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Anthony Shao
Microcosm, Inc./University of Southern California

Elizabeth A. Koltz
University of Southern California

James R. Wertz
Microcosm, Inc./University of Southern California

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Anthony Shao
Microcosm, Inc./University of Southern California
4940 W. 147th Street, Hawthorne, CA 90250; (310) 219-2700
ashao@microcosminc.com

Elizabeth A. Koltz
University of Southern California
854B Downey Way, Los Angeles, California 90089; (310) 968-0452
chapmane@usc.edu

James R. Wertz
Microcosm, Inc./University of Southern California
4940 W. 147th Street, Hawthorne, CA 90250; (310) 219-2700
jwertz@microcosminc.com

ABSTRACT

In the present budget environment, there is a strong need to drive down the cost of space missions. There is the perception that small satellites are inherently much lower cost than more traditional, larger satellites and can play a central role in reducing overall mission cost, but this effect has been difficult to quantify. Without quantifiable evidence of their value, we believe that small satellites are under-utilized as a method for reducing mission costs.

The purpose of this study is to quantify the relationship between cost and performance for Earth observation systems. We conclude that for an Earth observation system, an increase in performance, reduction in cost, or both, is possible by using multiple SmallSats at lower altitudes when compared to traditional systems. This paper provides an estimate for the level of cost reduction. Specifically,

- Past Earth observation systems have used traditional space technology to achieve the best possible performance, but have been very expensive
  - In addition, low-cost, responsive dedicated launch has not been available for SmallSats
- Using modern microelectronics, future SmallSat observation systems, **operating at a lower altitude than traditional systems**, have the potential for:
  - **Comparable or Better Performance (Resolution and Coverage)**
  - **Much Lower Overall Mission Cost (by a factor of 2 to 10)**
  - **Lower Risk (both Implementation and Operations)**
  - **Shorter Schedule**
- Relevant secondary advantages for the low-altitude SmallSats include:
  - Lower up-front development cost
  - More sustainable business model
  - More flexible and resilient
  - More responsive to both new technology and changing needs
  - Mitigates the problem of orbital debris

The principal demerits of the approach are the lack of a low-cost, responsive launch vehicles and the need for a new way of doing business and changing the way we think about the use of space assets. This paper provides the basis for this assessment and the quantitative results.

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1. PERFORMANCE-BASED COST MODELING

In this paper, we present the relationship between cost vs. altitude (for a fixed resolution and coverage requirement), cost vs. resolution, and cost vs. coverage. The main goal of *Performance-Based Cost Modeling* (PBCM) is to quantify the relationship between cost and performance, or measures of effectiveness (MoEs). This cost/performance relationship ultimately, can allow us to pursue potentially useful mission design alternatives, such as systems that are lower cost, better performing, or both. Questions that would be useful to ask when designing a system are:

- What is the cost per level of performance? (e.g. cost/resolution, cost/coverage rate, cost/photo)
- What is the best performance that can be achieved for a fixed cost?
- What is the lowest cost option for a mission with fixed requirements?

PBCM is an approach to enable programs to be able to ask these questions early in the design phase in order to drive down cost from the outset. Our first application of the PBCM is for Earth observing systems.

Traditional cost models for space systems are typically weight-based, primarily because mass allocation is determined early in mission design, but historically correlated well with actual hardware cost. To provide the underlying cost data for this study, we apply three cost models widely used throughout the aerospace cost modeling community [Apgar, 2011]:

- Unmanned Space Vehicle Cost Model (USCM8) [Tecolote Research, 2002]
- Small Satellite Cost Model (SSCM) [Aerospace Corp., 1996]
- NASA Instrument Cost Model (NICM) [Habib-agahi, 2010]

2. PBCM TECHNIQUE AND ASSUMPTIONS FOR EARTH OBSERVING SYSTEMS

Our goal is to determine cost as a function of performance for an Earth observing (EO) system. To do this, we predict the life-cycle costs by using the models listed above (USCM8, SSCM, and NICM) and define the performance as measured by two parameters; (1) the resolution at nadir, and (2) the area coverage rate. For a baseline mission, we will assume the following performance requirements:

- Imaging in the Visible
- Resolution = 0.5 meter at nadir
- Area Access Rate = 14,200 km^2/sec
- Mission Lifetime = 8 years

The coverage rate of 14,200 km^2/sec corresponds to the area access rate (AAR) of a system in a circular orbit at 800 km with a minimum working elevation angle of 30 deg. In order for a satellite at this altitude to meet the 0.5 m resolution requirement, the system will have a 0.88 m aperture telescope. We will define this as our baseline system with an 8-year design life. If the satellite life at a particular altitude is, for example, 4 years, then we will need twice as many satellites to cover the full 8-year mission duration. Similarly, if the coverage at a given altitude is one third of the baseline value, then we will need triple the number of satellites to provide the same coverage.

