Secondary Payloads in 2014: Assessing the Numbers

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Abstract—**In previous conferences, we have provided a brief history of secondary payloads (i.e., space missions that ride "piggyback" on the same rocket as a primary payload), with an emphasis on the census data (mass, lifetime, contributing organizations). In those conferences, we have identified a significant shift in the secondary payload market towards CubeSat-class missions; that shift has become an avalanche with more than 100 spacecraft launched in 2013.**

And although we have presented this topic several times at this conference, we believe that two reasons warrant an update: first, so many secondaries are launching in 2013 that the conclusions of 2012 must be re-examined and, second, we have updated our own database with a more thorough evaluation of mission success.

Therefore, in this paper, we will address these questions:

1) Can the launch/operations/regulatory infrastructure keep up with this avalanche of CubeSats? (Answer: yes, for now, but we fear we are one mishap away from regulatory shutdown.)

2) Are there new trends emerging in terms of the organizations and missions participating in CubeSats? (Answer: NASA, the DoD and universities are all greatly increasing participation. And we think this will all change again in 2014.)

3) Is there a response/change in the rest of the secondary payload market? Are those missions continuing in the same numbers? Are there changes in the kinds of missions pursued among the "larger" secondaries? (Answer: we still don't know. The market is very fluid.)

TABLE OF CONTENTS

1. INTRODUCTION

Rockets are expensive. Published costs begin at $20M for placing hundreds of kilograms to low-Earth orbit, and upwards of $100M for a flight to geostationary orbit. Even with new systems such as the SpaceX Falcon 9 promising to reduce those costs by a factor of 2-3, it will still be extremely expensive to put hardware in space. And, at the same time, almost every launch vehicle lifts off with extra capacity – tens to hundreds of kilograms.

It should not be surprising, then, that someone thought of ***secondary payloads***: adding a second spacecraft (or third, or more) to the same launch vehicle, making use of the rocket's mass margin that was unspent by the primary payload. The advantage of the secondary payload is the reduced price; the disadvantage is that the secondary has little to no control of the launch vehicle's target orbit or schedule.

The first secondary payload was the 20-kg SOLRAD-1, which accompanied the 100-kg Transit 2A flight in June 1960; both were Navy experiments. The first multi-agency secondary was the University of Iowa's 16-kg Injun-1, launched with Transit 4A and SOLRAD-3 in June 1961. From the 1960s through the early 1980s, secondaries were predominantly U.S. military missions. In 1981, commercial secondary opportunities became common with the advent of the Ariane ASAP platform; the second flight attempt of the Ariane-1 launch vehicle carried the AMSAT Phase-3A spacecraft. Since that time, there have been hundreds of secondary payloads.

We have discussed secondaries in each of the three previous conferences: three years, ago, we presented a statistical look at the more than 300 secondary payloads launched from 1990-2010, examining issues of mass, nations of origin and launch and mission type [1]. Examinations of the data indicated that the broad range of mission types, sizes and participating nations could be classified in several useful ways. For example, we were able to forecast a bifurcation of secondaries into the CubeSat-scale and ESPA-scale categories. Two years ago, we extended the analysis back to the first secondary payload in 1960 and updated the results to the present date [2]. We were able to confirm that the changes in the numbers and demographics of secondaries were tied to the availability of specific launch vehicles/systems (namely the Ariane, Dnepr, Shuttle and P-POD); and that the sharp increase in the number of CubeSat flights represented a significant change in the nature of secondaries. Last year, we observed that there had been almost twice as many secondaries flown in the four years from 2009-2012 than in the eight years previously (and those eight years had seen the most secondaries flown since

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the '60s). We examined the implications of having so many secondaries fly, and predicted that we were in the middle of a very significant shift in the number and nature of missions flown.

Better Data, Better Papers

Why, then, are we submitting a fourth paper? First, we have acquired more – and better – data; and second, the previous year was worth reviewing. We have further refined our database to categorize secondaries by mission type and levels of mission success. Moreover, not since the 1960s had we seen four consecutive years of more than 20 secondaries each, with a high of 36 payloads flown in one year. Not only is 2013 the fifth consecutive year of 30 or more secondary payloads, but an astonishing 115 secondary payloads are manifested for flight, nearly 3 times the previous high-water mark set in 2009. With so many new secondaries, we thought it appropriate to review our previous predictions and assessments.

The sharp increase in the number of secondaries is mainly due to the widespread adoption of the CubeSat/P-POD launch system. CubeSats did not exist in 2002, but now they are the dominant subcategory of secondaries. We will continue to study the nature and demographics of CubeSats.

Outline

Using launch manifests, catalogs of satellite orbital elements, published information and a commercial database, we have compiled a detailed list of all the secondary payloads since 1960; for the purposes of this paper, we will focus on missions from 2000-2013. We will reassess the claims of previous papers using the new data, and we will extend the previous work with additional data on mission success and failure. With this new data, we will further refine our forecasts of the launches available for various mission categories in the next few years.

Finally, we will expand our study of CubeSats, the fastest-growing category of secondaries.

Definition: Secondary Payload

For the purposes of this paper, a "secondary payload" is any self-sustained mission that is not the primary customer/payload on a launch vehicle. Our definition covers traditional secondary spacecraft mounted separately to the launch vehicle and deployed, strap-on experiments that remain with the last stage, and so-called "tertiary" spacecraft that are carried by/ejected from another spacecraft (the prime payload, or another secondary).

This definition does not cover hosted payloads, where a component or instrument is integrated with another spacecraft, drawing power, data and/or pointing from the main device. Hosted payloads are an important and successful segment of the rideshare industry. However, the metrics for hosted payloads and secondary payloads are sufficiently different that hosted payloads are outside the scope of this study

The spirit of this definition is to cover the spectrum of "piggyback" launch opportunities: taking advantage of excess launch capacity to fly a comparatively small/limited mission at a discounted price. .

To automate the process of sifting through the thousands of missions flown over the past 50 years, we use the following heuristics to identify the secondaries:

- There must be at least two spacecraft on the launch vehicle; the heaviest payload is assumed to be prime, and the rest could be secondaries. The spacecraft's COSPAR number is a good indicator; typically, the primary payload is given the "A" designation. Exceptions were made in the case of certain Dnepr launches where there may be as many as 17 payloads, and no one payload dominates the mass budget; all of the payloads are considered to be secondaries.
- The spacecraft is not in GEO; to our knowledge, there have not been any GEO "secondaries". When more than one spacecraft are on a GEO launch, they are a cost-share among co-equal spacecraft. Many GEO spacecraft have hosted payloads but, as noted previously, that is beyond the scope of this study.
- The spacecraft must have a launch mass of less than 500 kg. This restriction further enforces the philosophy of secondary launches.
- Missions involving the launch of identical/ complementary spacecraft are not considered to be secondaries. The Iridium, Orbcomm, Globalstar and Glonass constellations often fill one launch envelope with 3-6 spacecraft. This is less a secondary payload than a single primary customer making efficient use of the available capacity. This restriction eliminated more than six hundred Russian military surveillance/ communication spacecraft, as well as dozens of constellation elements noted above.

