B	DRAGONSAT	US	2009/07/15	163	157	3	LEO	STS	0	0	0
2009-038E	ANDE	US	2009/07/15	137	129	50	LEO	STS	0	0	0
2009-038F	ANDE	US	2009/07/15	145	140	25	LEO	STS	0	0	0
2009-039A	COSMOS2454	CIS	2009/07/21	944	916	825	LEO	Proton-K/DM-2	1880	245	1.06437e+08
2009-039B	STERKH	CIS	2009/07/21	945	915	810	LEO	Proton-K/DM-2	0	0	0
2009-040A	PROGRESS-M	CIS	2009/07/24	350	335	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2009-041A	DEIMOS-1	SPN	2009/07/29	662	660	90	LEO	Dnepr	1200	779	1.31005e+07
2009-041B	DUBAISAT	UAE	2009/07/29	680	661	190	LEO	Dnepr	0	0	0
2009-041C	UK-DMC	UK	2009/07/29	662	660	95	LEO	Dnepr	0	0	0
2009-041D	APRIZESAT	US	2009/07/29	673	603	12	LEO	Dnepr	0	0	0
2009-041E	NANOSAT	SPN	2009/07/29	671	581	22	LEO	Dnepr	0	0	0
2009-041F	APRIZESAT	US	2009/07/29	670	561	12	LEO	Dnepr	0	0	0
2009-042A	ASIASAT	AC	2009/08/11	35793	35781	3760	GEO	Atlas V 411	5566	1806	8.33668e+07
2009-043A	NAVSTAR	US	2009/08/17	20228	20095	2032	MEO	Delta 7925	0	0	0
2009-044A	JCSAT-RA	JPN	2009/08/21	35792	35782	4000	GEO	Ariane 5ECA	10500	4000	1.64257e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2009-044B	OPTUS	AUS	2009/08/21	35797	35776	2500	GEO	Ariane 5ECA	0	0	0
2009-045A	STS	US	2009/08/29	352	310	24400	LEO	STS	24400	0	491000000
2009-046A	PALAPA	INDO	2009/08/31	35796	35778	4100	GEO	Long March 3B	5100	1000	5.95477e+07
2009-047A	USA	US	2009/09/08	35796	35778	0	GEO		0	0	0
2009-048A	HTV-1	JPN	2009/09/10	342	334	16000	LEO	H-IIB	16000	0	180000000
2009-049A	METEOR-M	CIS	2009/09/17	821	817	2700	LEO	Soyuz-2	4500	-1121	0
2009-049B	STERKH	CIS	2009/09/17	820	814	2700	LEO	Soyuz-2	0	0	0
2009-049D	TATIANA	CIS	2009/09/17	821	814	98	LEO	Soyuz-2	0	0	0
2009-049E	UGATUSAT	CIS	2009/09/17	822	814	35	LEO	Soyuz-2	0	0	0
2009-049F	SUMBANDILA	SAFR	2009/09/17	481	481	81	LEO	Soyuz-2	0	0	0
2009-049G	BLITS	CIS	2009/09/17	823	817	7	LEO	Soyuz-2	0	0	0
2009-050A	NIMIQ	CA	2009/09/17	35798	35775	4745	GEO	Proton-M/Briz-M	6920	2175	8.33668e+07
2009-051A	OCEANSAT	IND	2009/09/23	724	721	1000	LEO	PSLV CA	1100	96	0
2009-051B	SWISSCUBE	SWTZ	2009/09/23	720	707	1	LEO	PSLV CA	0	0	0
2009-051C	BEESAT	GER	2009/09/23	717	707	1	LEO	PSLV CA	0	0	0
2009-051D	UWE-2	GER	2009/09/23	718	707	1	LEO	PSLV CA	0	0	0
2009-051E	ITUPSAT	TURK	2009/09/23	721	708	1	LEO	PSLV CA	0	0	0
2009-051F	RUBIN	GER	2009/09/23	794	714	0	LEO	PSLV CA	0	0	0
2009-052A	STSS	US	2009/09/25	1350	1348	1122	LEO	Delta 7920-10	3600	1356	7.09581e+07
2009-052B	STSS	US	2009/09/25	1350	1348	1122	LEO	Delta 7920-10	0	0	0
2009-053A	SOYUZ-TMA	CIS	2009/09/30	352	342	0	LEO	Soyuz FG	0	0	3.57286e+07
2009-054A	AMAZONAS	SPN	2009/10/01	35807	35766	5500	GEO	Ariane 5ECA	10500	2560	1.64257e+08
2009-054B	COMSATBW-1	GER	2009/10/01	35797	35777	2440	GEO	Ariane 5ECA	0	0	0
2009-055A	WORLDVIEW-2	US	2009/10/08	767	765	2615	LEO	Delta 7920-10	3017	402	7.09581e+07
2009-056A	PROGRESS-M	CIS	2009/10/15	348	314	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2009-057A	DMSP	US	2009/10/18	857	842	1200	LEO	Atlas V 401	7000	5800	8.33668e+07
2009-058A	NSS-12	SES	2009/10/29	35797	35775	5620	GEO	Ariane 5ECA	10500	1830	1.64257e+08
2009-058B	THOR	NOR	2009/10/29	35793	35779	3050	GEO	Ariane 5ECA	0	0	0
2009-059A	SMOS	ESA	2009/11/02	760	759	0	LEO	Rokot	1375	0	1.42915e+07
2009-059B	PROBA-2	ESA	2009/11/02	728	708	130	LEO	Rokot	0	0	0
2009-060A	POISK	ISS	2009/11/10	400	387	7250	LEO	Soyuz U	7200	-50	3.57286e+07
2009-061A	SJ-11-01	PRC	2009/11/12	702	685	0	LEO	Long March 2C	0	0	2.38191e+07
2009-062A	STS	US	2009/11/16	348	336	24400	LEO	STS	24400	0	491000000
2009-063A	COSMOS 2455	CIS	2009/11/20	908	903	7250	LEO	Soyuz U	7250	0	3.57286e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2009-064A	INTELSAT	ITSO	2009/11/23	35798	35777	5663	GEO	Atlas V 431	7092	1429	103000000
2009-065A	EUTELSAT	EUTE	2009/11/24	35804	35769	5627	GEO	Proton-M/Briz-M	6920	1293	8.33668e+07
2009-066A	IGS	JPN	2009/11/28	0	0	0	error	H-IIA 202	0	0	8.33668e+07
2009-067A	INTELSAT	ITSO		35796	35796	2484	GEO	Zenit 3SLB	3750	1266	1.06437e+08
2009-068A	WGS	US	2009/12/06	64827	31268	5990	error	Delta IV Medium+ (5-4)	0	0	8.21287e+07
2009-069A	YAOGAN	PRC	2009/12/09	666	629	0	LEO	Long March 2D	0	0	0
2009-070A	[GLONASS-M]	CIS	2009/12/14	19145	6606.03	1450	MEO	Proton-M/DM-2	0	0	0
2009-070B	[GLONASS-M]	CIS	2009/12/14	19146	6444.69	1450	MEO	Proton-M/DM-2	0	0	0
2009-070C	[GLONASS-M]	CIS	2009/12/14	19134	6283.35	1450	MEO	Proton-M/DM-2	0	0	0
2009-071A	WISE	US	2009/12/14	514	510	674	LEO	Delta 7320-10	1651	977	6.38623e+07
2009-072A	YAOGAN	PRC	2009/12/15	1205	1192	1040	LEO	Long March 4C	2800	1710	0
2009-072B	XIWANG-1	PRC	2009/12/15	1205	1193	50	LEO	Long March 4C	0	0	0
2009-073A	HELIOS	FR	2009/12/18	680	680	4200	LEO	Ariane 5GS	6200	2000	0
2009-074A	SOYUZ-TMA	CIS	2009/12/20	350	338	0	LEO	Soyuz FG	0	0	3.57286e+07
2009-075A	DIRECTV	US	2009/12/29	35788	35786	5900	GEO	Proton-M/Briz-M	6920	1020	8.33668e+07
2010-001A	BEIDOU	PRC	2010/01/16	35806	35768	0	GEO	Long March 3C	0	0	5.3593e+07
2010-002A	RADUGA-1M	CIS	2010/01/28	35798	35776	2500	GEO	Proton-M/Briz-M	3250	750	8.33668e+07
2010-003A	PROGRESS-M	CIS	2010/02/03	353	346	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2010-004A	STS	US	2010/02/08	348	334	24400	LEO	STS	24400	0	491000000
2010-005A	SDO	US	2010/02/11	35788	35784	3000	GEO	Atlas V 401	5950	2950	8.33668e+07
2010-006A	INTELSAT	ITSO	2010/02/12	35825	35816	2060	GEO	Proton-M/Briz-M	3250	1190	8.33668e+07
2010-007A	[GLONASS-M]	CIS	2010/03/01	19204	19043	1450	MEO	Proton-M/DM-2	0	0	0
2010-007B	COSMOS 2461	CIS	2010/03/01	19149	19123	1415	MEO	Proton-M/DM-2	0	0	0
2010-007C	[GLONASS-M]	CIS	2010/03/01	19136	19124	1450	MEO	Proton-M/DM-2	0	0	0
2010-008A	GOES	US	2010/03/04	35798	35768	3240	GEO	Delta IV Medium+ (4-2)	6390	3150	8.21287e+07
2010-009A	YAOGAN	PRC	2010/03/05	1185	996	933	LEO	Long March 4C	2800	1	0
2010-009B	YAOGAN	PRC	2010/03/05	1185	996	933	LEO	Long March 4C	0	0	0
2010-009C	YAOGAN	PRC	2010/03/05	1185	995	933	LEO	Long March 4C	0	0	0