In order to achieve the same resolution with diffraction-limited optics, we vary the aperture size in direct proportion to the altitude. Thus, at 400 km, we use an aperture of 0.44 m to achieve the same 0.5 m resolution. We assume that mass is proportional to the cube of the linear dimensions, which translates to assuming that the spacecraft dimensions scale linearly with the aperture and that the density of the various spacecraft are approximately the same. (The assumption of common density was validated by Reeves [1999].) Our baseline spacecraft dry mass at 800 km is then estimated to be 1,559 kg, corresponding to a typical observing satellite at that altitude. (The actual value has very little effect on the results when comparing costs, since it is the ratio of the masses that matters.)

At lower altitudes, we assume a shorter satellite design life. To make the model simple, we assume a design life proportional to the altitude, such that the design life is 8 years at 800 km, 4 years at 400 km, and 2 years at 200 km. Therefore, we will need more satellites at lower altitudes due to the shorter design life and the reduced coverage. Because the design life is shorter, we can assume less redundancy, and therefore lower mass at lower altitudes. As an initial estimate, we have reduced the mass/satellite as a function of altitude and also required 10% more satellites to cover potential launch failures.

Table 1. Input Data for the Earth Observing Performance-Based Cost Model

Mission Performance Requirements and Assumptions	Value
Resolution Requirement (m)	0.5
Area Access Rate (AAR) Requirement (km^2/sec)	14,200
Mission Life Requirement (yrs)	8
Wavelength to Observe (nm)	550
Payload % of Total S/C Dry Mass	31%
Propellant % of Total S/C Dry Mass	27%
Spacecraft Power/Spacecraft Dry Mass (W/kg)	1.30
Payload Power % of Spacecraft Bus Power (W)	46%
Spacecraft Datarate at 800 km Altitude (kbps)	800,000
Minimum Working Elevation Angle (deg)	30
Percentage of Launches that Fail	10%
Minimum Number of Satellites for No System Redundancy	2
Learning Curve	90%
Amortization Rate	8.0%
Cumulative Savings Effect of Amortization	19%
For Future Use:	
Launch Cost/kg to LEO for Payloads < 2,268 kg (FY13$)	$23,502
Launch Cost/kg to LEO for Payloads 2,268 - 11,340 kg (FY13$)	$12,548
Launch Cost/kg to LEO for Payloads > 11,340 kg (FY13$)	$11,777

Finally, there are financial issues associated with the satellite lifetime and the number of satellites required for the mission. We have defined an upfront cost equal to the non-recurring development cost plus the first production unit, often called the *theoretical first unit* (or TFU). The remainder of the spacecraft are built assuming a 90% learning curve, which is conservative for space products [NASA, 2008a]. Another advantage to building multiple satellites is that they don't all have to be built prior to the first launch. The production of the satellites can be spread out over time and, therefore, paid for over time. For this effect, we have initially used an 8% amortization rate and a total impact of amortization of a 19% reduction in cost for units built after the first one [Shao and Koltz, 2013].

All of the input assumptions are summarized in Table 1. Because there are a large number of assumptions, we looked at the impact of how varying each of the input assumptions affects the final results. Varying the inputs assumptions changed the numerical values of the results, essentially moving the result curves up and down (in Fig. 3), but does not change the relative results or the nature of the conclusions.