2. PRESENTATION OF DATA

This paper is based on a review of the launch history through 2013. Spacecraft information was collected from several online databases [3-6], double-checked against the Ascend SpaceTrack database, and assembled into one master list of the more than 7300 spacecraft launched through the end of 2013. We include launch failures in this list, since the missions had already committed to the secondary payload.

For the purposes of our study, the launch date of a secondary is not the date that the object lifts off from the surface of the Earth, but rather the date that the object is ejected/activated on-orbit. For example, the 28 Dove spacecraft carried by the Cygnus capsule to the ISS in December 2013 will be assigned launch dates in 2014, when they are ejected from the ISS and can begin operation. It is worth noting that this distinction is new for this paper;

before 2013, "tertiary" spacecraft usually were ejected within hours to days of launch. Now that nearly 40 spacecraft are in the queue to be carried to the ISS for ejection weeks to months later, this definition became relevant. Later in the paper, we will consider the implications of this new ISS capability.

From the list of all spacecraft launched, the subset of secondaries was identified using the rules defined above. This left 835 secondary payload missions flown in 55 years, an average of 15 per year. As shown in Figure 1, the last 14 years have exceeded the historical average, and the sequence from 2009-2012 indicates a step increase towards a new period of high-volume secondaries, more than twice the historic average. The year 2013 is a significant step increase from even the high-volume years of this century. Are the 115 secondary payloads of 2013 an anomaly, or an indication of a radical shift in space flight?

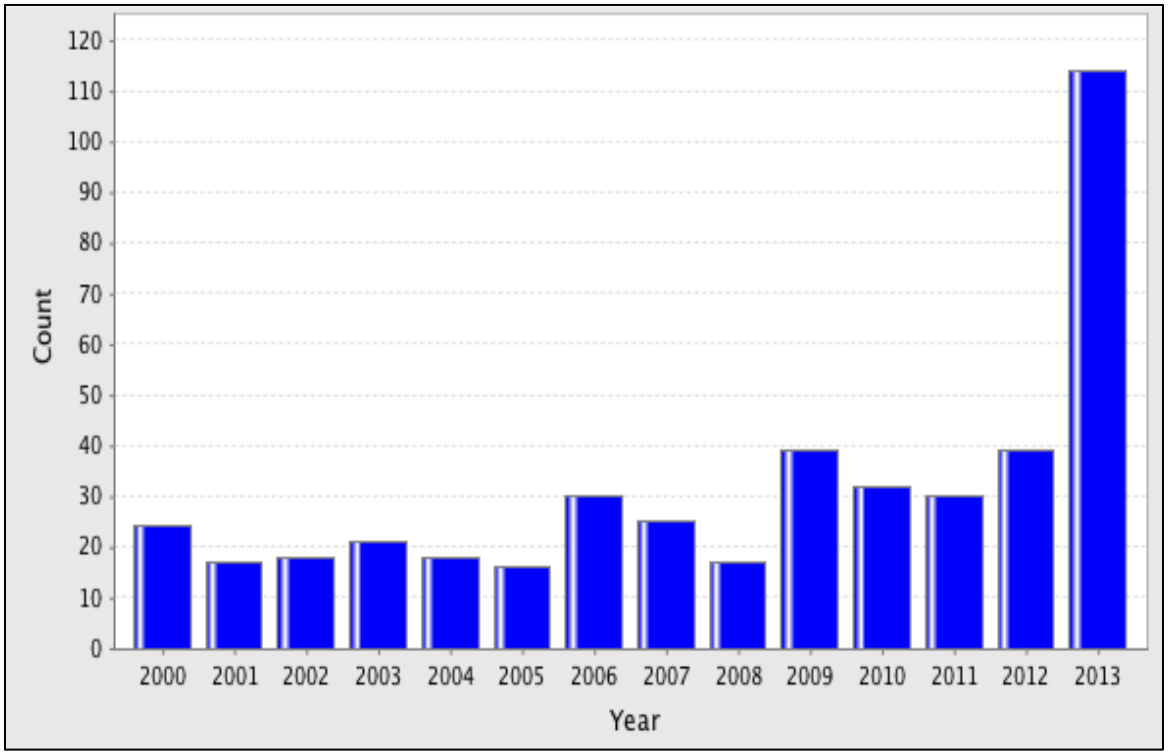

Figure 1. Secondaries Launched Per Year, 2000-2013

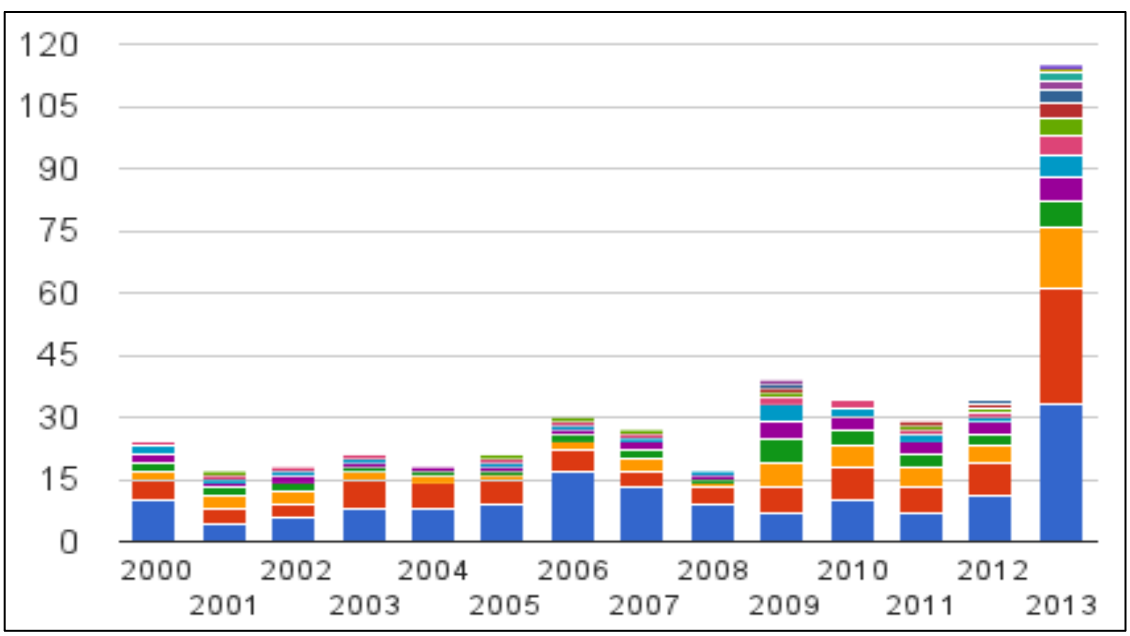

Figure 2. Number of Secondaries on Each Launch, 2000-2013. Each launch is color-coded, with the largest launch at the bottom of the stack, in blue, the second-largest launch atop it in red, etc.