2010-010A	ECHOSTAR	US	2010/03/20	35798	35775	6380	GEO	Proton-M/Briz-M	6920	540	8.33668e+07
2010-011A	SOYUZ-TMA	CIS	2010/04/02	360	350	0	LEO	Soyuz FG	0	0	3.57286e+07
2010-012A	STS	US	2010/04/05	346	322	24400	LEO	STS	24400	0	491000000
2010-013A	CRYOSAT	ESA	2010/04/08	725	713	669	LEO	Dnepr	669	0	1.31005e+07
2010-014A	COSMOS 2460	CIS	2010/04/16	270	180	6900	LEO	Soyuz U	6900	0	3.57286e+07
2010-015A	OTV	US	2010/04/22	400	400	5000	LEO	Atlas V 501	7941	2941	1.08527e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2010-016A	SES-1	SES	2010/04/24	35797	35776	2560	GEO	Proton-M/Briz-M	6920	4360	8.33668e+07
2010-017A	COSMOS2463	CIS	2010/04/27	1022	968	825	LEO	Kosmos 3M	775	-50	1.70299e+07
2010-018A	PROGRESS-M	CIS	2010/04/28	373	347	7450	LEO	Soyuz U	7200	-250	3.57286e+07
2010-019A	STS	US	2010/05/14	359	336	24400	LEO	STS	24400	0	491000000
2010-020A	HAYATO	JPN	2010/05/20	172	166	1	LEO	H-IIA 202	0	0	8.33668e+07
2010-020B	WASEDA-SAT2	JPN	2010/05/20	183	177	1	LEO	H-IIA 202	0	0	0
2010-020C	NEGAI	JPN	2010/05/20	190	176	1	LEO	H-IIA 202	0	0	0
2010-020D	AKATSUKI	JPN	2010/05/20	0	0	518	Solar	H-IIA 202	0	0	0
2010-020E	IKAROS	JPN	2010/05/20	0	0	310	Solar	H-IIA 202	0	0	0
2010-020F	UNITEC-1	JPN	2010/05/20	0	0	16	Solar	H-IIA 202	0	0	0
2010-021A	ASTRA	SES	2010/05/21	35806	35767	5500	GEO	Ariane 5ECA	10500	2560	1.64257e+08
2010-021B	COMSATBW-2	GER	2010/05/21	35796	35775	2440	GEO	Ariane 5ECA	0	0	0
2010-022A	NAVSTAR	US	2010/05/28	20225	20113	1630	MEO	Delta IV Medium+ (4.2)	0	0	0
2010-023A	SERVIS	JPN	2010/06/02	1214	1188	900	LEO	Rokot	1225	325	1.42915e+07
2010-024A	BEIDOU	PRC	2010/06/02	35797	35774	2200	GEO	Long March 3C	3800	1600	5.3593e+07
2010-025A	BADR-5	AB	2010/06/03	35806	35766	5420	GEO	Proton-M/Briz-M	6920	1500	8.33668e+07
2010-026A	DRAGON	US	2010/06/04	140	138	4000	LEO	Falcon 9	10450	6450	56500000
2010-027A	SJ-12	PRC	2010/06/15	598	582	0	LEO	Long March 2D	0	0	0
2010-028A	PICARD	FR	2010/06/15	728	724	100	LEO	Dnepr	775	495	1.31005e+07
2010-028F	PRISMA	SWED	2010/06/15	785	722	180	LEO	Dnepr	0	0	0
2010-029A	SOYUZ-TMA	CIS	2010/06/15	357	347	0	LEO	Soyuz FG	0	0	3.57286e+07
2010-030A	TANDEM-X	GER	2010/06/21	510	507	1350	LEO	Dnepr	1700	350	1.31005e+07
2010-031A	OFEQ	ISRA	2010/06/22	629	400	189	LEO	Shavit 1	189	0	0
2010-032A	COMS	SKOR	2010/06/26	35790	35784	2400	GEO	Ariane 5ECA	10500	3300	1.64257e+08
2010-032B	ARABSAT-5A	AB	2010/06/26	35802	35771	4800	GEO	Ariane 5ECA	0	0	0
2010-033A	PROGRESS-M	CIS	2010/06/30	359	336	7450	LEO	Soyuz U	7450	0	3.57286e+07
2010-034A	ECHOSTAR	US	2010/07/10	35798	35776	5520	GEO	Proton-M/Briz-M	6920	1400	8.33668e+07
2010-035A	CARTOSAT	IND	2010/07/12	645	621	694	LEO	PSLV CA	1100	282	0
2010-035B	STUDSAT	IND	2010/07/12	632	611	1	LEO	PSLV CA	0	0	0
2010-035C	AISSAT	NOR	2010/07/12	630	612	6	LEO	PSLV CA	0	0	0
2010-035D	ALSAT	ALG	2010/07/12	673	672	116	LEO	PSLV CA	0	0	0
2010-035E	TISAT	SWTZ	2010/07/12	628	607	1	LEO	PSLV CA	0	0	0
2010-036A	BEIDOU	PRC	2010/07/31	35921	35669	0	GEO	Long March 3A	2600	0	5.3593e+07
2010-037A	NILESAT	EGYP	2010/08/04	35815	35758	3200	GEO	Ariane 5ECA	10500	4250	1.64257e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2010-037B	RASCOM-QAF	RASC	2010/08/04	35796	35777	3050	GEO	Ariane 5ECA	0	0	0
2010-038A	YAOGAN	PRC	2010/08/09	627	624	2700	LEO	Long March 4C	2800	100	0
2010-039A	AEHF-1	US	2010/08/14	35797	35776	6168	GEO	Atlas V 531	7475	1307	1.08527e+08
2010-040A	TIANHUI	PRC	2010/08/24	504	488	2500	LEO	Long March 2D	0	0	0
2010-041A	[GLONASS-M]	CIS	2010/09/02	19188	5153.96	1450	MEO	Proton-M/DM-2	0	0	0
2010-041B	[GLONASS-M]	CIS	2010/09/02	19223	4992.62	1450	MEO	Proton-M/DM-2	0	0	0
2010-041C	[GLONASS-M]	CIS	2010/09/02	19178	4831.28	1450	MEO	Proton-M/DM-2	0	0	0
2010-042A	CHINASAT	PRC	2010/09/04	35795	35783	5100	GEO	Proton-M/Briz-M	6920	1820	8.33668e+07
2010-043A	COSMOS 2467	CIS	2010/09/08	1495	1494	225	LEO	Rokot	1375	700	1.42915e+07
2010-043B	STRELA	CIS	2010/09/08	1510	1497	225	LEO	Rokot	0	0	0
2010-043C	COSMOS 2468	CIS	2010/09/08	1505	1484	225	LEO	Rokot	0	0	0
2010-044A	PROGRESS-M	CIS	2010/09/10	355	349	7450	LEO	Soyuz U	7450	0	3.57286e+07
2010-045A	QZS-1	JPN	2010/09/11	38953	32632	4000	GEO	H-IIA 202	4100	100	8.33668e+07
2010-046A	USA	US	2010/09/21	1105	1102	0	LEO	Atlas V 501	0	0	1.08527e+08
2010-047A	YAOGAN	PRC	2010/09/22	668	626	0	LEO	Long March 2D	0	0	0
2010-047B	ZHEDA	PRC	2010/09/22	652	618	2	LEO	Long March 2D	0	0	0
2010-047C	ZHEDA	PRC	2010/09/22	651	619	2	LEO	Long March 2D	0	0	0
2010-048A	SBSS	US	2010/09/26	632	630	0	LEO	Minotaur 4	1000	0	0
2010-049A	COSMOS 2469	CIS	2010/09/30	39326	1003	1900	HEO	Molniya 2BL	0	0	0
2010-050A	CHANG'E-2	PRC	2010/10/01	0	0	2300	Moon	Long March 3C	0	0	5.3593e+07
2010-051A	SJ-6G	PRC	2010/10/06	602	584	1000	LEO	Long March 4B	2800	1600	2.97739e+07
2010-051B	SJ-6H	PRC	2010/10/06	601	586	200	LEO	Long March 4B	0	0	0
2010-052A	SOYUZ-TMA	CIS	2010/10/07	355	347	0	LEO	Soyuz FG	0	0	3.57286e+07
2010-053A	XM-5	US	2010/10/14	35794	35780	5984	GEO	Proton-M/Briz-M	6920	936	8.33668e+07
2010-054A	GLOBALSTAR	GLOB	2010/10/19	1414	1413	700	LEO	Proton-M/Briz-M	0	0	8.33668e+07
2010-054B	GLOBALSTAR	GLOB	2010/10/19	1414	1413	700	LEO	Proton-M/Briz-M	0	0	0
2010-054C	GLOBALSTAR	GLOB	2010/10/19	1415	1412	700	LEO	Proton-M/Briz-M	0	0	0
2010-054D	GLOBALSTAR	GLOB	2010/10/19	1414	1413	700	LEO	Proton-M/Briz-M	0	0	0
2010-054E	GLOBALSTAR	GLOB	2010/10/19	1414	1413	700	LEO	Proton-M/Briz-M	0	0	0
2010-054F	GLOBALSTAR	GLOB	2010/10/19	1414	1413	700	LEO	Proton-M/Briz-M	0	0	0
2010-055A	PROGRESS-M	CIS	2010/10/27	355	352	7450	LEO	Soyuz U	7450	0	3.57286e+07
2010-056A	EUTELSAT	EUTE	2010/10/28	34612	271	5370	HEO	Ariane 5ECA	10500	3070	1.64257e+08
2010-056B	BSAT-3B	JPN	2010/10/28	35799	35775	2060	GEO	Ariane 5ECA	0	0	0
2010-057A	BEIDOU	PRC	2010/10/31	35817	35757	0	GEO	Long March 3C	3800	0	5.3593e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2010-058A	MERIDIAN	CIS	2010/11/02	38466	1890	2000	HEO	Soyuz-2	0	0	0