This model allows the user to change any of the assumptions very easily. A more detailed assessment will be done to determine the relationships and their impact on changing each assumption [Shao and Koltz, 2013]. The summary of other assumptions we've made to generate the results are consolidated in the listed below:

- The optical payload assumes diffraction limited optics
- Space system mass is proportional to the cube of the linear dimensions – equivalent to saying that most spacecraft have about the same density
- Non-redundancy mass reduction factor – A 5% reduction in estimated mass for every year the design life is reduced starting at 8 years (e.g., 10% for 6 yrs, 20% for 4 yrs, 30% at 2 yrs)
- All missions are flown in a circular orbit
- All missions work at the same minimum elevation angle of 30 deg
- Design life is proportional to altitude (e.g., 8 yrs at 800 km, 2 yrs at 200 km)
- Wright learning curve for multiple units
- Costs postponed due to spacecraft being built and launched later are reduced to Present Value to account for the value of delayed spending

One of the parameters that has not yet been modeled is the launch cost. Again, we expect this cost to change the numerical results, but not the relative results. At high altitudes, we have a small number of larger satellites and at low altitudes we have a large number of much smaller satellites. Generally, the cost/kg will be higher for the smaller satellites, but the total mass launched to orbit (the number of satellites times the mass per satellite) is much less (Table 2, line 17), such that we anticipate only a small impact on the results. This will be quantified in later work.

Table 2. Physical Parameters of 3 Select Mission Altitudes and 3 Example Observation Systems (PBCM Version 1).

	Physical Parameters	Model Predictions			Examples		
					NanoEye	Quickbird	GeoEye-2
1	Orbital Altitude (km)	200	400	800	215	482	681
2	Resolution (m)	0.5	0.5	0.5		0.65	0.32
3	Payload Aperture Diameter (m)	0.22	0.44	0.88	0.23	0.60	1.10
4	Spacecraft Dry Mass (kg)	24.4	194.8	1,558.6	23.0	995.0	2,086.0
5	Non-Redundancy Mass Reduction	30.0%	20.0%	0.0%			
6	Corrected Spacecraft Dry Mass (kg)	17.0	155.9	1,558.6			
7	Spacecraft Wet Mass (kg)	21.6	197.9	1,979.4	76.4	1,028	2,540
8	Payload Power (W)	10.2	93.5	935.2			
9	Payload Datarate (kbps)	273,345	489,309	800,000			
10	Spacecraft Area Access Rate (km^2/sec)	4,858	8,696	14,217	5,177	10,034	12,819
11	Satellite Orbital Period (min)	88.5	92.6	100.9	88.8	94.2	98.4
12	Spacecraft Design Lifetime (yrs)	2	4	8	2.15	4.82	6.81
13	No. of Sats Needed for Same Coverage at Any Given Time	2.9	1.6	1.0	2.7	1.4	1.1
14	Number of Satellites Required for Entire Mission	11.7	3.3	1.0	10.2	2.4	1.3
15	Number of Redundant Satellites	1.2	0.3	0.0	1.0	0.2	0.0
16	No. of Satellites to Build w/ System Redundancy*	12.9	3.6	1.0	11.2	2.6	1.3
17	Total Launch Mass (kg)	279	712	1,979	859	2,659	3,309

* Note that fractions of satellites have been allowed in this model for purposes of comparison simplicity and a smoother display of results

3. PRELIMINARY RESULTS FOR EARTH OBSERVING SYSTEMS

3.1 Physical and Cost Parameters

We selected 3 mission altitudes of 200 km, 400 km, and 800 km and applied the technique and assumptions described in the previous section and in greater detail in a separate report [Shao and Koltz, 2013]. Table 2 shows the results for each of the physical parameters. We also have provided 3 real observation system examples for reference, which include NanoEye [Wertz, Van Allen, and Barcley, 2010], Quickbird [Digital Globe, 2013; Spaceflight Now, 2000], and GeoEye-2 [GeoEye, 2013; Space News, 2012]. We start off by determining the payload aperture diameters using diffraction-limited optics and we see that the aperture is linearly proportional to the mission altitude (i.e., 0.22 m at 200 km, 0.44 m at 400 km, and 0.88 m at 800 km). The payload power and data rates are estimated by the methods described by Shao and Koltz [2013]. As can be seen in Table 2, the payload power and datarate scale proportionally to the mission altitude as well. **For a fixed resolution, we see that the spacecraft mass required at 200 km is 17 kg, but is almost 2 orders of magnitude larger (1559 kg) at 800 km.** This is a very significant difference in mass and will generate a substantial difference in mission cost, as will be seen in Table 3.