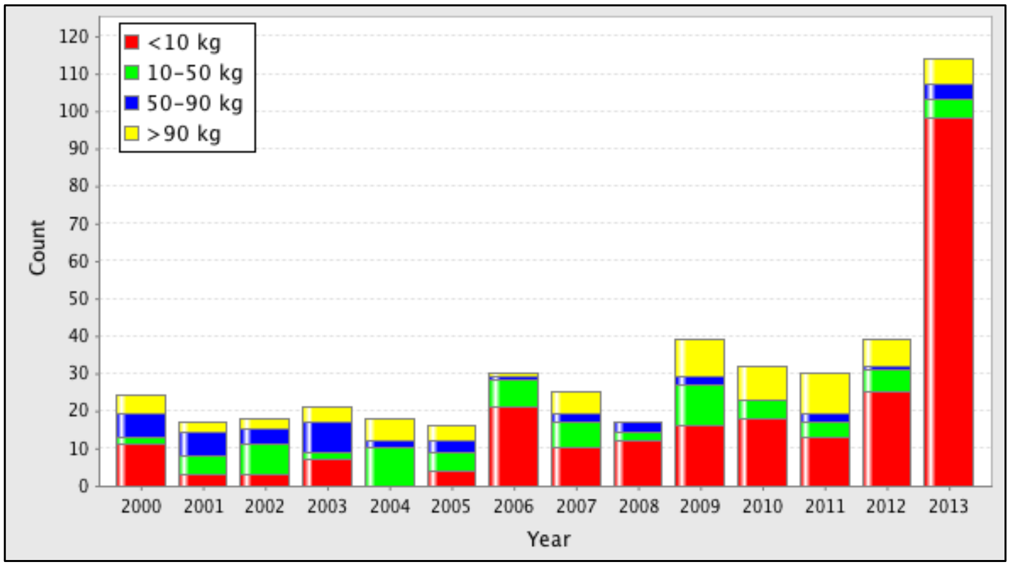

Figure 3. Secondaries by Launch Mass, 2000-2013

For the first 53 years of secondary payloads (1960-2012), secondaries comprised only 7.5% of the spacecraft flown. In 2012, 30% of the missions flown were secondaries, and in 2013, they were 53% (115 of 217). This change is worth examining. The number of launches (and thus primaries) is not decreasing; over the last 5 years, between 75 and 85 launches are attempted each year. Instead, many more secondaries are being place on the same launch. As shown in Figure 2, the manifest of 2013 is dominated by three launches, carrying 33 secondaries (Dnepr), 28 (ORS-3) and 15 (Falcon-9 Flight 8). Each of these flights carry more missions than the average number of missions flown in any calendar year, and the Dnepr flight has more secondary payloads than were flown in any year prior to 2009!

We believe that these "mega-launches" carrying 10 or more secondary payloads will become increasingly common, and thus the total number of secondaries flown will exceed 30 per year for the near future. This is not a bold prediction, as we can account for those totals in two launches: PlanetLabs is placing 28 Dove spacecraft onto the Cygnus launch in December 2013, with scheduled ejections from the ISS in 2014, and the Qb50 launch (1 rocket, 50+ spacecraft) has slipped from 2014 to 2015.

What has changed, that these mega-launches are now common, and the total number of secondaries has increased so dramatically? We identify three related trends: the space industry has finally caught up with the microelectronics revolution of the 1990s, Russia and India have developed the infrastructure to support commercial mega-launches, and both spacefaring branches of the United States have embraced the CubeSat standard. Arguably, all three of those trends are extensions of the CubeSat revolution. We will examine each of these trends, starting with CubeSats.

CubeSats

As shown in Figure 3, the total number of secondaries launched each year with mass greater than 10 kg has been roughly constant since 2000, averaging about 15 per year. The sharp increase in the number of secondaries can be attributed to the CubeSat class (which was introduced in prototype form in 2000, and the first true CubeSats were launched in 2003). As shown in Figure 4, not all spacecraft under 10 kg are CubeSats, but almost all are. CubeSats comprise 75% of the secondaries flown in 2013, and there is every indication that this trend will continue.

Three years ago, we predicted a bifurcation in spacecraft mass, driven by the launch vehicle constraints. We predicted that the standard interfaces would cause spacecraft developers to either build CubeSat-class missions (under 10 kg) or ESPA/ASAP-class missions (above 90 kg). Now, after four years of study, we must confess that the bifurcation has not happened, and may never happen. First, the ESPA capability has not become standard issue in the US, as it has for the CubeSat, and thus there is not a steady supply for larger systems. Furthermore, several launch brokers have developed standard launch adapters in the 10-90 kg range (including the University of Toronto Space Flight Laboratory and various integrators on Russian and Indian rockets). Should the ESPA ring become standard, we still believe that secondary payload missions will gravitate towards either CubeSat-class or the >90 kg class. But we are not holding our breath.

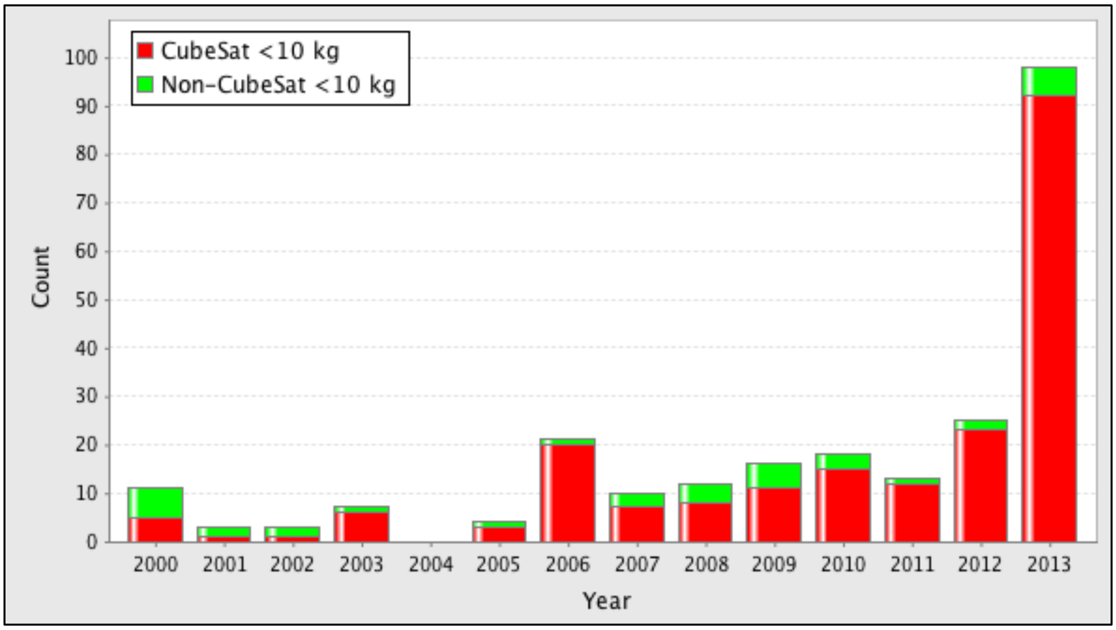

Figure 4. Number of Spacecraft Under 10 kg by Category, 2000-2013

National and International Trends

Using our database, we have also categorized secondaries by the launch provider (Figure 5), one can see that the main four providers (US, Russia, India and Japan) are all increasing their capacity over the past few years. But, as shown in Figure 6, the customers served by those nations are quite different. The US, Japan, Europe and China serve mainly their own nations, while India and Russia are open for business. As noted above, India and especially Russia have shown a willingness to sell excess capacity to secondaries. We cannot presume to know whether or not this is a profitable strategy, other than to note that both appear to be flying more secondaries, not fewer.

