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# POTENTIAL OPPORTUNITIES FOR SECONDARY AND HOSTED PAYLOADS ON NASA MISSIONS

**Jonah E. Zimmerman**
Stanford University Department of Aeronautics & Astronautics, USA, jonahz@stanford.edu

**Andrew Ow**
Stanford University Graduate School of Business, USA, andrew.ow@gsb.stanford.edu

**G. Scott Hubbard**
Stanford University Department of Aeronautics & Astronautics, USA, scotthub@stanford.edu

Many spacecraft do not utilize the full capacity of the launch vehicle that places them in orbit. One concept for utilization of this unused launch vehicle capacity is the inclusion of secondary and/or hosted payloads (SHPs), possibly enabling low-cost access to space. Currently, SHPs are infrequently used and NASA missions were identified as a potential opportunity for a policy change requiring SHPs. In this paper the potential for secondary and hosted payloads on NASA missions is examined by analyzing past launches and estimating the unused launch vehicle capacity. By evaluating the difference between the launch vehicle capacity and payload mass the unused capacity was calculated. This simple method gives an upper bound and does not take into account many factors that would prevent the inclusion of SHPs. It was determined that 39,600 kg of payload capacity was unused on NASA missions between January of 2006 and August of 2013. The value of this capacity was calculated as 663 million USD by using methods from a previously published study of space transportation costs.

## I. INTRODUCTION

The concept of using a single launch vehicle to launch multiple payloads is not new to the aerospace industry. In June of 1960 an early United States electronic signals intelligence satellite was launched atop a navigation satellite, shown in figure 1 [1]. This configuration allowed for two spacecraft that travelled to similar orbits to be carried on a single launch vehicle, thus saving the cost of an additional rocket but increasing the mission complexity and risk.

Unfortunately, terminology for this type of arrangement varies widely and different groups sometimes use the same words with different meanings. Rideshare, auxiliary payload, secondary payload, hosted payload, piggyback, and others are in use throughout the field, but in this paper the term secondary payload will be used to describe multiple spacecraft being launched on a single launch vehicle. This can refer to situations where there is a wide discrepancy in mass between the payloads, such as a large earth observation satellite and a CubeSat*. It can also refer to situations where the two are similar in size, such as Ariane 5 launches with the SYstème de Lancement Double Ariane (SYLDA) where two large communications satellites are launched to geostationary transfer orbit (GTO).

The term hosted payload will be used to describe a payload that is permanently physically attached to the primary spacecraft, and often relying on the primary for power, communications, and thermal control. This hosted payload may be directly related to the primary payload, such as a suite of transponders on a

Figure 1: Galactic Radiation and Background (GRAB) signals intelligence satellite being integrated with a Transit navigation satellite in 1960 [1].

* CubeSats are nanosatellites constructed from 10cm cubes, each with a mass of approximately 1.3 kg.

 

communications satellite, or may be completely unrelated.

## II. MOTIVATION

In 2010, the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) formed a Center of Excellence for Commercial Space Transportation (COE CST) [2]. The COE was established with the goal of identifying solutions for existing and anticipated problems affecting the commercial space industry and is a cost sharing partnership of academia, industry, and government.

Previously, a research roadmap was developed for the Center of Excellence by capturing the input of various stakeholders in the commercial space transportation field [3-5]. In this process, priority research tasks were also identified. One such task is concerned with answering the question, “what is the space market?” and the work presented in this paper is a small subset of that overall research topic, specifically suggested by multiple industry partners.

Secondary and hosted payloads (SHPs) appeal to many within the aerospace field for a variety of reasons. For very small spacecraft they are currently the only means of reaching orbit. The smallest operational launch vehicles are in the class of Orbital Science’s Pegasus, which is capable of lifting several hundred kilograms into low earth orbit (LEO) at a price of approximately 36 million USD [3]. For spacecraft with masses of less than 100 kg these launch vehicles are often too expensive.