2010-059A	FENGYUN	PRC	2010/11/04	829	826	0	LEO	Long March 4C	2800	0	0
2010-060A	COSMO-SKYMED	IT	2010/11/06	623	622	1700	LEO	Delta 7420-10	1895	195	6.38623e+07
2010-061A	SKYTERRA	US	2010/11/14	35825	35748	5400	GEO	Proton-M/Briz-M	6920	0	8.33668e+07
2010-062A	STPSAT	US	2010/11/20	560	558	135	LEO	Minotaur 4	1250	708	0
2010-062B	RAX	US	2010/11/20	560	558	1	LEO	Minotaur 4	0	0	0
2010-062C	O/OREOS	US	2010/11/20	560	558	1	LEO	Minotaur 4	0	0	0
2010-062D	FASTSAT-HSV01	US	2010/11/20	560	558	180	LEO	Minotaur 4	0	0	0
2010-062E	FALCONSAT	US	2010/11/20	560	558	161	LEO	Minotaur 4	0	0	0
2010-062F	FAST	US	2010/11/20	560	558	30	LEO	Minotaur 4	0	0	0
2010-062J	BALLAST	US	2010/11/20	560	558	0	LEO	Minotaur 4	0	0	0
2010-062K	BALLAST	US	2010/11/20	560	558	0	LEO	Minotaur 4	0	0	0
2010-062L	NANOSAIL-D2	US	2010/11/20	560	558	4	LEO	Minotaur 4	0	0	0
2010-062M	FAST	US	2010/11/20	560	558	30	LEO	Minotaur 4	0	0	0
2010-063A	USA	US	2010/11/21	35800	35800	0	GEO	Delta IV Heavy	14220	0	1.81856e+08
2010-064A	ZHONGXING-20A	PRC	2010/11/24	35795	35778	0	GEO	Long March 3A	2600	0	5.3593e+07
2010-065A	HYLAS	UK	2010/11/26	35792	35782	2570	GEO	Ariane 5ECA	10500	2537	1.64257e+08
2010-065B	INTELSAT	ITSO	2010/11/26	35800	35773	5393	GEO	Ariane 5ECA	0	0	0
2010-066A	DRAGON	US	2010/12/08	306	281	4000	LEO	Falcon 9	10450	6442	56500000
2010-066B	QBX2	US	2010/12/08	187	173	1	LEO	Falcon 9	0	0	0
2010-066C	SMDC	US	2010/12/08	184	173	1	LEO	Falcon 9	0	0	0
2010-066D	PERSEUS	US	2010/12/08	190	179	1	LEO	Falcon 9	0	0	0
2010-066E	PERSEUS	US	2010/12/08	183	176	1	LEO	Falcon 9	0	0	0
2010-066F	QBX1	US	2010/12/08	197	185	1	LEO	Falcon 9	0	0	0
2010-066G	PERSEUS	US	2010/12/08	193	183	1	LEO	Falcon 9	0	0	0
2010-066H	PERSEUS	US	2010/12/08	190	180	1	LEO	Falcon 9	0	0	0
2010-066J	MAYFLOWER	US	2010/12/08	194	179	1	LEO	Falcon 9	0	0	0
2010-067A	SOYUZ-TMA	CIS	2010/12/15	346	341	0	LEO	Soyuz FG	0	0	3.57286e+07
2010-068A	BEIDOU	PRC	2010/12/17	35883	35696	0	GEO	Long March 3A	2600	0	5.3593e+07
2010-069A	EUTELSAT	EUTE	2010/12/26	35797	35790	6150	GEO	Proton-M/Briz-M	6920	770	8.33668e+07
2010-070A	HISPASAT	SPN	2010/12/29	35809	35765	5320	GEO	Ariane 5ECA	10500	715	1.64257e+08
2010-070B	KOREASAT	SKOR	2010/12/29	35795	35778	4465	GEO	Ariane 5ECA	0	0	0
2011-001A	ELEKTRO-L	CIS	2011/01/20	35801	35771	1700	GEO	Zenit 3SLB	3750	2050	1.06437e+08
2011-002A	USA	US	2011/01/20	1023	252	0	LEO	Delta IV Heavy	0	0	1.81856e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2011-003A	HTV-2	JPN	2011/01/22	348	346	16000	LEO	H-IIB	16000	0	180000000
2011-004A	PROGRESS-M	CIS	2011/01/28	345	270	7450	LEO	Soyuz U	7450	0	3.57286e+07
2011-005A	GEO-IK	CIS	2011/02/01	137	297.123	1400	LEO	Rokot	1600	200	1.42915e+07
2011-006A	USA	US	2011/02/06	1230	1202	0	LEO	Minotaur 1	0	0	1.70124e+07
2011-007A	ATV-2	ESA	2011/02/16	385	359	19357	LEO	Ariane 5ES	19357	0	1.66734e+08
2011-008A	STS	US	2011/02/24	355	318	24400	LEO	STS	24400	0	491000000
2011-009A	[GLONASS-K]	CIS	2011/02/26	19143	291.521	935	HEO	Soyuz 2-1B	0	0	0
2011-010A	OTV	US	2011/03/05	420	400	5000	LEO	Atlas V 501	7900	2900	1.08527e+08
2011-011A	USA	US	2011/03/11	35700	35700	0	GEO	Delta IV Medium+ (4-2)	6390	0	8.21287e+07
2011-012A	SOYUZ-TMA	CIS	2011/04/04	392	377	0	LEO	Soyuz FG	0	0	3.57286e+07
2011-013A	BEIDOU	PRC	2011/04/09	35895	35681	0	GEO	Long March 3A	2600	0	5.3593e+07
2011-014A	USA	US	2011/04/15	1100	1100	0	LEO	Atlas V 411	11000	0	8.33668e+07
2011-015A	RESOURCESAT-2	IND	2011/04/20	821	819	1200	LEO	PSLV	1100	-300	1.78643e+07
2011-015B	YOUTHSAT	IND	2011/04/20	823	802	100	LEO	PSLV	0	0	0
2011-015C	X-SAT	SING	2011/04/20	822	802	100	LEO	PSLV	0	0	0
2011-016A	INTELSAT	ITSO	2011/04/22	35792	35781	3000	GEO	Ariane 5ECA	10500	1547	1.64257e+08
2011-016B	YAHSAT	UAE	2011/04/22	35794	35779	5953	GEO	Ariane 5ECA	0	0	0
2011-017A	PROGRESS-M	CIS	2011/04/27	404	375	7450	LEO	Soyuz U	7450	0	3.57286e+07
2011-018A	MERIDIAN	CIS	2011/05/04	39255	1100	2000	HEO	Soyuz 2-1A	0	0	0
2011-019A	SBIRS	US	2011/05/07	35796	35777	0	GEO	Atlas V 401	5950	0	8.33668e+07
2011-020A	STS	US	2011/05/16	345	337	24400	LEO	STS	24400	0	491000000
2011-021A	TELSTAR	CA	2011/05/20	35796	35778	4970	GEO	Proton-M/Briz-M	6920	1950	8.33668e+07
2011-022A	GSAT-8	IND	2011/05/20	35814	35759	3100	GEO	Ariane 5ECA	10500	2310	1.64257e+08
2011-022B	ST-2	STCT	2011/05/20	35792	35781	5090	GEO	Ariane 5ECA	0	0	0
2011-023A	SOYUZ-TMA	CIS	2011/06/07	417	370	0	LEO	Soyuz FG	0	0	3.57286e+07
2011-024A	SAC-D	ARGN	2011/06/10	655	653	1350	LEO	Delta 7320-10	1579	229	6.38623e+07
2011-025A	RASAD	IRAN	2011/06/15	153	149	15	LEO	Safir-2	25	10	0
2011-026A	CHINASAT	PRC	2011/06/20	35800	35767	5000	GEO	Long March 3B	5100	100	5.95477e+07
2011-027A	PROGRESS-M	CIS	2011/06/21	383	343	7450	LEO	Soyuz U	7450	0	3.57286e+07
2011-028A	COSMOS	CIS	2011/06/27	242	201	6600	LEO	Soyuz U	6600	0	3.57286e+07
2011-029A	ORS-1	US	2011/06/30	420	410	475	LEO	Minotaur 1	475	0	1.70124e+07
2011-030A	SJ-11-03	PRC	2011/07/06	701	689	0	LEO	Long March 2C	0	0	2.38191e+07
2011-031A	STS	US	2011/07/08	385	371	24400	LEO	STS	24400	0	491000000
2011-031B	PSSC-2		2011/07/08	174	167	4	LEO	Zenit-3F	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2011-032A	TIANLIAN	PRC	2011/07/11	35795	35776	2250	GEO	Long March 3C	3800	1550	5.3593e+07
2011-033A	GLOBALSTAR	GLOB	2011/07/13	1414	1414	700	LEO	Soyuz 2-1A	0	0	0
2011-033B	GLOBALSTAR	GLOB	2011/07/13	1414	1413	700	LEO	Soyuz 2-1A	0	0	0
2011-033C	GLOBALSTAR	GLOB	2011/07/13	1414	1413	700	LEO	Soyuz 2-1A	0	0	0
2011-033D	GLOBALSTAR	GLOB	2011/07/13	1414	1413	700	LEO	Soyuz 2-1A	0	0	0
2011-033E	GLOBALSTAR	GLOB	2011/07/13	1415	1413	700	LEO	Soyuz 2-1A	0	0	0
2011-033F	GLOBALSTAR	GLOB	2011/07/13	1415	1413	700	LEO	Soyuz 2-1A	0	0	0
2011-034A	GSAT-12	IND	2011/07/15	35806	35768	1410	GEO	PSLV XL	0	0	0
2011-035A	SES-3	US	2011/07/15	35797	35776	3112	GEO	Proton-M/Briz-M	6920	2538	8.33668e+07
2011-035B	KAZSAT-2	CIS	2011/07/15	35789	35784	1270	GEO	Proton-M/Briz-M	0	0	0