And while one could make the argument that ITAR restrictions are limiting the US secondary market to only American payloads, it should be noted that almost all of the secondaries launched in the US in recent years have been US government sponsored flights, either DoD-sponsored secondaries or NASA, through the Educational Launch of Nanosatellites (ELaNa) Program. With the US government supplying so many secondary opportunites to government and university payloads, there is little opportunity or interest in a commercial market. What market there is for commercial secondaries is going to Russia, apparently.

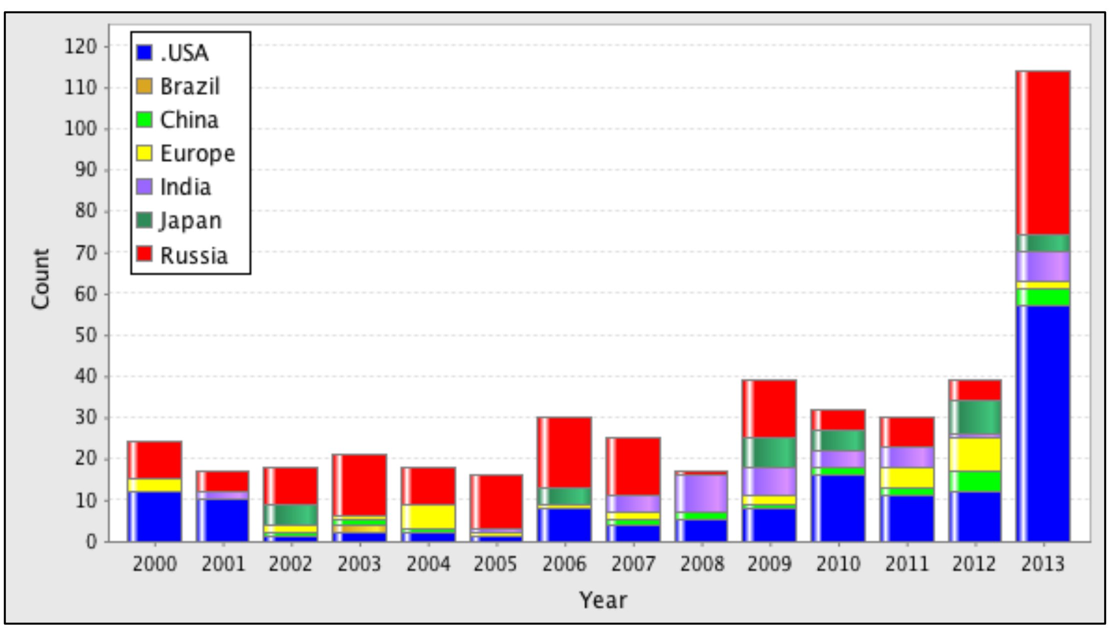

Figure 5. Missions Manifested per Year According to the Nationality of the Launch Provider, 2000-2013

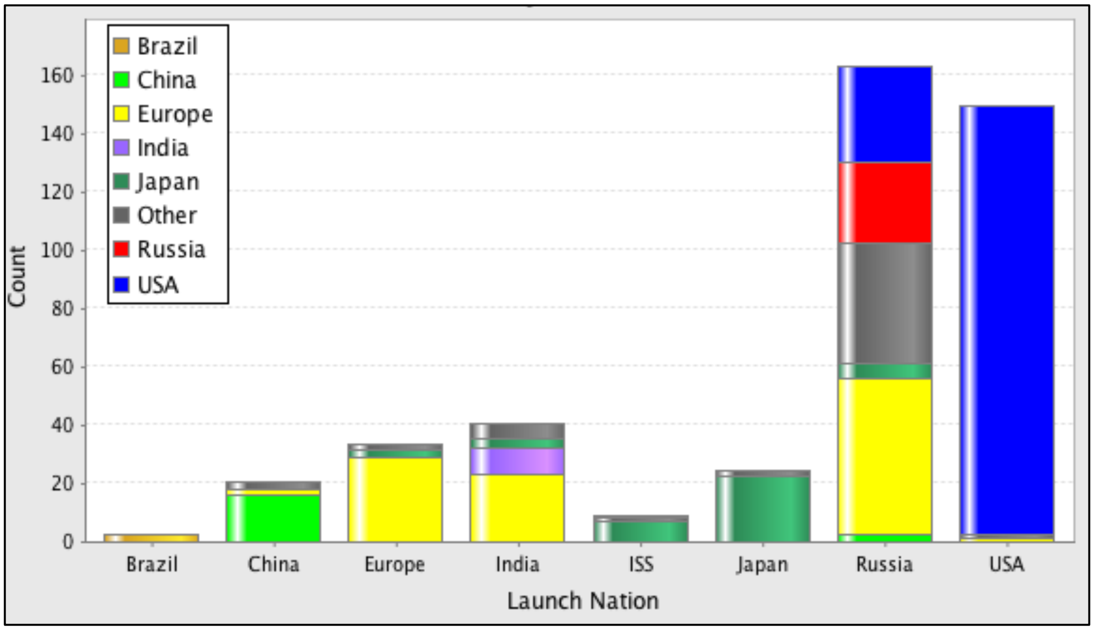

Figure 6. Nationality of Secondary Payloads, Categorized by Nationality of Launch Provider

As shown in Figure 7, the US, who had been the leading developer of secondary payloads until the 1990s, appears to be returning to that spot. Qb50 nonwithstanding, we believe that the United States will continue to be the largest developer of secondaries, driven by the launch availability. For example, NASA has a backlog of nearly 50 CubeSat missions it has selected for flight through the Educational Launch of Nanosatellites (ELaNa) program, and PlanetLabs has their 28 Dove spacecraft on track for a 2014 deployment from the ISS.

By contrast, Russia does not seem to be invested in building its own secondaries, with only handful flown in the past 10 years. This reluctance to build secondaries surprising, given that Russian rockets have flown an average of 10 secondaries per year for the past decade! However, it must be noted again that the Soviet/Russian Strela/Gonets program is responsible for producing in excess of 600 missions flown over the past 40 years, easily matching the total of all other secondaries. As noted in Section 1, we have not considered Strela/Gonets missions to be true secondaries, as multiple copies of the same spacecraft are launched together. We, at least, would find it interesting to further study the history of Russian secondaries to see if there are other cultural/economic reasons for their lack of secondary payloads.