For other payloads they are simply a low-cost means of reaching orbit. The Commercially Hosted Infrared Payload (CHIRP) is a United States Air Force technology demonstration mission that was flown as a hosted payload on a commercial communications satellite, SES-2, and is shown in figure 2. The Office of Space Commercialization estimated that by flying this mission as a hosted payload rather than a standalone spacecraft, the total cost was reduced by 87% while still allowing 80% of the mission objectives to be accomplished [4].

Despite the advantages of SHPs they are infrequently used. Worldwide in 2012, just 27 of the 78 orbital launches contained secondary payloads. Additionally, 8 of those 27 launches included related payloads, such as multiple spacecraft in a single constellation. For many programmatic reasons, these launches with related secondary payloads are much simpler because they do not involve interactions between different agencies, customers, or nations. Hosted payloads are more difficult to identify due to their physical nature. Two publicized commercial hosted payloads were launched in 2012 on Intelsat 22 and SES-2 [4].

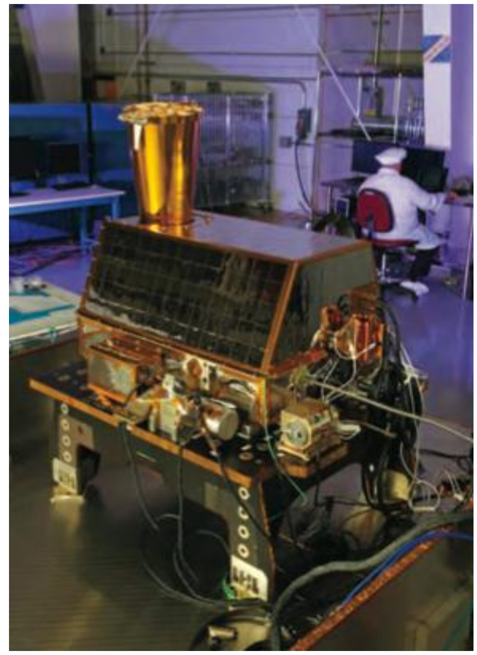

Figure 2: The Commercially Hosted Infrared Payload affixed to SES-2 [6].

## III. GOAL

Given that SHPs offer many advantages and yet are relatively infrequently used, our overall goal is to determine ways to enable SHPs. There are three possible focus areas: commercial, defense, and civil government launches. Of the three, civil government (NASA) launches are the most appealing for our work due to the combination of public information about the payloads and launch vehicles and the centralized way in which launches are arranged. Defense launches, while procured and organized via centralized structure, have little public information and hence commentary on those launches is difficult.

Commercial launches are performed through a variety of operators, spacecraft and launch vehicle manufacturers, and launch service providers. This variety makes any comprehensive analyses or statements problematic.

By focusing on NASA launches, if a comprehensive analysis shows that SHPs would significantly benefit the agency, new policies could be introduced to require them on launches that have excess capacity. Therefore our specific goal now becomes developing that analysis. It will have three separate components that must be demonstrated:

1) NASA launches have significant excess capacity
2) This excess capacity is a valuable resource and should be utilized
3) There exist high-return missions that could utilize excess launch vehicle capacity

If all three of these points can be proven, then a powerful argument exists for the mandatory inclusion of SHPs on future NASA missions. This paper will focus on the first point, while the second will be covered briefly. Further analysis of the second and third points is the subject of future work.

## IV. METHODS

In order to determine the extent to which NASA launches have excess capacity, a database was compiled containing every NASA launch since January of 2006, totaling 34 launches. For each launch, the capacity of the launch vehicle to the destination orbit is determined. Then the payload mass itself is found. The difference between these two values gives the excess capacity of the launch vehicle in terms of payload mass.

In most cases the launch vehicle capacity can be found from the payload user's guide, published by the launch vehicle manufacturer. The payload mass for NASA missions is frequently listed in NASA publications about the mission. In some cases however when the mission trajectory takes the spacecraft to a non-standard orbit, the payload capacity is not given by the launch vehicle manufacturer. In these cases the estimation of the payload capacity is difficult.