2011-036A	NAVSTAR	US	2011/07/16	20188	20119	1630	MEO	Delta IV Medium+ (4-2)	0	0	8.21287e+07
2011-037A	SPEKTR-R	CIS	2011/07/18	327929	6396	3660	error	Zenit-3F	0	0	0
2011-038A	BEIDOU	PRC	2011/07/26	35886	35678	0	GEO	Long March 3A	2600	0	5.3593e+07
2011-039A	SJ-11-02	PRC	2011/07/29	702	686	0	LEO	Long March 2C	2200	0	2.38191e+07
2011-040A	JUNO	US	2011/08/05	0	0	3625	Solar	Atlas V 551	0	0	1.08527e+08
2011-041A	ASTRA	SES	2011/08/06	35798	35777	5325	GEO	Ariane 5ECA	10500	2265	1.64257e+08
2011-041B	BSAT-3C	JPN	2011/08/06	35788	35787	2910	GEO	Ariane 5ECA	0	0	0
2011-042A	PAKSAT-1R	PAKI	2011/08/11	35799	35775	5120	GEO	Long March 3B	5100	-20	5.95477e+07
2011-043A	HAIYANG	PRC	2011/08/15	967	966	1500	LEO	Long March 4B	2800	1300	2.97739e+07
2011-044A	EDUSAT	IT	2011/08/17	693	637	10	LEO	Long March 4B	2800	2142	2.97739e+07
2011-044B	NIGERIASAT-2	NIG	2011/08/17	696	681	268	LEO	Long March 4B	0	0	0
2011-044C	NIGERIASAT-X	NIG	2011/08/17	699	681	86	LEO	Long March 4B	0	0	0
2011-044D	RASAT	TURK	2011/08/17	697	665	95	LEO	Long March 4B	0	0	0
2011-044E	APRIZESAT	US	2011/08/17	694	608	12	LEO	Long March 4B	0	0	0
2011-044F	APRIZESAT	US	2011/08/17	694	625	12	LEO	Long March 4B	0	0	0
2011-044G	SICH	CIS	2011/08/17	700	683	175	LEO	Long March 4B	0	0	0
2011-045A	EXPRESS-AM4	CIS	2011/08/17	20316	661	5800	HEO	Proton-M/Briz-M	0	0	8.33668e+07
2011-046A	GRAIL-A	US	2011/09/10	0	0	307	Moon	Delta 7920H	0	0	0
2011-046B	GRAIL-B	US	2011/09/10	0	0	307	Moon	Delta 7920H	0	0	0
2011-047A	CHINASAT	PRC	2011/09/17	35794	35781	5000	GEO	Long March 3B	5100	100	5.95477e+07
2011-048A	COSMOS 2473	CIS	2011/09/20	35793	35780	0	GEO	Proton-M/Briz-M	6920	0	8.33668e+07
2011-049A	SES-2	SES	2011/09/21	35798	35775	0	GEO	Ariane 5ECA	10500	0	1.64257e+08
2011-049B	ARABSAT-5C	AB	2011/09/21	35811	35762	4800	GEO	Ariane 5ECA	0	0	0
2011-050A	IGS	JPN	2011/09/23	0	0	0	error	H-IIA 202	0	0	8.33668e+07

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2011-051A	EUTELSAT	EUTE	2011/09/24	35757	35757	4600	GEO	Zenit 3SL	5450	850	1.06437e+08
2011-052A	TACSAT	US	2011/09/27	12031	724	450	HEO	Minotaur 4	0	0	0
2011-053A	TIANGONG	PRC	2011/09/29	358	349	8000	LEO	Long March 2F	8400	400	0
2011-054A	QUETZSAT	MEX	2011/09/29	35798	35776	5514	GEO	Proton-M/Briz-M	6920	1406	8.33668e+07
2011-055A	[GLONASS-M]	CIS	2011/10/02	19154	2572.5	1450	MEO	Soyuz 2-1B	0	0	0
2011-056A	INTELSAT	ITSO	2011/10/05	35798	35776	3200	GEO	Zenit 3SLB	3750	550	1.06437e+08
2011-057A	EUTELSAT	EUTE	2011/10/07	35803	35769	5400	GEO	Long March 3B	5100	-300	5.95477e+07
2011-058A	MEGHA-TROPIQUES	IND	2011/10/12	867	854	1000	LEO	PSLV CA	1788	748	0
2011-058B	JUGNU	IND	2011/10/12	866	838	1	LEO	PSLV CA	0	0	0
2011-058C	VESSELSAT	LUXE	2011/10/12	867	847	29	LEO	PSLV CA	0	0	0
2011-058D	SRMSAT	IND	2011/10/12	867	850	10	LEO	PSLV CA	0	0	0
2011-059A	VIASAT-1	US	2011/10/19	35798	35775	6740	GEO	Proton-M/Briz-M	6920	180	8.33668e+07
2011-060A	GALILEO-PFM	ESA	2011/10/21	23224	23220	700	MEO	Soyuz-2-1B	0	0	0
2011-060B	GALILEO-FM2	ESA	2011/10/21	23229	23216	700	MEO	Soyuz-2-1B	0	0	0
2011-061A	SUOMI	US	2011/10/28	828	826	1976	LEO	Delta 7920-10	3017	1036	7.09581e+07
2011-061B	DICE-F	US	2011/10/28	781	453	1	LEO	Delta 7920-10	0	0	0
2011-061C	DICE-Y	US	2011/10/28	776	452	1	LEO	Delta 7920-10	0	0	0
2011-061D	RAX-2	US	2011/10/28	777	453	1	LEO	Delta 7920-10	0	0	0
2011-061E	AUBIESAT-1	US	2011/10/28	775	450	1	LEO	Delta 7920-10	0	0	0
2011-061F	M-CUBED	US	2011/10/28	777	451	1	LEO	Delta 7920-10	0	0	0
2011-062A	PROGRESS-M	CIS	2011/10/30	514	490	7450	LEO	Soyuz U	7450	0	3.57286e+07
2011-062C	CHIBIS-M	CIS	2011/10/30	465	450	0	LEO	Soyuz U	0	0	0
2011-063A	SHENZHOU	PRC	2011/10/31	296.189	333	0	LEO	Long March 2F	0	0	0
2011-064A	[GLONASS-M]	CIS	2011/11/04	19176	11150.8	1450	MEO	Proton-M/Briz-M	0	0	8.33668e+07
2011-064B	[GLONASS-M]	CIS	2011/11/04	19171	11121	1450	MEO	Proton-M/Briz-M	0	0	0
2011-064C	[GLONASS-M]	CIS	2011/11/04	19190	11121	1450	MEO	Proton-M/Briz-M	0	0	0
2011-065A	PHOBOS-GRUNT	CIS	2011/11/08	125	112	13200	Mars	Zenit 2SB	0	0	0
2011-066A	TIANXUN	PRC	2011/11/09	460	452	35	LEO	Long March 4B	2800	0	2.97739e+07
2011-066B	YAOGAN	PRC	2011/11/09	497	483	0	LEO	Long March 4B	0	0	0
2011-067A	SOYUZ-TMA	CIS	2011/11/14	402	389	0	LEO	Soyuz FG	0	0	3.57286e+07
2011-068A	CHUANGXIN	PRC	2011/11/20	805	782	0	LEO	Long March 2D	0	0	0
2011-068B	SHIYAN	PRC	2011/11/20	11091.3	782	0	HEO	Long March 2D	0	0	0
2011-069A	ASIASAT	AC	2011/11/25	35792	35781	3813	GEO	Proton-M/Briz-M	6920	3107	8.33668e+07
2011-070A	MSL	US	2011/11/26	0	0	8463	Mars	Atlas V 541	0	0	1.08527e+08

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2011-071A	[GLONASS-M]	CIS	2011/11/28	19160	11031.9	1450	MEO	Soyuz-2-1B	0	0	0
2011-072A	YAOGAN	PRC	2011/11/29	507	504	0	LEO	Long March 2C	2200	0	2.38191e+07
2011-073A	BEIDOU	PRC	2011/12/01	35895	35676	0	GEO	Long March 3A	0	0	5.3593e+07
2011-074A	AMOS-5	ISRA	2011/12/11	35792	35781	996	GEO	Proton-M/Briz-M	6920	4776	8.33668e+07
2011-074B	LUCH	CIS	2011/12/11	35813	35759	1148	GEO	Proton-M/Briz-M	0	0	0
2011-075A	IGS	JPN	2011/12/12	0	0	0	error	H-IIA 202	0	0	8.33668e+07
2011-076A	ELISA	FR	2011/12/17	684	682	200	LEO	Soyuz ST	4500	2583	0
2011-076B	ELISA	FR	2011/12/17	684	682	200	LEO	Soyuz ST	0	0	0
2011-076C	ELISA	FR	2011/12/17	684	682	200	LEO	Soyuz ST	0	0	0
2011-076D	ELISA	FR	2011/12/17	684	682	200	LEO	Soyuz ST	0	0	0
2011-076E	SSOT	CHLE	2011/12/17	624	622	117	LEO	Soyuz ST	0	0	0
2011-076F	PLEIADES	FR	2011/12/17	699	697	1000	LEO	Soyuz ST	0	0	0
2011-077A	NIGCOMSAT	NIG	2011/12/19	35797	35777	5150	GEO	Long March 3B	5100	-50	5.95477e+07
2011-078A	SOYUZ-TMA	CIS	2011/12/21	405	394	0	LEO	Soyuz FG	0	0	3.57286e+07
2011-079A	ZIYUAN	PRC	2011/12/22	775	773	2100	LEO	Long March 4B	2800	700	2.97739e+07
2011-080A	GLOBALSTAR	GLOB	2011/12/28	1414	1413	700	LEO	Soyuz FG	0	0	3.57286e+07
2011-080B	GLOBALSTAR	GLOB	2011/12/28	1414	1413	700	LEO	Soyuz FG	0	0	0