We have also categorized all missions as being military, civil government, commercial or university (Figure 8). University-class missions indicate that the spacecraft was designed, built and operated by students, with student training elevated to one of the most important aspects of the mission. As discussed in prior papers, the first 20 years of secondaries were dominated by US military missions. Civil space missions became the dominant class of mission from 1980 until the early 1990s, when university-class missions began being manifested in large numbers. The large spike in University-class missions in 2013 is due in large part to the NASA ELaNa program. We expect that trend to continue, however, we do anticipate to see larger numbers of military secondaries in 2013-2014, mainly CubeSats. We will discuss the implications of this increase in university and military payloads in the conclusion.

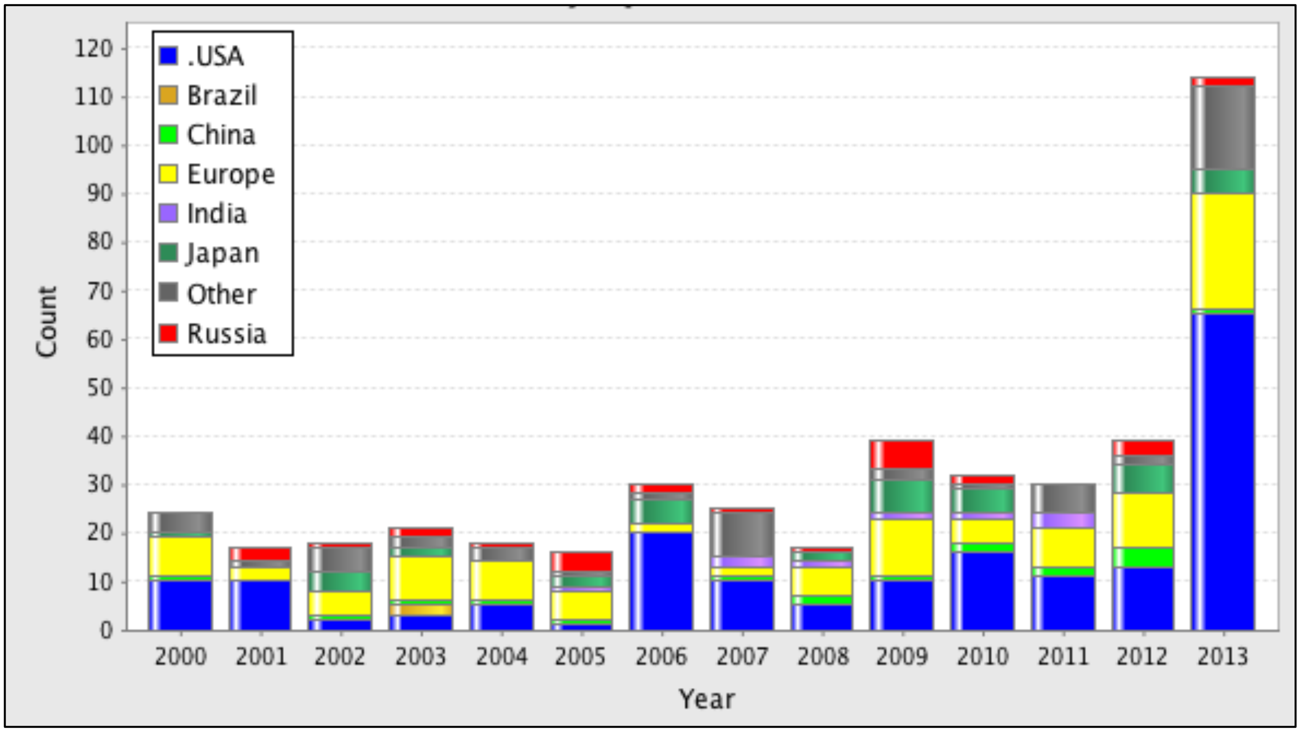

Figure 7. Secondaries by Spacecraft Nation, 2000-2013

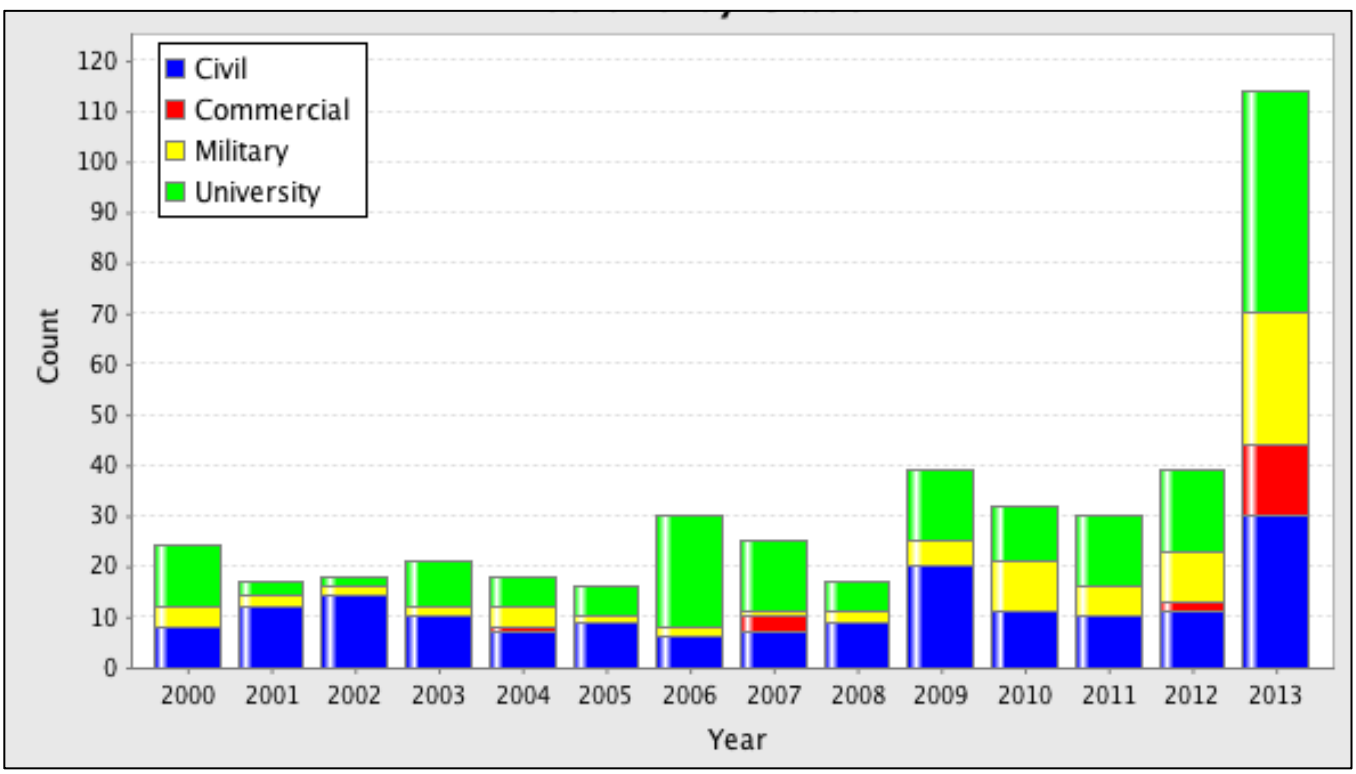

Figure 8. Secondary Payload Mission by Type of Spacecraft Developer, 2000-2013

New this year, we have categorized each secondary payload by the class of its primary mission, typically communications (including Automatic Identification System – AIS), science measurements, or a technology demonstration. As shown in Figure 9, some missions don't fit into these three categories: "other commercial" includes missions such as the Celestis capsules carrying ashes into orbit; "other military" includes ELINT and similar functions, and "educational only" indicates that the mission had no real function other than sending down telemetry and low-resolution images for the edification of the design team. Educational-only missions are sometimes called "BeepSats", and are almost all built by universities. (But not all university missions are BeepSats.)