To demonstrate the nature of this problem, the governing relationship is given below in equation 1.

$$\frac{m_i}{m_f} = \exp\left[\frac{\Delta V}{I_{sp} g}\right] \qquad [1]$$

This is frequently referred to as the Tsiolkovsy rocket equation and relates the ratio of the initial to final mass of the rocket to the delivered change in velocity and the rocket's specific impulse. This relation is plotted in figure 3 to emphasize its highly non-linear nature. We can use this equation to determine the uncertainty in calculated payload capacity given some uncertainty in the parameter in brackets.

Using values that approximate the United Launch Alliance Centaur Upper Stage ($I_{sp}$ of 450s, $\Delta V$ of 5 km/s, mi of 25,000 kg) and assuming a 5% error on the parameter in brackets, the resulting uncertainty in payload capacity is more than 450 kg. Uncertainties of this magnitude are unacceptable for this project, and hence any launch to an orbit for which there is no published vehicle capacity will be ignored. This applies to 10 of the 34 launches since January of 2006.

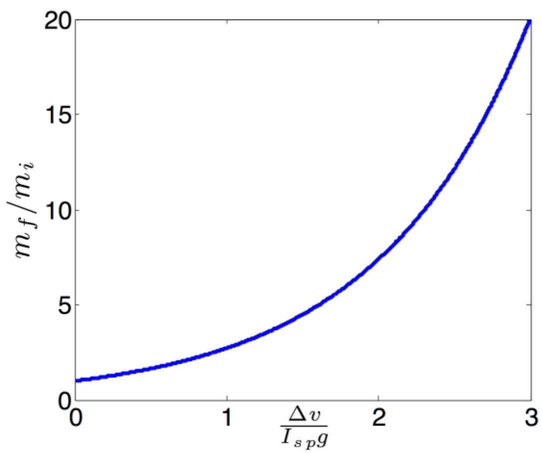


Figure 3: Relationship between normalized $\Delta V$ and final to initial mass ratio.

The method described above for calculating the unused payload capacity has other limitations. By focusing only on mass, it ignores cases where the payload volume may be the primary constraint. Additionally, to include secondary payloads a suitable adapter must be available and for some launch vehicles these adapters have yet to be developed. Therefore the data presented here must be understood to represent an upper bound of the true unused payload capacity.

## V. RESULTS

The database of NASA launches now contains 24 launches with useable information. Combined, these launches put a total of 55,600 kg of payload into orbit but also had 39,600 kg of unused capacity, or 42%. Averaging, that is 5,280 kg per year of unused capacity or 1,650 kg per launch.

The data can also be evaluated in various ways to identify trends and other interesting features. First the data will be broken down by launch vehicle. This is done in figures 4 and 5 where the number of launches and the cumulative unused capacity are given, respectively. In the years considered the Delta II, Delta IV, Atlas V, Taurus XL, Pegasus XL, Antares, and Falcon 9 launch vehicles were used. This includes the demonstration flights of both Antares and Falcon 9.