2011-080C	GLOBALSTAR	GLOB	2011/12/28	1414	1413	700	LEO	Soyuz FG	0	0	0
2011-080D	GLOBALSTAR	GLOB	2011/12/28	1414	1413	700	LEO	Soyuz FG	0	0	0
2011-080E	GLOBALSTAR	GLOB	2011/12/28	1414	1413	700	LEO	Soyuz FG	0	0	0
2011-080F	GLOBALSTAR	GLOB	2011/12/28	1414	1414	700	LEO	Soyuz FG	0	0	0
2012-001A	ZIYUAN	PRC	2012/01/09	505	500	2630	LEO	Long March 4B	2800	170	2.97739e+07
2012-001B	VESSELSAT	LUXE	2012/01/09	478	467	28	LEO	Long March 4B	0	0	0
2012-002A	FENGYUN	PRC	2012/01/13	35796	35782	1369	GEO	Long March 3A	2600	1231	5.3593e+07
2012-003A	WGS	US	2012/01/20	11002.2	35767	0	MEO	Delta IV Medium	0	0	8.21287e+07
2012-004A	PROGRESS-M	CIS	2012/01/25	421	355	7450	LEO	Soyuz U	7450	0	3.57286e+07
2012-005A	NAVID	IRAN	2012/02/03	165	149	50	LEO	Safir-2	0	0	0
2012-006A	LARES	IT	2012/02/13	1449	1439	400	LEO	Vega	1300	882.5	2.50939e+07
2012-006B	ALMASAT-1	IT	2012/02/13	1274	307	12.5	LEO	Vega	0	0	0
2012-006C	E-ST@R	IT	2012/02/13	1094	296	1	LEO	Vega	0	0	0
2012-006D	GOLIAT	ROM	2012/02/13	1088	297	1	LEO	Vega	0	0	0
2012-006E	MASAT	HUN	2012/02/13	1092	297	1	LEO	Vega	0	0	0
2012-006F	XATCOBEO	SPN	2012/02/13	1009	294	0	LEO	Vega	0	0	0
2012-006G	PW-SAT	POL	2012/02/13	1047	296	1	LEO	Vega	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2012-006H	ROBUSTA	FR	2012/02/13	1102	296	0	LEO	Vega	0	0	0
2012-006J	UNICUBESAT	IT	2012/02/13	1112	296	1	LEO	Vega	0	0	0
2012-007A	SES-4	SES	2012/02/14	35794	35780	6180	GEO	Proton-M/Briz-M	5500	0	8.33668e+07
2012-008A	BEIDOU	PRC	2012/02/24	35795	35779	0	GEO	Long March 3C	3800	0	5.3593e+07
2012-009A	MUOS-1	US	2012/02/24	35804	35767	3820	GEO		0	0	0
2012-010A	ATV-3	ESA	2012/03/23	414	403	19357	LEO	Ariane 5ES	19357	0	1.66734e+08
2012-011A	INTELSAT	ITSO	2012/03/25	35798	35774	6400	GEO	Proton-M/Briz-M	6920	520	8.33668e+07
2012-012A	COSMOS 2479	CIS	2012/03/30	35794	35778	0	GEO	Proton-K/DM-2	4900	0	1.06437e+08
2012-013A	APSTAR	PRC	2012/03/31	35798	35775	5054	GEO	Long March 3B	5000	0	5.95477e+07
2012-014A	USA	US	2012/04/03	1096	1084	0	LEO	Delta IV Medium	0	0	8.21287e+07
2012-015A	PROGRESS-M	CIS	2012/04/20	375	358	7450	LEO	Soyuz U	7450	0	3.57286e+07
2012-016A	YAHSAT	UAE	2012/04/23	35793	35780	6000	GEO	Proton-M/Briz-M	6920	920	8.33668e+07
2012-017A	RISAT	IND	2012/04/26	541	538	1858	LEO	PSLV XL	0	0	0
2012-018A	BEIDOU	PRC	2012/04/29	21598	21458	0	MEO	Long March 3B	0	0	5.95477e+07
2012-018B	BEIDOU	PRC	2012/04/29	21606	21449	0	MEO	Long March 3B	0	0	0
2012-019A	AEHF-2	US	2012/05/04	45969	26171	6168	error		0	0	0
2012-020A	TIANHUI	PRC	2012/05/06	504	487	2500	LEO	Long March 2D	0	0	0
2012-021A	YAOGAN	PRC	2012/05/10	481	468	0	LEO	Long March 4B	0	0	2.97739e+07
2012-021B	TIANTUO	PRC	2012/05/10	434	430	9	LEO	Long March 4B	0	0	0
2012-022A	SOYUZ-TMA	CIS	2012/05/15	427	404	0	LEO	Soyuz FG	0	0	3.57286e+07
2012-023A	JCSAT-13	JPN	2012/05/15	35796	35779	4528	GEO	Ariane 5ECA	10500	3002	1.64257e+08
2012-023B	VINASAT-2	VTNM	2012/05/15	35796	35777	2970	GEO	Ariane 5ECA	0	0	0
2012-024A	COSMOS 2480	CIS	2012/05/17	269	197	0	LEO	Soyuz U	0	0	3.57286e+07
2012-025A	GCOM-W1	JPN	2012/05/17	704	701	1991	LEO	H-IIA 202	4750	1752	8.33668e+07
2012-025B	ARIRANG-3	SKOR	2012/05/17	694	680	1000	LEO	H-IIA 202	0	0	0
2012-025C	SDS-4	JPN	2012/05/17	671	660	0	LEO	H-IIA 202	0	0	0
2012-025D	HORYU	JPN	2012/05/17	665	649	7	LEO	H-IIA 202	0	0	0
2012-026A	NIMIQ	CA	2012/05/17	35792	35782	4745	GEO	Proton-M/Briz-M	5500	755	8.33668e+07
2012-027A	DRAGON	US	2012/05/22	406	392	4000	LEO	Falcon 9	10450	6450	56500000
2012-028A	CHINASAT	PRC	2012/05/26	10823.9	35774	5200	MEO	Long March 3B	0	0	5.95477e+07
2012-029A	YAOGAN	PRC	2012/05/29	1207	1201	0	LEO	Long March 4C	0	0	0
2012-030A	INTELSAT	ITSO	2012/06/01	35799	35774	6094	GEO	Zenit 3SL	5250	0	1.06437e+08
2012-031A	NUSTAR	US	2012/06/13	628	611	365	LEO	Pegasus XL	250	0	1.78643e+07
2012-032A	SHENZHOU	PRC	2012/06/16	355	334	0	LEO	Long March 2F	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2012-033A	USA	US	2012/06/20	35886	862	0	HEO	Atlas V 401	0	0	8.33668e+07
2012-034A	USA	US	2012/06/29	35674	219	0	HEO	Atlas V 401	0	0	0
2012-035A	ECHOSTAR	US	2012/07/05	35793	35780	6100	GEO	Ariane 5ECA	10500	2390	1.64257e+08
2012-035B	METEOSAT-10	EUME	2012/07/05	35789	35778	2010	GEO	Ariane 5ECA	0	0	0
2012-036A	SES-5	SES	2012/07/09	35795	35778	6007	GEO	Proton-M/Briz-M	6920	913	8.33668e+07
2012-037A	SOYUZ-TMA	CIS	2012/07/15	423	402	0	LEO	Soyuz FG	0	0	3.57286e+07
2012-038A	HTV-3	JPN	2012/07/21	421	399	16000	LEO	H-IIB	16000	0	180000000
2012-039A	KANOPUS-V	CIS	2012/07/22	502	501	473	LEO	Soyuz FG	4650	3084	3.57286e+07
2012-039B	BKA	BELA	2012/07/22	506	504	400	LEO	Soyuz FG	0	0	0
2012-039C	EXACTVIEW-1	CA	2012/07/22	822	805	100	LEO	Soyuz FG	0	0	0
2012-039D	TET-1	GER	2012/07/22	496	493	120	LEO	Soyuz FG	0	0	0
2012-039E	MKA-PN	CIS	2012/07/22	821	804	473	LEO	Soyuz FG	0	0	0
2012-040A	TIANLIAN	PRC	2012/07/25	35805	35769	2200	GEO		0	0	0
2012-041A	COSMOS 2481	CIS	2012/07/28	1512	1481	0	LEO	Rokot	1375	0	1.42915e+07
2012-041B	GONETS-M	CIS	2012/07/28	1511	1479	280	LEO	Rokot	0	0	0
2012-041C	YUBELEINY	CIS	2012/07/28	1510	1482	0	LEO	Rokot	0	0	0
2012-041D	GONETS-M	CIS	2012/07/28	1512	1477	280	LEO	Rokot	0	0	0
2012-042A	PROGRESS-M	CIS	2012/08/01	412	399	7450	LEO	Soyuz U	7450	0	3.57286e+07
2012-043A	INTELSAT	ITSO	2012/08/02	35797	35776	6094	GEO	Ariane 5ECA	10500	1081	1.64257e+08
2012-043B	HYLAS	UK	2012/08/02	35793	35781	3325	GEO	Ariane 5ECA	0	0	0
2012-044A	TELKOM	INDO	2012/08/06	4436	267	0	HEO		0	0	0
2012-044B	EXPRESS-MD2	CIS	2012/08/06	4794	268	0	HEO		0	0	0
2012-045A	INTELSAT	ITSO	2012/08/19	35794	35779	6400	GEO	Zenit 3SL	5250	0	1.06437e+08
2012-046A	RBSP	US	2012/08/30	30501	603	681	HEO	Atlas V 401	0	0	8.33668e+07
2012-046B	RBSP	US	2012/08/30	30656	611	681	HEO	Atlas V 401	0	0	0
2012-047A	SPOT	FR	2012/09/09	699	697	720	LEO	PSLV CA	0	0	0
2012-047B	PROITERES	JPN	2012/09/09	657	637	15	LEO	PSLV CA	0	0	0
2012-048A	USA	US	2012/09/13	1051	511	0	LEO	Atlas V 401	0	0	8.33668e+07