You can see that the AAR is less at lower altitudes, and therefore will require additional satellites to satisfy the coverage rate requirement of 14,200 km^2/sec. Thus, the number of satellites needed to support the same coverage rate at 800 km, is 2.9 at 200 km and 1.6 at 400 km. Then based on the design life of each spacecraft and accounting for launch failures, we determine the number of satellites required for the entire 8-year mission. For the baseline mission providing 0.5 m resolution in the visible at the required AAR, for 8 years, our 3 options are:

A. 1.0 1,559-kg traditional large satellite flown at 800 km

B. 3.6 156-kg satellites flown at 400 km

C. 12.9 17-kg SmallSats flown at 200 km

Notice the last line in Table 2 shows us that even with approximately 13 satellites, the total launch mass for the mission at 200 km is only about 280 kg compared to the ~2,000 kg single traditional large satellite needed to satisfy the mission at 800 km. **Reducing the altitude by a factor of 4, reduces the total launch mass by nearly an order of magnitude.**

The projected cost values, in constant year dollars, for several cost items using USCM8 and NICM is displayed in Table 3a, and for comparison using SSCM in Table 3b. The key cost values here are:

- The total upfront cost (line 2)
- The remaining recurring cost with learning curve (line 6)
- The total adjusted system cost after amortization (line 12)

The total upfront cost for both the 200 and 400 km mission are much less than the upfront cost for the 800 km mission. However, both missions at the lower altitude have additional costs associated with the

Table 3a. Cost Predictions for the 3 Selected Altitudes using USCM8 and NICM [Apgar, 2011], and 3 Example Observation Systems (PBCM Version 1).

	Cost Estimates - USCM8 and NICM (from SME)	Model Predictions			Examples		
					NanoEye	Quickbird	GeoEye-2
1	Orbital Altitude (km)	200	400	800	215	482	681
2	Total Upfront Cost (FY13$M)	$41.39	$209.24	$1,181.83	$12.0	$60.0	$835.0
3	Total NRE Cost (FY13$M)	$19.60	$131.93	$909.61	$10.0		
4	TFU or T1 Cost (FY13$M)	$21.79	$77.31	$272.22	$2.0	$60.0	$835.0
5	Total RE Production Cost w/ Learning Curve (FY13$M)	$190.24	$228.91	$272.22	$22.5	$134.3	$1,045.0
6	Remaining RE Production Cost w/ Learning Curve (FY13$M)	$168.45	$151.60	$0.00	$20.5	$74.3	$210.0
7	Average RE Unit Cost per Spacecraft (FY13$M)	$14.77	$63.64	$272.22	$2.0	$51.9	$835.0
8	Nth (Last) Unit Cost (FY13$M)	$12.77	$58.68	N/A	$2.0	$50.6	N/A
9	Equivalent Present Value of Amortized Cost (FY13$M)	$136.42	$122.77	$0.00	$16.6	$60.2	$170.1
10	Total System Cost Before Amortizing (FY13$M)	$209.84	$360.83	$1,181.83	$32.5	$134.3	$1,045.0
11	Total System Cost to be Amortized (FY13$M)	$168.45	$151.60	$0.00	$20.5	$74.3	$210.0
12	Total Adjusted System Cost After Amorizing (FY13$M)	$177.81	$332.01	$1,181.83	$28.6	$120.2	$1,005.1

Table 3b. Cost Predictions for 3 Select Mission Altitudes using SSCM [Apgar, 2011], and 3 Example Observation Systems (PBCM Version 1).

	Cost Estimates - SSCM (1996) (from SME)	Model Predictions			Examples		
					NanoEye	Quickbird	GeoEye-2
1	Orbital Altitude (km)	200	400	800	215	482	681
2	Total Upfront Cost (FY13$M)	$4.65	$43.30	$753.22	$12.0	$60.0	$835.0
3	NRE Cost (FY13$M)	$2.22	$26.98	$567.10	$10.0		
4	TFU or T1 (FY13$M)	$2.43	$16.32	$186.11	$2.0	$60.0	$835.0
5	Total RE Production Cost w/ Learning Curve (FY13$M)	$21.24	$48.32	$186.11	$22.5	$134.3	$1,045.0
6	Remaining RE Production Cost w/ Learning Curve (FY13$M)	$18.81	$32.00	$0.00	$20.5	$74.3	$210.0
7	Average RE Unit Cost per Spacecraft (FY13$M)	$1.65	$13.44	$186.11	$2.0	$51.9	$835.0
8	Nth (Last) Unit Cost (FY13$M)	$1.43	$12.39	N/A	$2.0	$50.6	N/A
9	Equivalent Present Value of Amortized Cost (FY13$M)	$15.23	$25.92	$0.00	$16.6	$60.2	$170.1
10	Total System Cost Before Amortizing (FY13$M)	$23.46	$75.30	$753.22	$32.5	$134.3	$1,045.0
11	Total System Cost to be Amortized (FY13$M)	$18.81	$32.00	$0.00	$20.5	$74.3	$210.0
12	Total Adjusted System Cost After Amorizing (FY13$M)	$19.88	$69.22	$753.22	$28.6	$120.2	$1,005.1