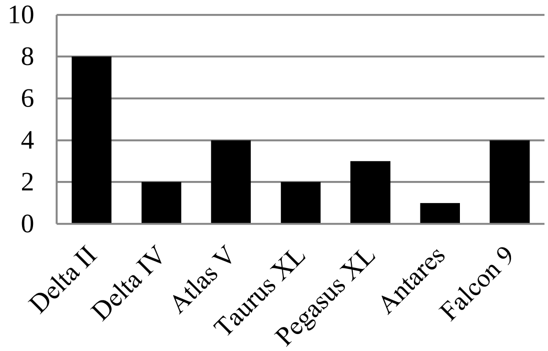


Figure 4: Breakdown by launch vehicle of number of launches in database

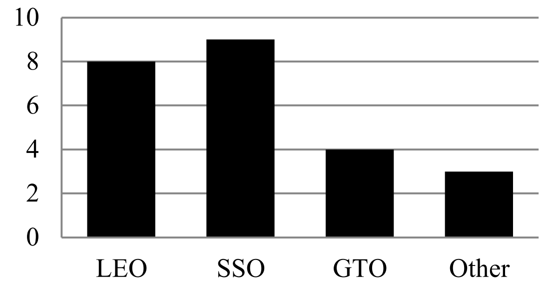


Figure 6: Breakdown by orbit of number of launches in database. LEO here does not include polar sun-synchronous orbits, which are included in SSO.

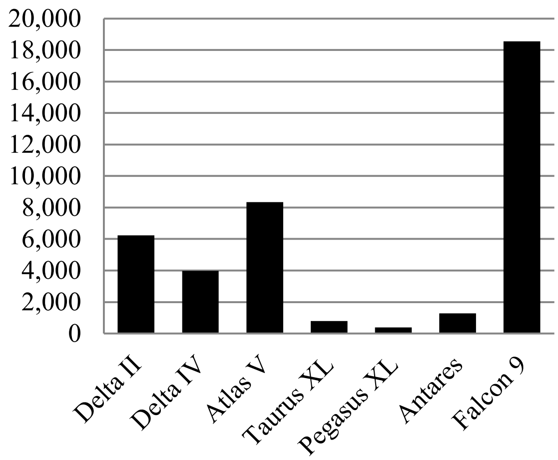


Figure 5: Cumulative unused capacity [kg] in database for each launch vehicle

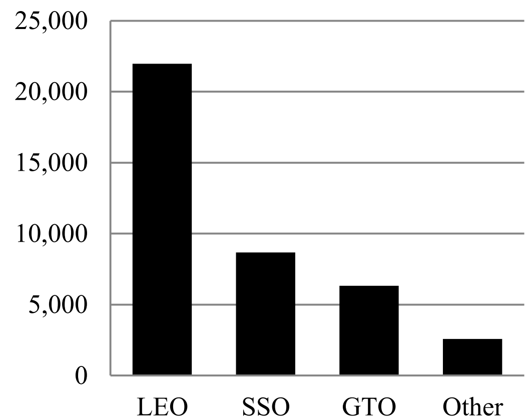


Figure 7: Cumulative unused capacity [kg] in database for each orbit. Note that polar sun-synchronous orbits are included in SSO, not LEO.

Several interesting facts are discernible from these two graphs. First, the Delta II by far has the most launches but it is third in the amount of unused capacity. This result is caused by two main factors: (1) many NASA spacecraft destined for low earth orbit were small enough to be launched with the Delta II, and (2) these launches are more likely to be to orbits for which published capacities exist.

A second trend noticeable is that Orbital Science's vehicles (Taurus, Pegasus, and Antares) have very low unused capacities. This is driven by the relatively small size of these vehicles, especially the Taurus and Pegasus. The last point is that Falcon 9, despite only having 4 launches accounts for 18,500 kg out of the 39,500 kg of total unused capacity, or 47%. One reason for the significant amount of unused capacity is that Falcon is a much newer vehicle than the others, with the exception of Antares, and as such operates with larger margins [5]. Secondly, because this includes resupply missions to the International Space Station, there were additional constraints on propellant margin in order to ensure safety of personnel.

The data may also be broken down by the destination orbit. This is done in figures 6 and 7, where the number of launches and the cumulative capacity are given, respectively. The destination orbits are broken into 4 categories: low earth orbit – LEO - (not including polar sun synchronous orbits), polar sun synchronous orbits (SSO), geostationary transfer orbits, (GTO) and other orbits. Other includes primarily earth orbits with very high apogees.