2012-048B	SMDC	US	2012/09/13	1051	511	0	LEO	Atlas V 401	0	0	0
2012-048C	AENEAS	US	2012/09/13	1051	511	3	LEO	Atlas V 401	0	0	0
2012-048D	CSSWE	US	2012/09/13	1051	511	3	LEO	Atlas V 401	0	0	0
2012-048E	CXBN	US	2012/09/13	1051	511	2.5	LEO	Atlas V 401	0	0	0
2012-048F	CP5	US	2012/09/13	1051	511	1	LEO	Atlas V 401	0	0	0
2012-048G	CINEMA	US	2012/09/13	1051	511	3	LEO	Atlas V 401	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2012-048H	RE	US	2012/09/13	1051	511	4	LEO	Atlas V 401	0	0	0
2012-048J	SMDC	US	2012/09/13	1051	511	0	LEO	Atlas V 401	0	0	0
2012-048K	AEROCUBE	US	2012/09/13	1051	511	1	LEO	Atlas V 401	0	0	0
2012-048L	AEROCUBE	US	2012/09/13	1051	511	1	LEO	Atlas V 401	0	0	0
2012-048M	AEROCUBE	US	2012/09/13	1051	511	1	LEO	Atlas V 401	0	0	0
2012-049A	METOP-B	EUME	2012/09/17	822	818	4093	LEO	Soyuz 2-1A	0	0	0
2012-050A	BEIDOU	PRC	2012/09/18	21595	21461	0	MEO	Long March 3B	0	0	5.95477e+07
2012-050B	BEIDOU	PRC	2012/09/18	21576	21480	0	MEO	Long March 3B	0	0	0
2012-051A	ASTRA	SES	2012/09/28	35804	35768	6000	GEO	Ariane 5ECA	10500	1100	1.64257e+08
2012-051B	GSAT-10	IND	2012/09/28	35793	35779	3400	GEO	Ariane 5ECA	0	0	0
2012-052A	VRSS-1	VENZ	2012/09/29	655	618	0	LEO	Long March 2D	0	0	0
2012-053A	NAVSTAR	US	2012/10/04	10586.1	20150	1630	MEO	Delta IV Medium	0	0	8.21287e+07
2012-054A	DRAGON	US	2012/10/08	425	402	4000	LEO	Falcon 9	10450	6308	56500000
2012-054B	ORBCOMM	US	2012/10/08	204	145	142	LEO	Falcon 9	0	0	0
2012-055A	GALILEO-FM3	ESA	2012/10/12	23230	23214	700	MEO	Soyuz 2-1B	0	0	0
2012-055B	GALILEO-FM4	ESA	2012/10/12	23228	23217	700	MEO	Soyuz 2-1B	0	0	0
2012-056A	SJ-9A	PRC	2012/10/14	650	618	0	LEO	Long March 2C	0	0	2.38191e+07
2012-056B	SJ-9B	PRC	2012/10/14	648	622	0	LEO	Long March 2C	0	0	0
2012-057A	INTELSAT	ITSO	2012/10/14	35794	35780	3200	GEO	Proton-M/Briz-M	5500	2300	8.33668e+07
2012-058A	SOYUZ-TMA	CIS	2012/10/23	417	400	0	LEO	Soyuz FG	0	0	3.57286e+07
2012-059A	BEIDOU	PRC	2012/10/25	35794	35779	0	GEO	Long March 2C	0	0	2.38191e+07
2012-060A	PROGRESS-M	CIS	2012/10/31	411	355	7450	LEO	Soyuz U	7450	0	3.57286e+07
2012-061A	LUCH	CIS	2012/11/02	35808	35766	1148	GEO	Proton-M/Briz-M	5500	0	8.33668e+07
2012-061B	YAMAL	CIS	2012/11/02	35793	35781	1640	GEO	Proton-M/Briz-M	0	0	0
2012-062A	STAR	BRAZ	2012/11/10	35798	35777	3125	GEO	Ariane 5ECA	10500	2375	1.64257e+08
2012-062B	EUTELSAT	EUTE	2012/11/10	35794	35778	5000	GEO	Ariane 5ECA	0	0	0
2012-063A	MERIDIAN	CIS	2012/11/14	38997	1359	2000	HEO	Soyuz 2-1A	0	0	0
2012-064A	HUANJING	PRC	2012/11/18	494	478	890	LEO	Long March 2C	0	0	2.38191e+07
2012-064B	FENGNIAO	PRC	2012/11/18	494	480	190	LEO	Long March 2C	0	0	0
2012-064C	XINYAN	PRC	2012/11/18	492	479	30	LEO	Long March 2C	0	0	0
2012-065A	ECHOSTAR	US	2012/11/20	35799	35774	6683	GEO	Proton-M/Briz-M	5500	0	8.33668e+07
2012-066A	YAOGAN	PRC	2012/11/25	1112	1068	0	LEO	Long March 4C	2800	0	0
2012-066B	YAOGAN	PRC	2012/11/25	1112	1068	0	LEO	Long March 4C	0	0	0
2012-066C	YAOGAN	PRC	2012/11/25	1112	1068	0	LEO	Long March 4C	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2012-067A	CHINASAT	PRC	2012/11/27	10556.4	35777	0	MEO		0	0	0
2012-068A	PLEIADES	FR	2012/12/02	699	697	1000	LEO	Soyuz 2-1A	0	0	0
2012-069A	EUTELSAT	EUTE	2012/12/03	35809	35764	5200	GEO	Zenit 3SL	5000	0	1.06437e+08
2012-070A	YAMAL	CIS	2012/12/08	35794	35779	5250	GEO	Proton-M/Briz-M	5500	250	8.33668e+07
2012-071A	OTV	US		400	400	5000	LEO	Atlas V 501	7900	2900	1.08527e+08
2012-072A	KMS	NKOR	2012/12/12	573	495	100	LEO	Unha-1	0	0	0
2012-073A	GOKTURK	TURK	2012/12/18	691	667	400	LEO	Long March 2D	0	0	0
2012-074A	SOYUZ-TMA	CIS	2012/12/19	417	410	0	LEO	Soyuz FG	0	0	3.57286e+07
2012-075A	SKYNET	UK	2012/12/19	35802	35771	4800	GEO	Ariane 5ECA	10500	2800	1.64257e+08
2012-075B	MEXSAT	MEX	2012/12/19	35792	35780	2900	GEO	Ariane 5ECA	0	0	0
2013-001A	COSMOS 2482	CIS	2013/01/15	1517	1472	225	LEO	Rokot	1375	700	1.42915e+07
2013-001B	COSMOS	CIS	2013/01/15	1504	1476	225	LEO	Rokot	0	0	0
2013-001C	COSMOS 2484	CIS	2013/01/15	1515	1474	225	LEO	Rokot	0	0	0
2013-002A	IGS	JPN	2013/01/27	515	512	0	LEO		0	0	0
2013-002B	IGS	JPN	2013/01/27	524	512	0	LEO		0	0	0
2013-003A	STSAT-2C	SKOR	2013/01/30	1432	295	93	LEO	Naro-1	0	0	0
2013-004A	TDRS	US	2013/01/31	35842	35731	3454	GEO	Atlas V 401	4950	1496	8.33668e+07
2013-005A	GLOBALSTAR	GLOB	2013/02/06	1414	1413	700	LEO	Soyuz FG	0	0	3.57286e+07
2013-005B	GLOBALSTAR	GLOB	2013/02/06	1415	1413	700	LEO	Soyuz FG	0	0	0
2013-005C	GLOBALSTAR	GLOB	2013/02/06	1414	1413	700	LEO	Soyuz FG	0	0	0
2013-005D	GLOBALSTAR	GLOB	2013/02/06	1415	1413	700	LEO	Soyuz FG	0	0	0
2013-005E	GLOBALSTAR	GLOB	2013/02/06	1414	1414	700	LEO	Soyuz FG	0	0	0
2013-005F	GLOBALSTAR	GLOB	2013/02/06	1414	1413	700	LEO	Soyuz FG	0	0	0
2013-006A	AMAZONAS	SPN	2013/02/07	35810	35764	6265	GEO	Ariane 5ECA	10500	960	1.64257e+08
2013-006B	AZERSPACE	AZER	2013/02/07	35795	35776	3275	GEO	Ariane 5ECA	0	0	0
2013-007A	PROGRESS-M	CIS	2013/02/11	420	414	7450	LEO	Soyuz U	7450	0	3.57286e+07
2013-008A	LANDSAT	US	2013/02/11	703	702	2700	LEO	Atlas V 401	0	0	8.33668e+07
2013-009A	SARAL	IND	2013/02/25	785	784	409	LEO	PSLV CA	1100	450.5	0
2013-009B	AAUSAT3	DEN	2013/02/25	786	769	1	LEO	PSLV CA	0	0	0
2013-009C	SAPPHIRE	CA	2013/02/25	787	771	148	LEO	PSLV CA	0	0	0
2013-009D	NEOSSAT	CA	2013/02/25	786	771	74	LEO	PSLV CA	0	0	0
2013-009E	STRAND	UK	2013/02/25	783	771	4	LEO	PSLV CA	0	0	0
2013-009F	BRITE-AUSTRIA	ASRA	2013/02/25	784	769	6.5	LEO	PSLV CA	0	0	0
2013-009G	UNIBRITE	ASRA	2013/02/25	783	771	7	LEO	PSLV CA	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2013-010A	DRAGON	US	2013/03/01	409	380	4000	LEO	Falcon 9	10450	6450	56500000
2013-011A	SBIRS	US	2013/03/19	35760	35711	4500	GEO	Atlas V 401	4950	450	8.33668e+07
2013-012A	SATMEX	MEX	2013/03/26	35796	35777	0	GEO	Proton-M/Briz-M	5500	0	8.33668e+07
2013-013A	SOYUZ-TMA	CIS	2013/03/28	418	413	0	LEO	Soyuz FG	0	0	3.57286e+07
2013-014A	ANIK	CA	2013/04/15	35795	35779	4900	GEO	Proton-M/Briz-M	5500	600	8.33668e+07