Mission Success

Another new part of this study is an indicator of mission success. We have reviewed the reports for as many missions as we could find launched from 2000-2013, and assigned each mission a status from 0 to 5, corresponding to the major milestones in a mission's operation.

- 0 (Prelaunch). The mission has been manifested, but has not launched.
- 1 (Launched). The mission has launched. Missions lost to launch failure will have Mission Status 1.
- 2 (Ejected). The secondary has been confirmed to have ejected from the rocket. Missions that are ejected, but never contacted, have status 2.
- 3 (Commisioning). Two-way communication has been established, and the spacecraft is being commissioned for operations.
- 4 (Initial operations). The spacecraft has commenced primary mission operations.
- 5 (Mission success). Minimum mission success criteria have been achieved.

Where mission success criteria have been available, we have checked the mission status against these criteria. We have also looked for failure and anomaly reports, indicating whether a mission has completed its objectives before succumbing to failure.

As shown in Figure 10, of the 353 secondaries to have launched between January 1, 2000 and the writing of this paper (November 2013), 10% were lost to launch failures, and 23% were either never contacted or were lost soon after commissioning began. Only 67% of secondaries launched have commenced primary operations, and only 45% can be confirmed to have achieved mission success. Some of the 18% that began primary operations but have not been declared a success, 14 missions (4%) have been launched in the last two years, and can be assumed to be still working towards mission success. Another 5% are unknown, and thus might fit in the success category.