mission (i.e. the remaining production cost). **Even without adjusting the cost due to advantages of amortization, the total system cost (line 10) shows that at lower altitudes the life-cycle costs are much less, even with many more satellites to build.** (Again, the life-cycle cost in this version of the PBCM does not include launch or operations cost. However, it is predicted that adding these in later versions will not affect the relationship between the altitude and the final total mission life-cycle cost.)

Results from Table 3b have notably different values because USCM8 is developed by parametric cost modeling of traditional large satellite systems, and the SSCM is derived from parametric cost modeling of SmallSats [Apgar, 2011].

3.2 Cost vs. Coverage

Figure 1 shows the relationship between cost and coverage for 2 mission altitudes at a fixed resolution of 0.5 m. In order to have twice the coverage at a given altitude, it takes twice as many satellites, which increases the cost by approximately 1.8 times. (Recall that we introduced a 90% learning curve in this model to account for the production of multiple units.) **Flying high increases cost because it is more expensive to achieve a given resolution**.

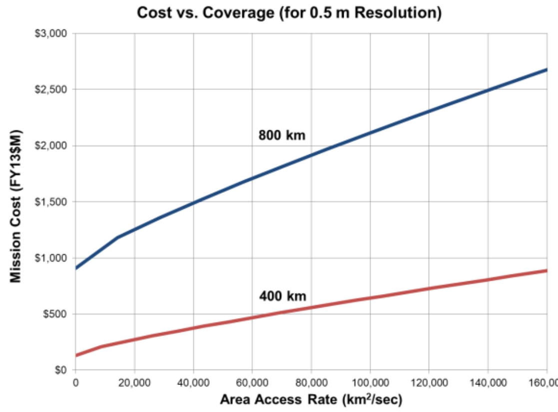

Figure 1. Cost vs. Coverage for a 0.5 m Resolution Requirement at 400 km and 800 km.

3.3 Cost vs. Resolution

Figure 2 shows the relationship between cost and resolution for 2 mission altitudes. For a given mission altitude, if a higher resolution is desired, you must build a larger satellite and, therefore, spend more money. **At any altitude, twice the resolution increases the spacecraft mass by 8 times and increases the cost by about 4.5 times.**

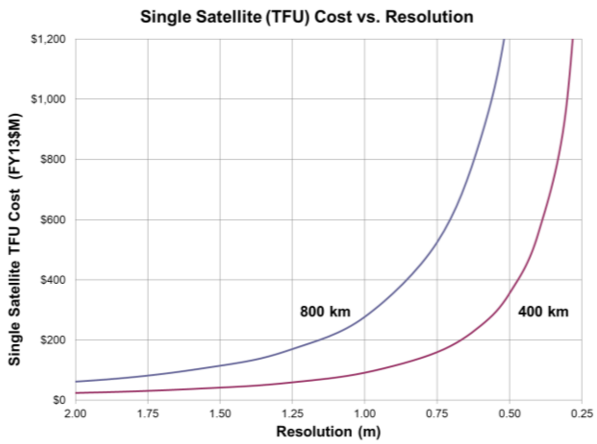

Figure 2. Single Satellite Theoretical First Unit Cost vs. Resolution at 400 km and 800 km.

3.4 Cost vs. Altitude for Fixed Resolution and Coverage

The relationship between total mission life-cycle cost and altitude for a fixed resolution and fixed coverage requirement is shown in Fig. 3 over a range of altitudes in LEO. In the figure, the blue lines represent predictions using USCM8 and NICM, and the red lines represent predictions using SSCM. The solid lines represent the cost predictions using spacecraft bus mass values that fall within the range specified by the cost models. Extrapolated predictions based on values that are outside these specified mass ranges are indicated by the dotted lines in Fig. 3. The Standard Error of the Estimate (SEE) of 34% has been added to the plot as vertical dashed bars.