2013-015A	BION	CIS	2013/04/19	579	471	0	LEO	Soyuz 2-1A	0	0	0
2013-015B	OSSI-1	SKOR	2013/04/19	552	263	1	LEO	Soyuz 2-1A	0	0	0
2013-015C	DOVE-2	US	2013/04/19	573	564	6	LEO	Soyuz 2-1A	0	0	0
2013-015D	AIST-2	CIS	2013/04/19	572	565	39	LEO	Soyuz 2-1A	0	0	0
2013-015E	BEESAT-3	GER	2013/04/19	565	561	1	LEO	Soyuz 2-1A	0	0	0
2013-015F	SOMP	GER	2013/04/19	565	562	0	LEO	Soyuz 2-1A	0	0	0
2013-015G	BEESAT-2	GER	2013/04/19	565	562	1	LEO	Soyuz 2-1A	0	0	0
2013-016A	BELL	US	2013/04/21	161	153	1	LEO	Antares 110	4600	1092	77500001
2013-016B	DOVE-1	US	2013/04/21	169	160	5	LEO	Antares 110	0	0	0
2013-016C	ALEXANDER	US	2013/04/21	152	134	1	LEO	Antares 110	0	0	0
2013-016D	CYGNUS PAYLOAD SIM	US	2013/04/21	150	144	3500	LEO	Antares 110	0	0	0
2013-016E	GRAHAM	US	2013/04/21	175	161	1	LEO	Antares 110	0	0	0
2013-017A	PROGRESS-M	CIS	2013/04/24	418	360	7450	LEO	Soyuz U	7450	0	3.57286e+07
2013-018A	GAOFEN	PRC	2013/04/26	655	628	1266	LEO	Long March 2D	0	0	0
2013-018B	NEE-01	ECU	2013/04/26	654	626	1	LEO	Long March 2D	0	0	0
2013-018C	TURKSAT-3USAT	TURK	2013/04/26	654	627	2	LEO	Long March 2D	0	0	0
2013-018D	CUBEBUG	ARGN	2013/04/26	654	626	1	LEO	Long March 2D	0	0	0
2013-019A	COSMOS	CIS	2013/04/26	19176	19084	0	MEO	Soyuz 2-1B	0	0	0
2013-020A	CHINASAT	PRC	2013/05/01	35757	35757	5400	GEO	Long March 3B	5100	0	5.95477e+07
2013-021A	PROBA-V	ESA	2013/05/07	819	813	140	LEO	Vega	1300	1159	2.50939e+07
2013-021B	VNREDSAT	VTNM	2013/05/07	685	683	0	LEO	Vega	0	0	0
2013-021C	ESTCUBE	EST	2013/05/07	672	656	1	LEO	Vega	0	0	0
2013-022A	EUTELSAT	EUTE	2013/05/14	35797	35777	5470	GEO	Proton-M/Briz-M	5500	0	8.33668e+07
2013-023A	NAVSTAR	US	2013/05/15	10348.4	20174	1630	MEO	Atlas V 401	0	0	8.33668e+07
2013-024A	WGS	US	2013/05/25	10318.7	31982	0	MEO	Delta IV Medium	0	0	8.21287e+07
2013-025A	SOYUZ-TMA	CIS	2013/05/28	420	416	0	LEO	Soyuz FG	0	0	3.57286e+07
2013-026A	SES-6	SES	2013/06/03	35802	35771	6100	GEO	Proton-M/Briz-M	6920	0	8.33668e+07
2013-027A	ATV-4	ESA	2013/06/05	420	416	19357	LEO	Ariane 5ES	19357	0	1.66734e+08
2013-028A	COSMOS	CIS	2013/06/07	732	713	0	LEO	Soyuz 2-1B	0	0	0

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2013-029A	SHENZHOU	PRC	2013/06/11	337	333	0	LEO	Long March 2F	0	0	0
2013-030A	RESURS	CIS	2013/06/25	471	457	6570	LEO	Soyuz 2-1B	0	0	0
2013-031A	O3B	O3B	2013/06/25	8068	8063	700	MEO	Soyuz FG	0	0	3.57286e+07
2013-031B	O3B	O3B	2013/06/25	8067	8065	700	MEO	Soyuz FG	0	0	0
2013-031C	O3B	O3B	2013/06/25	8069	8063	700	MEO	Soyuz FG	0	0	0
2013-031D	O3B	O3B	2013/06/25	8068	8063	700	MEO	Soyuz FG	0	0	0
2013-032A	COSMOS	CIS	2013/06/27	498	494	0	LEO	Strela	1700	0	0
2013-033A	IRIS	US	2013/06/28	662	622	236	LEO	Pegasus XL	236	0	1.78643e+07
2013-034A	IRNSS-1A	IND	2013/07/01	35864	35709	1425	GEO	PSLV XL	0	0	0
2013-035A	SJ-11-05	PRC	2013/07/15	704	688	0	LEO	Long March 2C	0	0	2.38191e+07
2013-036A	MUOS-2	US	2013/07/19	35822	35800	3820	GEO	Atlas V 551	3900	80	1.08527e+08
2013-037A	OBJECT	PRC	2013/07/19	675	660	0	LEO	Long March 2D	0	0	0
2013-037B	OBJECT	PRC	2013/07/19	674	666	0	LEO	Long March 2D	0	0	0
2013-037C	OBJECT	PRC	2013/07/19	607	558	0	LEO	Long March 2D	0	0	0
2013-038A	ALPHASAT	IM	2013/07/25	35798	35776	6550	GEO	Ariane 5ECA	10500	1890	1.64257e+08
2013-038B	INSAT-3D	IND	2013/07/25	35801	35773	2060	GEO	Ariane 5ECA	0	0	0
2013-039A	PROGRESS-M	CIS	2013/07/27	420	416	7450	LEO	Soyuz U	7450	0	3.57286e+07
2013-040A	HTV-4	JPN	2013/08/03	408	189	16000	LEO	H-IIB	16000	0	180000000
2013-041A	WGS	US	2013/08/08	10081	7123	5897	MEO	Delta IV Medium+ (5-4)	0	0	8.21287e+07
2013-042A	ARIRANG-5	SKOR	2013/08/22	563	543	1400	LEO	Naro-1	0	0	0
2013-043A	USA	US	2013/08/28	0	0	0	error	Delta IV Heavy	0	0	1.81856e+08
2013-044A	EUTELSAT	EUTE	2013/08/29	35790	35781	6000	GEO	Ariane 5ECA	10500	1850	1.64257e+08
2013-044B	GSAT-7	IND	2013/08/29	35818	35755	2650	GEO	Ariane 5ECA	0	0	0
2013-045A	AMOS-4	ISRA	2013/08/31	35792	35780	996	GEO	Zenit 3SLB	0	0	1.06437e+08
2013-046A	YAOGAN	PRC	2013/09/01	1099	1081	0	LEO	Long March 4C	0	0	0
2013-046B	YAOGAN	PRC	2013/09/01	1099	1081	0	LEO	Long March 4C	0	0	0
2013-046C	YAOGAN	PRC	2013/09/01	1100	1081	0	LEO	Long March 4C	0	0	0
2013-047A	LADEE	US	2013/09/07	0	0	383	Moon	Minotaur V	0	0	0
2013-048A	GONETS-M	CIS	2013/09/11	1507	1482	280	LEO	Rokot	1375	535	1.42915e+07
2013-048B	GONETS-M	CIS	2013/09/11	1508	1493	280	LEO	Rokot	0	0	0
2013-048C	GONETS-M	CIS	2013/09/11	1511	1494	280	LEO	Rokot	0	0	0
2013-049A	SPRINT-A	JPN	2013/09/14	1156	952	348	LEO	Epsilon	0	0	0
2013-050A	AEHF-3	US	2013/09/18	50050	3765	6168	error	Atlas V 531	0	0	1.08527e+08
2013-051A	CYGNUS	US	2013/09/18	420	416	3500	LEO	Antares 110	3750	250	77500001

COSPAR	Name	State	Date	Ap	Pe	Mass	Type	Launch Vehicle	Capacity	Wastage	Cost
2013-052A	FENGYUN	PRC	2013/09/23	828	827	0	LEO	Long March 4C	2800	0	0
2013-053A	KUAIZHOU	PRC	2013/09/25	289	280	0	LEO	Long March 4C	0	0	0
2013-054A	SOYUZ-TMA	CIS	2013/09/25	420	416	0	LEO	Soyuz FG	7450	0	3.57286e+07
2013-055A	CASSIOPE	CA	2013/09/29	1485	325	500	LEO	Falcon 9 1.1	0	0	0
2013-055B	CUSAT	US	2013/09/29	1483	325	41	LEO	Falcon 9 1.1	0	0	0
2013-055C	DANDE	US	2013/09/29	1485	325	365	LEO	Falcon 9 1.1	0	0	0
2013-055D	POPACS	US	2013/09/29	1480	325	2	LEO	Falcon 9 1.1	0	0	0
2013-055E	POPACS	US	2013/09/29	1482	324	1.5	LEO	Falcon 9 1.1	0	0	0
2013-055F	POPACS	US	2013/09/29	1481	325	1	LEO	Falcon 9 1.1	0	0	0
2013-055G	CUSAT	US	2013/09/29	1487	319	41	LEO	Falcon 9 1.1	0	0	0
2013-056A	ASTRA 2E	SES	2013/09/29	35793	35781	6000	GEO	Proton-M/Briz-M	6920	920	8.33668e+07

Appendix B

Launch Vehicle Database

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Delta IV Heavy	28790	14220	155000000	1.81856e+08	6316.65	12788.8	2.02
STS	24400	0	491000000	491000000	20123	0	0
Titan 402B	21680	5600	350000000	4.16834e+08	19226.7	74434.7	3.87
Titan 403B	21680	0	350000000	4.16834e+08	19226.7	74434.7	3.87
Titan 401B	21680	0	350000000	4.16834e+08	19226.7	74434.7	3.87