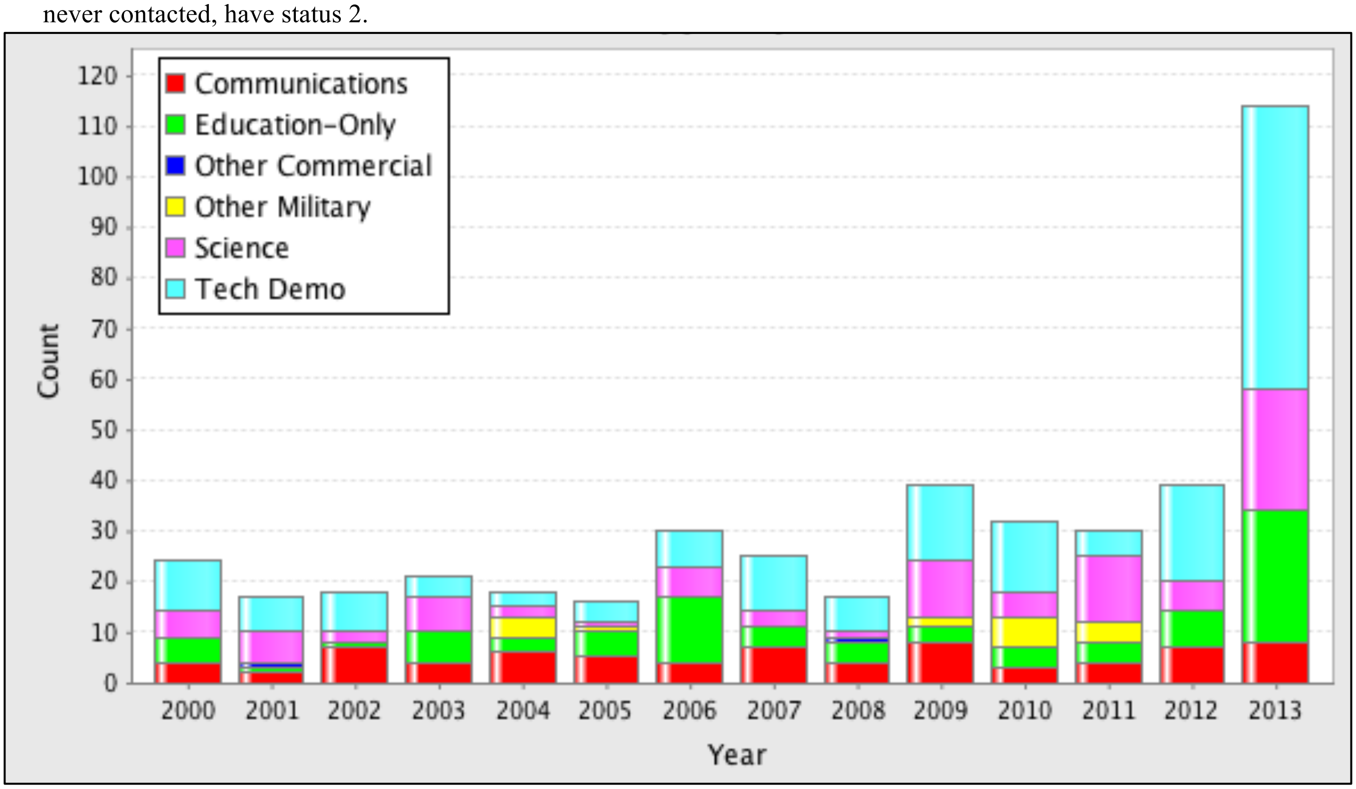

Figure 9. Mission Class of Secondary Payloads, 2000-2013

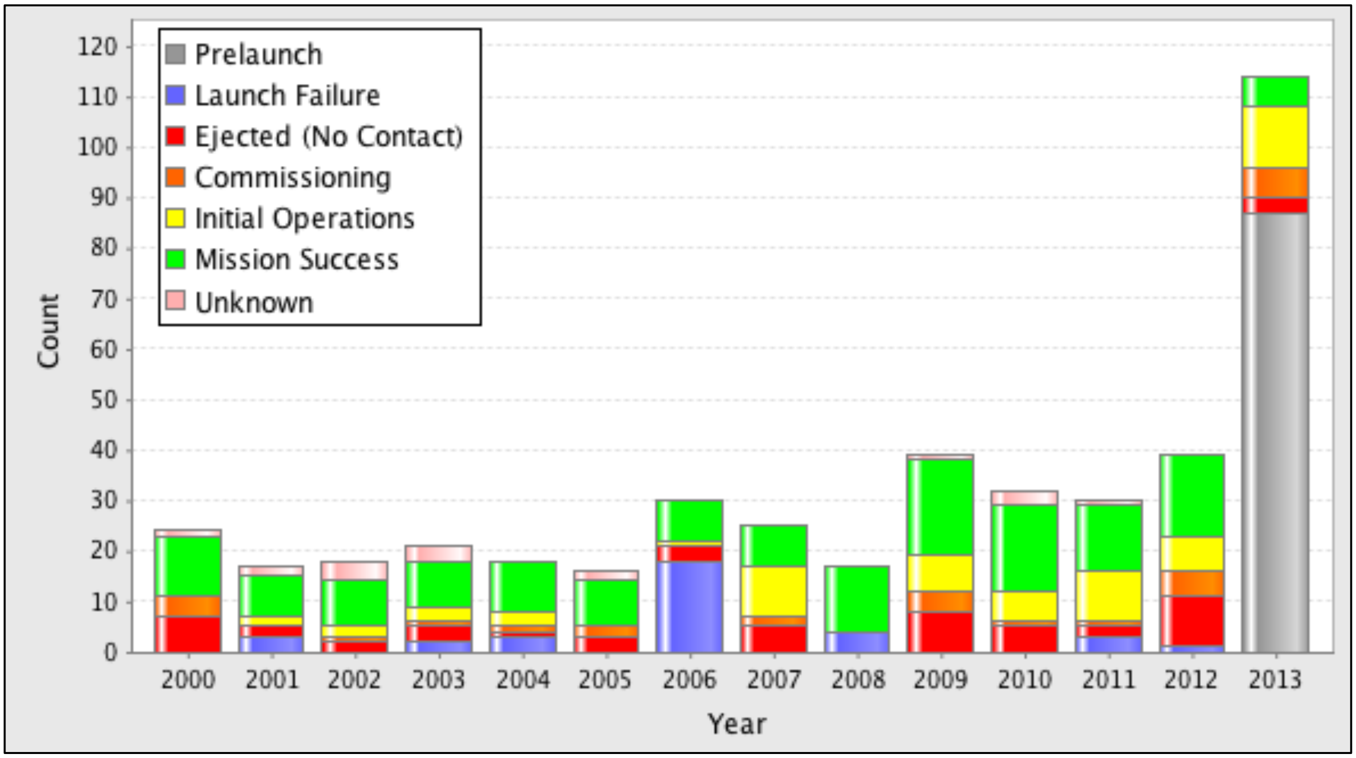

Figure 10. Level of Mission Success of Secondary Payloads by Year, 2000-2013

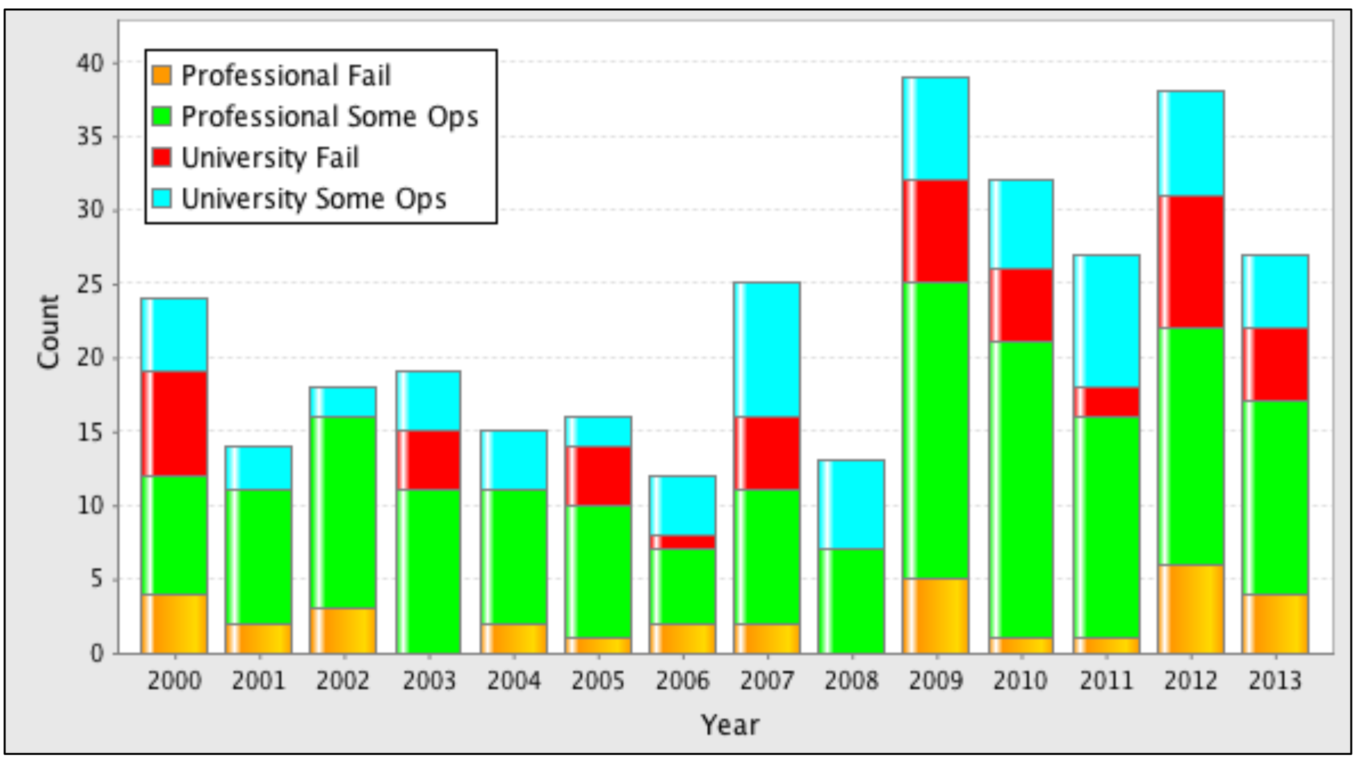

Figure 11: Mission Success by Type of Spacecraft Developer, 2000-2013

Why do so many secondary missions fall short of mission success? Well, bluntly, those failure numbers are amplified by universities (Figure 11). Of the 319 secondaries to reach orbit from 2000-2013, 197 were professional missions, and 122 were from universities. (As an aside, note that more than 60% of recent secondaries are from government agencies, contractors and private organizations. The increase in secondaries cannot be attributed to universities alone.) Worldwide, professional secondaries achieve some or all of their mission objectives 83% of the time. When looking at that number, one should note that many of the failed missions were high-risk/high-reward flights of opportunity (e.g., solar sail demonstrators). By contrast, university-led missions have a success rate of 60%. And a very large proportion of these failures are during initial separation and checkout, indicative of errors in assembly and test (e.g., correctable errors). This 40% failure rate is consistent over the past 14 years, which could indicate that universities are not getting better. However, one must take into account the fact that most of the failed missions are from programs launching their first-ever spacecraft.