The results clearly show that using smaller satellites at lower altitudes can provide much lower cost missions for an observation system with specified performance requirements. We have also included 3 real observation systems as examples for comparison against this model. There have been many assumptions made to produce the results of this PBCM. However, changing the values of these assumptions, do not change the shape of the curves in Fig. 3. That is, **the relationship between mission cost and altitude remained the same over a very wide range of assumed inputs** because the shape of these curves depend only on physics and the empirical mass-based cost models.

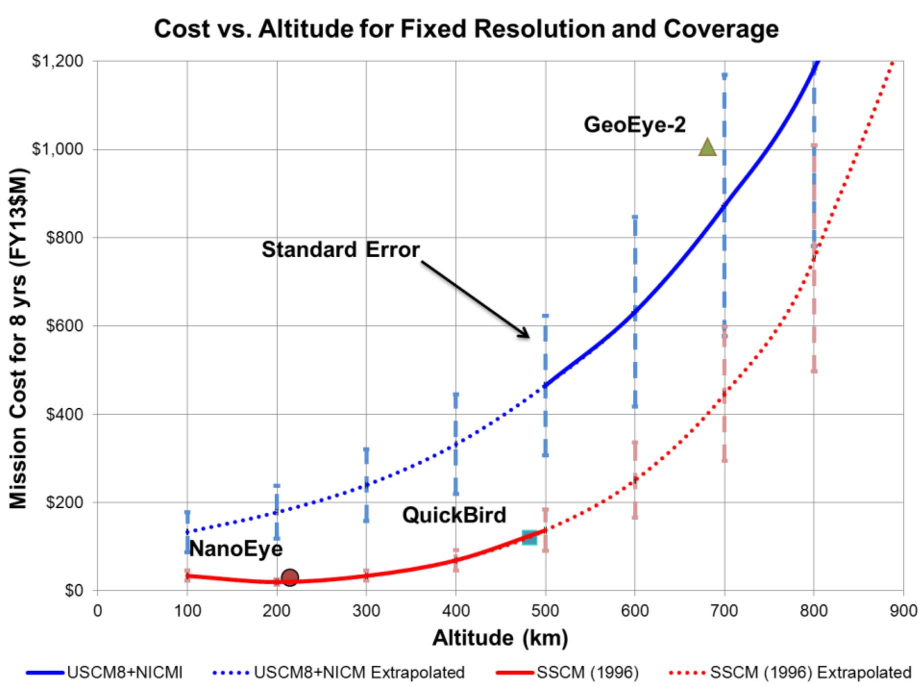

Figure 3. Cost vs. Altitude for a Fixed Resolution (0.5 m) and Coverage Rate (14,200 km^2/sec). The mission cost, in PBCM Version 1, excludes cost associated with launch and operations.

Our most substantive conclusion is that **by significantly reducing the altitude of an Earth observation system, we can achieve the same performance in terms of resolution and coverage, but at dramatically less cost**. Why is that the case? Basically, if we reduce the altitude by a factor of 2, we will also reduce the sensor aperture and linear dimensions of the spacecraft by a factor of 2. This reduces the volume and mass of the spacecraft by a factor of 8, which, according to the traditional mass-based cost models, reduces the cost by a factor of about 4.5. We will likely need more spacecraft at the lower altitude because of reduced coverage per satellite and possibly a shorter design life or greater atmospheric drag, but even with more spacecraft, it will be a much lower cost and more robust system that is less sensitive to spacecraft or launch failures. In addition, schedules are shorter, spending is spread out over time, and the problem of orbital debris essentially goes away below roughly 500 km [Wertz, et al. 2012]. This path has the potential to be an important option for Earth observing systems, particularly in times of critical budget problems.