Titan 404B	21680	0	350000000	4.16834e+08	19226.7	74434.7	3.87
Titan Centaur 401B	21680	5600	350000000	4.16834e+08	19226.7	74434.7	4.87
Ariane 5ES	21500	0	140000000	1.66734e+08	7755.05	0	0
Proton-M/Briz-M	21000	5500	70000000	8.33668e+07	3969.85	15157.6	3.82
Atlas V 551	20520	8670	92500000	1.08527e+08	5288.85	12517.6	2.37
Proton-K/DM-2M	19760	4930	75000000	1.06437e+08	5386.49	21589.7	4.01
Proton-K/DM-2	19760	4930	75000000	1.06437e+08	5386.49	21589.7	4.01
H-IIB	19000	8000	180000000	180000000	9473.68	22500	2.38
Atlas V 541	18955	7980	92500000	1.08527e+08	5725.52	13599.9	2.38
Atlas V 531	17250	7200	92500000	1.08527e+08	6291.43	15073.2	2.4
Zenit 3SL	15876	6066	75000000	1.06437e+08	6704.28	17546.5	2.62
Atlas V 431	15718	7640	103000000	103000000	6553	13481.7	2.06

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Atlas V 521	15080	6285	75000000	8.7995e+07	5835.22	14000.8	2.4
Delta IV Medium+ (5-4)	14140	7300	70000000	8.21287e+07	5808.25	11250.5	1.94
Atlas V 421	14067	6830	70000000	8.33668e+07	5926.41	12206	2.06
Zenit 2	13920	0	35000000	4.96707e+07	3568.29	0	0
Falcon 9	13150	4850	56500000	56500000	4296.58	11649.5	2.71
Delta IV Medium+ (4-2)	13140	6390	70000000	8.21287e+07	6250.28	12852.7	2.06
Atlas V 511	12590	5270	92500000	1.08527e+08	8620.11	20593.4	2.39
Atlas V 411	12150	5950	70000000	8.33668e+07	6861.47	14011.2	2.04
H-IIA 2024	11730	5000	85000000	9.97277e+07	8501.94	19945.5	2.35
Delta IV Medium+ (5-2)	11470	5490	70000000	8.21287e+07	7160.31	14959.7	2.09
Long March 3B	11200	5100	50000000	5.95477e+07	5316.76	11676	2.2
Atlas IIIB	10759	4119	65000000	7.74121e+07	7195.1	18793.9	2.61
Atlas V 501	10300	3970	92500000	1.08527e+08	10536.6	27336.8	2.59
Ariane 44L	10200	4790	100000000	1.41916e+08	13913.4	29627.6	2.13
H-IIA 202	9940	4100	70000000	8.33668e+07	8387.01	20333.4	2.42
Atlas V 401	9797	4950	70000000	83400000	8509.42	16841.8	1.98
Long March 2E	9500	3500	50000000	7.09581e+07	7469.27	20273.7	2.71

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Ariane 5G	9500	6700	125000000	1.48869e+08	15670.5	22219.3	1.42
Delta IV Medium	9420	4440	70000000	8.21287e+07	8718.55	18497.5	2.12
Long March 3C	9100	3800	45000000	5.3593e+07	5889.34	14103.4	2.39
Ariane 44LP	9100	4030	90000000	1.27725e+08	14035.7	31693.4	2.26
Atlas IIIA	8640	4037	90000000	1.27725e+08	14782.9	31638.5	2.14
Atlas IIAS	8618	3719	90000000	1.27725e+08	14820.7	34343.8	2.32
Ariane 42L	7900	3200	80000000	1.13533e+08	14371.3	35479	2.47
Ariane 44P	7600	3465	80000000	1.13533e+08	14938.5	32765.6	2.19
Soyuz U	7450	1660	30000000	3.57286e+07	4795.79	21523.3	4.49
Soyuz FG	7450	1660	30000000	3.57286e+07	4795.79	21523.3	4.49
Atlas IIA	7280	3039	90000000	144000000	19748.1	47307	2.4
Ariane 42P	6600	2600	70000000	9.93413e+07	15051.7	38208.2	2.54
Delta 7920H-9.5	6097	0	50000000	5.95477e+07	9766.73	0	0
Antares 130	6050	0	77500000	77500000	12809.9	0	0
Long March 3A	6000	2600	45000000	5.3593e+07	8932.16	20612.7	2.31
Delta 7920H-10	5959	0	50000000	5.95477e+07	9992.91	0	0
Delta 7920H-10L	5899	0	50000000	5.86634e+07	9944.63	0	0

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Antares 131	5700	0	77500000	77500000	13596.5	0	0
Delta 7920-9.5	5030	0	50000000	7.09581e+07	14107	0	0
GSLV	5000	1900	35000000	4.16834e+07	8336.68	21938.6	2.63
Ariane 40	5000	1900	65000000	9.22455e+07	18449.1	48550.3	2.63
Delta 7920-10	4844	0	50000000	7.09581e+07	14648.6	0	0
Delta 7920-10L	4805	0	50000000	7.09581e+07	14767.5	0	0
Antares 120	4800	0	77500000	77500000	16145.8	0	0
Antares 110	4800	0	77500000	77500000	16145.8	0	0
Long March 2C	4400	1400	20000000	2.38191e+07	5413.43	17013.6	3.14
Antares 121	4400	0	77500000	77500000	17613.6	0	0
Tsyklon 3	4100	0	20000000	2.38191e+07	5809.54	0	0
PSLV	3700	1050	15000000	1.78643e+07	4828.2	17013.6	3.52
Tsyklon 2	3350	0	20000000	2.38191e+07	7110.18	0	0
Dnepr	3200	0	11000000	1.31005e+07	4093.91	0	0
Delta 7420-9.5	3185	0	45000000	6.38623e+07	20051	0	0
Titan 2G	3175	1043	34000000	70850000	22315	67929.1	3.04
Delta 7420-10	3099	0	45000000	6.38623e+07	20607.4	0	0

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Delta 7320-9.5	2809	0	45000000	6.38623e+07	22734.9	0	0
Long March 4B	2800	0	25000000	2.97739e+07	10633.5	0	0
Delta 7320-10	2703	0	45000000	6.38623e+07	23626.4	0	0
Rokot	1950	0	12000000	1.42915e+07	7328.95	0	0
M-V	1900	1280	57000000	6.78844e+07	35728.6	53034.7	1.48
Vega	1500	0	21070400	2.50939e+07	16729.3	0	0
Kosmos 3	1400	0	12000000	1.70299e+07	12164.2	0	0
Kosmos 3M	1400	0	12000000	1.70299e+07	12164.2	0	0
Taurus XL	1320	0	25000000	2.97739e+07	22556	0	0
Start-1	632	0	9000000	1.07186e+07	16959.8	0	0
Minotaur 1	607	0	14500000	1.70124e+07	28027	0	0
Pegasus XL	443	0	15000000	1.78643e+07	40325.8	0	0
Falcon 1	409	0	6000000	7.14573e+06	17471.2	0	0
Ariane 5ECA	0	10500	140000000	1.64257e+08	0	15643.6	0
Zenit 3SLB	0	3750	75000000	1.06437e+08	0	28383.2	0
Delta 7326-9.5	0	934	45000000	6.38623e+07	0	68375	0
Delta 7326-10	0	898	45000000	6.38623e+07	0	71116.1	0

LV	P (LEO, kg)	P (GTO, kg)	Cost (TY$)	Cost (2014$)	C/P (LEO)	C/P (GTO)	
Delta 7425-9.5	0	1110	45000000	6.38623e+07	0	57533.6	0
Delta 7425-10	0	1073	45000000	6.38623e+07	0	59517.5	0
Delta 7426-9.5	0	1056	45000000	6.38623e+07	0	60475.6	0
Delta 7426-10	0	1029	45000000	6.38623e+07	0	62062.5	0
Delta 7925-9.5	0	1819	50000000	7.09581e+07	0	39009.4	0
Delta 7925-10	0	1747	50000000	7.09581e+07	0	40617.1	0
Delta 7925-10L	0	1739	50000000	7.09581e+07	0	40617.1	0
Delta 7926-9.5	0	1660	50000000	7.09581e+07	0	40804	0
Delta 7926-10	0	1581	50000000	7.09581e+07	0	42745.8	0
Delta 7926-10L	0	1578	50000000	7.09581e+07	0	44881.8	0
Delta 7925H	0	2171	50000000	7.09581e+07	0	44967.1	0
Delta 7925H-10	0	2123	50000000	7.09581e+07	0	32684.5	0
Delta 7925H-10L	0	2102	50000000	7.09581e+07	0	33423.5	0
Delta 7926H	0	1981	50000000	7.09581e+07	0	33757.4	0
Delta 7926H-10	0	1934	50000000	7.09581e+07	0	35819.3	0
Delta 7926H-10L	0	1916	50000000	7.09581e+07	0	36689.8	0