3. PREDICTIONS

It is easy to look at the manifest for 2010-2013 and predict that CubeSats will dominate the secondaries for at least the near future. As noted above, the largest number of non-CubeSat secondaries launched in a given year was 30, which happened in 2013 – but there were 80 CubeSats launched in that year. There are already 60 CubeSats announced for launch in 2014, and the Qb50 constellation should launch in 2015. However, there are three factors to keep in mind:

(1) The launch rates for missions above 10 kg have been quite consistent for a decade (Figure 3), on the order of 15-20 per year (and 30 in 2013). It is only by comparison to CubeSats that they seem to be shrinking. There is every reason to believe that these opportunities will continue to be available.

(2) There are missions that require more aperture than is available on a CubeSat, and thus there will be a need for larger secondaries. When the 6U dispenser becomes available (2014), it will be interesting to see whether it provides sufficient size/mass for such missions. We expect to see a migration of the professional missions away from the 3U size to the 6U size.

(3) The Year of Reckoning for CubeSats has arrived. With more CubeSats flying this year than ever before – with more CubeSats flying this year than pretty much any class of spacecraft has flown in one year – we will have a good sense of the potential of this class. If we see failure rates on the order of 40% (the historical norm for CubeSats), then NASA and the DoD may reverse course. We fear that at least a third of the class of 2013 will fail to meet their mission objectives. But what frightens us more is the sheer logistics of launching an operating so many spacecraft. We suspect that there will be significant challenges in identifying/ tracking/ coordinating the ground operations of the 20+ spacecraft ejected on a single Dnepr flight. Even with acceptable failure rates, we believe that the number of CubeSats manifested may be reduced by the demands of logistics/management. The three main culprits (the Dnepr, ORS-3 and Falcon flight 8 launches) are all scheduled to launch after the submission of this paper, but we will be able to assess the situation at the 2014 IEEE Aerospace Conference. We fear the worst.

(4) If/when the ESPA platform becomes standard on US EELV flights, we may see an increase in the 100+ kg class missions. But we're still waiting.

For missions originating in the US, we recommend that the CubeSat platform be given serious consideration (including the 6U dispenser). The sheer number of available launches is worth the tradeoff in mission performance; missions can be performed at a fraction of the cost and in greatly reduced time. A descoped mission that fits the P-POD dispenser has a much greater chance of timely success than a larger system.

For missions originating outside the US, the CubeSat dispenser does not provide such dramatic benefits over other form factors. For now, the US CubeSat launch market (and its large supply of available launchers) is unavailable to international payload developers. ESA has created the "Fly Your Satellite" program to nuture the development of university payloads [8], but this opportunity is limited to a half-dozen schools in the first year. Moreover, as demonstrated by the many Russian and Indian launches, there is ready capacity for spacecraft larger than CubeSats. Thus, for international missions, the sacrifice in mission performance by fitting into a 6U will not be offset by a significant increase in flight availability.

4. CONCLUSIONS

Historically, secondaries were a small fraction of the total number of payloads manifested (about 7.5%). However, they have been launched in steady numbers worldwide, and those numbers are poised to increase in the coming years; in 2013, for the first time ever, more than half the missions launched were secondaries. Whether the manifests for 2014 and 2015 have such a skewed percentage, we can confidently attest that in both absolute numbers and in terms of "market share", more secondaries will fly than have ever before. Some of the credit goes to larger secondary payload missions, the bulk of the new manifests will go to CubeSat-class spacecraft.

What are the implications? First, it appears that Russian launch vehicle companies have made a business case for "prime-less" launches, where dozens of spacecraft are lofted on the same launch vehicle, but none have the rights of the primary payload. We are very interested to see whether this December 2013 Dnepr launch is the first of many, or an integration nightmare never to be attempted again. Similarly, with ORS-3, the DoD has demonstrated the ability to integrate 28 CubeSats in 16 P-PODs on a single launch ... but will they ever wish to do that again? On the one hand, the ability to integrate dozens of missions on (relatively) low-cost launchers has profound implications for continued access for secondary payloads. We may find ourselves in the very curious market condition where the supply of secondary launches exceeds the ability of the payload community to fill. (Assuming that any of these launch providers ever want to integrate so many payloads, and that the FCC, FAA, NOAA and other regulatory agencies ever recover from the shock of processing so many applications.)

We believe that this day of reckoning is a few years away. Through the ELaNa program, NASA has more than 50 CubeSats in the queue for launch, and has secondary opportunities lined up for several years. The Qb50 program is still scheduled to fly, now in 2015. With the OUTSAT and GEMSAT missions, the DoD has now qualified and flown an 8-P-POD dispenser for the Atlas V EELV. There can be no disputing that CubeSats have significantly changed the secondary launch market.

But, in our opinion, there are limits to the optimism. In the US, the CubeSat revolution has been driven by the "free launches" given out by NASA and the DoD. If those free launches were taken away, it's not clear how many of these missions would fly. Certainly, at the very least, the number of participating universities would be greatly diminished; few of us could afford to pay the $125,000 sticker price for a CubeSat launch [9].

For that reason, we are skeptical of the calls for a dedicated launcher for spacecraft of this size. CubeSats work very well as secondaries, allowing the prime to shoulder the bulk of the launch and integration costs. Without the prime to pay the bills (or at least without NASA and/or the Air Force to pay the bills), how many CubeSats will fly?

Future Work

We are still open to a revision to our original definition of secondaries. It would be beneficial to look at the Soviet Strela program (with its 600 orbital vehicles). Despite the fact that Strelas launched in groups of six on the same rocket (with no other payloads present), they might fit a modified definition of secondary payload. (In which case the Soviets were the dominant secondary payload provider/customer for the first 40 years of spaceflight.)

There are other logistic challenges to this database. NORAD has catalogued more than 38,000 distinct manmade objects in orbit since 1957. We relied on NORAD/SpaceTrak definitions to determine which of those 38,000 objects were spacecraft (as opposed to fragmentary debris and rocket bodies). It is entirely possible that secondaries were counted among the debris (or left on rocket bodies). Similarly, given the classified nature of the majority of the U.S. secondaries in the 1960s, it is very difficult to acquire data on those systems.

The task of classifying each secondary payload according to its civil, commercial, government or university nature proved to be much more difficult than anticipated; the sheer number of secondaries, the challenge of acquiring secondary payload data from the first 20 years of space flight, and the other issues with the database meant that the work is not ready completed. We believe that this topic is worth continued study. Finally, the aftereffects of the mega-launches of 2013 and 2014 will be worth reviewing.

5. ACKNOWLEDGEMENTS

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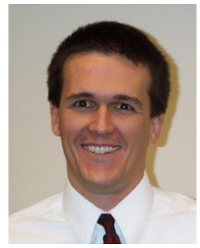
BIOGRAPHY



Michael Swartwout *is an assistant professor of aerospace and mechanical engineering at Saint Louis University. His primary research interests are in the intersection of operations, design, economics and organizational behavior, with a particular interest in the development of low-cost experimentation in space. Michael is also contributing to his secondary payload database by sponsoring two university CubeSats: COPPER, launched in November 2013, and Argus, scheduled for mid-2014. Michael earned his PhD from Stanford, where he was the project manager for the Sapphire student satellite, launched as a secondary in 2001. His BS and MS are from the University of Illinois.*