5. SMALLSAT SCHEDULES, RELIABILITY, AND RISK

SmallSat missions provide much shorter schedules, comparable reliability, and significantly less risk than traditional large satellite missions. SmallSat schedules are much shorter than for traditional satellites [Shao and Koltz, 2013]. For instance, according to the Performance of Defense Acquisition System Annual Report [DoD, 2013a], traditional major defense programs take 8.8 years in development (Milestone B) and well over 10 years from Milestone A to implementation. Reliability of SmallSats (including single-string SmallSats) is essentially similar to that of traditional large satellites according to a Goddard study [NASA, 2008] of over 1,500 spacecraft launched between 1995 and 2007.

Risk is defined as the probability of a negative event times the impact or consequences of that event. Non-recurring cost for SmallSats is 1 to 2 orders of magnitude less than for traditional satellites [NASA, 2008b]. Therefore, implementation risk is low due to low non-recurring cost and short schedules. The consequences of failing to implement a SmallSat system will not endanger the larger, more traditional system. Operational risk of SmallSats is also much lower than traditional systems due to shorter operational life and the availability of spares (on orbit or on the ground) or back-up. SmallSats also support the DoD objective of disaggregation [DoD, 2013b]. Shao and Koltz [2013] provide a study on SmallSat Schedule, Reliability, and Risk.

6. CONCLUSIONS FOR SMALLSAT EARTH OBSERVING SYSTEMS

Past Earth observation systems have used traditional space technology to achieve the best possible performance, but have been very expensive. In addition, low-cost, responsive dedicated launch has not been available for SmallSats. However, using modern microelectronics, future SmallSats observation systems at a lower altitude than traditional system have the potential for many substantial capabilities.

> **Due to advancements in technology and modern microelectronics, SmallSats at lower altitudes now have the potential for much lower overall mission cost, comparable or better performance, lower implementation and operations risk, and shorter schedules.**

Some relevant secondary advantages for low-altitude SmallSats include:

- Lower up-front development cost
- More sustainable business model
- More flexible and resilient
- More responsive to both new technology and changing needs
- Mitigates the problem of orbital debris

SmallSat observation systems need greater field of view (FoV) agility than larger, higher altitude systems. The needed agility is inversely proportional to altitude, but moments of inertia are also much smaller. Responsive, low-cost, small launch systems are needed for operational missions. All of this requires changing the way we do business in space and how we think about using space systems. This culture change is probably the most challenging thing, and the USC/Microcosm *Reinventing Space Project* [2013] is directed at continuing to find ways to make progress in this direction.

7. FUTURE WORK

There are plans to update this model to include other estimation techniques, other cost factors, and new and updated cost models. The 2 main additions are adding launch costs and operations costs. We ultimately would like to expand the PBCM capability to communication systems and other types of missions. The PBCM is one of many ways the *Reinventing Space Project* [2013] plans to research potential ways to reduce space mission cost.

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9. APPENDIX

Cost vs. Cost Overruns

Cost overruns, i.e., cost in excess of the original budget, are typically the primary concern for government acquisition. This is a management problem associated with cost performance relative to expectations and relative to the total amount of money available for a set of tasks. They are also a problem for the contractor since overruns erode their credibility and may reduce the available fee. This problem is most easily resolved by simply reducing expectations. For example, if we originally planned to buy 100 airplanes for $10 billion, but changes in the system have made each plane more expensive, then the easiest solution is to simply reduce the number of airplanes to, say 75, to keep the budget at $10 billion. Both the contracting process and contractor are satisfied and the cost overrun disappears.

The problem, of course, comes in when trying to meet the needs of the end user. In our airplane example, we were buying the planes to accomplish a set of missions, presumably with a few extra planes to account for maintenance and downtime. But now we have only three-quarters as many planes as we needed. This means fewer missions can be accomplished, either because of the smaller number of planes or because we had to divert resources from some other activity to buy the additional 25 planes. From the point of view of the end user, it isn't the management problem of cost overruns that is important, but rather the problem of how much performance can we achieve for how much money.

A second distinction arises depending on whether the program is an operational activity or an R&D activity. For operational programs, such as GEO communications satellites, cost overruns are both important but bad. For these systems, cost should be well understood and well controlled. However, for R&D programs some amount of cost overrun should be acceptable and expected. If there are never any overruns in R&D programs, then we're clearly not pushing hard enough on cost reduction, and we should make our cost goals more aggressive.

For the purpose of creating much lower cost, high utility missions, cost (and schedule) for a given level of performance should be our measure of success, **not** whether cost overruns occur. This alternate approach is a major purpose of creating Performance-Based Cost Modeling.