These data reveal other interesting features. Most launches are to LEO and SSO, but LEO appears to have much more unused capacity; 22,000 kg compared to 8,700 kg. However, this is largely driven by the Falcon 9 launches and when they are removed, SSO becomes the orbit with the most unused capacity.

The data can also be used to find any trends with time. This is done in figures 8 and 9, where the number of launches and the total unused capacity are given, respectively.

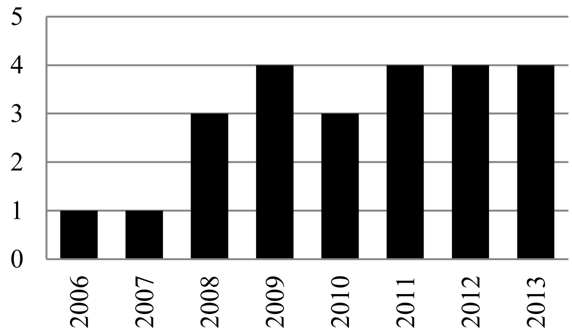


Figure 8: Number of launches per year in database

While figure 8 seems to suggest that there was a lull in launches in 2006 and 2007, in fact there were 4 launches in both years but unfortunately most of those launches were to orbits for which there is no published payload capacity. In the entire time frame there were between 3 and 6 launches each year.

Figure 9 clearly shows that the amount of unused capacity is not decreasing with time. Similar to the previous figures, these data are somewhat skewed by the Falcon 9 flights, but even without those missions there are on average 3,700 kg of unused capacity per year since 2010. This clearly indicates that the unused capacity is not decreasing with time.

## VI. VALUE OF UNUSED CAPACITY

Determining the value of the unused launch vehicle capacity will be considered further in future analyses and here only a rough approximation is presented. A 2002 study by the Futron Corporation evaluated space transportation costs and yielded the data on western launch vehicles traveling to LEO and GTO shown in table 1.

| Vehicle Class | LEO | GTO |
|---|---|---|
| Small (Pegasus, Taurus) | $8,445 | $18,841 |
| Medium (Delta II, Antares) | $4,994 | $12,133 |
| Heavy (Atlas V, Delta IV, Falcon 9) | $4,440 | $17,032 |

Table 1: Estimated price per pound of payload capacity

Using the data from table 1, we can estimate the value of the cumulative unused capacity, resulting in $663M, or averaging to $86.4M per year or $27.6M per launch. This method gives only a very approximate value because the original study was compiled using data from launches that were 6-23 years earlier than the time period used in this paper.

## VII. CONCLUSIONS

The stated goal of this work is to show that it would be beneficial for NASA to develop a policy requiring secondary and hosted payloads on future missions. The first step towards this is to show that there is substantial unused launch vehicle capacity on past NASA missions.

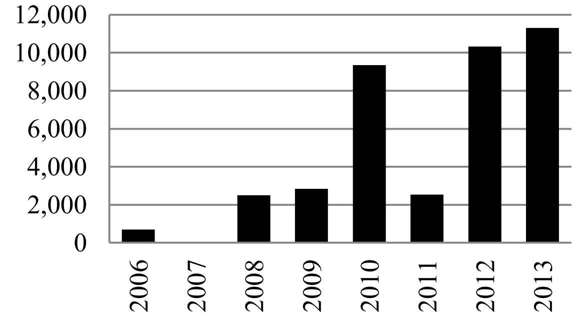


Figure 9: Cumulative unused capacity [kg] for each year of launches in database

This was done by compiling a database of all 34 launches between January of 2006 and August of 2013 and finding for each: the destination orbit, the payload capacity, and the payload mass. By analyzing these data in various ways we have identified the launch vehicles and orbits where the majority of the unused capacity lies. Additionally, the amount of unused capacity appears to be increasing with time.

A very approximate method was used to show that the value of the unused capacity is roughly $663M. Future work will focus on a more accurate model of the value of this unused capacity and to establish the types of missions that would benefit most from a SHP policy.

## VIII. ACKNOWLEDGEMENTS

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