# A COST MODEL FOR A UNIVERSITY SATELLITE PROGRAM

Emery I. Reeves<sup>®</sup> Visiting Scholar U.S. Air Force Academy U.S. Air Force Academy CO 80840

#### Abstract

A number of universities are involved in designing small satellites for research or for educational projects. The amateur radio community is also engaged in similar projects. Study of the economic basis for these projects shows a number of common elements such as the number of people involved, degree of dedication, use of available hardware, and schedule span times. This paper is an attempt to summarize this experience and formulate a common economic model as an aid to planning future projects and examining process characteristics of such programs.

#### **Introduction**

## <u>Purpose of paper</u>

ecres

A small number of universities have instituted spacecraft design programs under several guises. In some cases they are full blown research programs aimed at examining new spacecraft design technology or providing principal investigators with access to space for research. Other programs are conducted by student groups, sometimes supplemented by volunteers, with varying degree of faculty participation<sup>1,2,3,4</sup>. The amateur radio community has launched and operates a number of spacecraft which are used for

communication experiments and a variety of amateur radio projects<sup>5</sup>. All of these spacecraft are small, typically less than 50 kg., and most of them have performed quite well<sup>6</sup>. They also are not very expensive on a per unit basis. Several years ago these spacecraft were called "lightsats" however this term has been usurped by the government/aerospace industry to describe any satellite of less than mammoth proportions. In this paper, I will refer to the small satellites designed by the university/ amateur community as "cheapsats" not to denigrate their quality or performance but merely to differentiate them from the current crop of small "largesats". This paper discusses the cost of these programs, methods commonly used to keep the costs low, and a comparison of these costs to larger programs.

#### Nature of model

Costs of any program are of two types: direct and indirect. Direct costs are labor and material. Indirect costs include facility related expenses (buildings, tools, equipment) and personnel related expenses. For this model, both types of cost are treated in a single wrap number of \$100,000 per person year. Obviously salary is only a portion of this number since indirect costs generally exceed half of the cost per labor unit and any single number is an average over all labor categories. True

Visiting Scholar, Department of Astronautics Associate Fellow AIAA

average labor cost is probably neither significantly less or much larger than this number.

Material costs are usually a small portion of a spacecraft program. This is true of largesat programs as well as light sats and cheapsats. However sometimes the separation between labor and material cost is fuzzy because components or assemblies are purchased or subcontracted. In this paper, I restrict material costs to individual piece parts and stock materials. As far as more complex assemblies and components, this cost model assumes that cheapsat programs rarely use "space" hardware. Instead, with a few exceptions, they use terrestrial hardware and modify it for space use or they build from scratch. Under this presumption, any off the shelf

item whether raw stock, a piece part, or a manufactured item is considered material. The effort expended to modify or "toughen" the item for space use is principally labor cost.

## Definition of terms

A conventional spacecraft development program consists of the 4 phases presented in Figure 1. Typical labor loading versus time is shown in Figure 1 and the phases are defined in Table 1. Although the numbers used here are hypothetical, they are based on extensive experience. This largesat model yields several significant numbers summarized in Table 3. The cost per unit weight has been escalating steadily, and approximately doubles each 10 years.



Figure 1 Schedule and Manpower Loading for a Typical "Largesat" Program

12 2 2 2

Program Phase	Description	Milestones
Preliminary Design	Performance allocation to subsystems and components Mockup and breadboard construction Team buildup	Program start PDR
Detail Design	Engineering model construction and test Stress, derating, and reliability analysis Drawing preparation Parts procurement Ground test and orbital ops planning	CDR
Manufacture and Component Qualification	Construction of qualification and flight hardware	Hardware delivery
1 651	Design verification tests	
Integration and Test	Assembly and test of qualification and flight spacecraft	Launch

Table 1 Largesat Program Phases

Characteristic	Descriptors
Physical	Weight 1000 kg
	Volume 10 m <sup>3</sup>
	Power 1000 w
Complexity	10 Subsystems
	50 components
	50,000 electronic parts
Cost	100 <b>\$M</b>
	or 100 \$K /kg

Table 2 Largesat Characteristics

Fully qualified "space" hardware is built to complete engineering data<sup>7</sup> using high reliability parts and full manufacturing and process controls. A typical unit (generally the first) is subjected to environmental test at qualification level. On some programs, the qualification unit is flown. The qualification unit is sometimes called the prototype or the type test unit. As a rule of thumb, a fully qualified space component costs \$1M to develop and qualify and \$100K per copy to produce. Also, as a rule of thumb, it takes over a year to procure a high-rel electronic part.

There is a tendency in academia to apply the term prototype to hardware which has been constructed for engineering test or proof of concept. I prefer the term engineering model for this class of hardware. An engineering model is defined as a functional preprototype. It may be constructed with generic parts but is constructed to flight packaging design. A lot of the hardware flown on cheapsats is really closer to engineering model hardware than either prototype or flight hardware.

## Assumptions

The assumptions for the cost model are presented in Table 3. The cost model covers design, construction, and test of a flight article. Conceptual design activities which precede the start of detail design are not included and the cost of effort associated with launch vehicle integration (LVI) is not addressed. For a largesat program using a dedicated booster, LVI is a small but significant part of the normal design process. For a cheapsat being flown as a secondary payload or "hitchhiker" the full cost of LVI may be a significant cost element. Launch cost is also not included.

Satellite Characteristics: 50 kg
Included tasks: Hardware design,
planning.
Excluded tasks: LVI, launch and orbital operations
Labor cost: \$100,000/person year All
labor fully paid.
Table 2 Cost Model Assumptions

 Table 3 Cost Model Assumptions

#### Program Model

## <u>Summary</u>

If the largesat data of the previous paragraphs is scaled to a cheapsat, the cheapsat ought to cost about \$5 M, and have about 2500 electronic piece parts. (Electronic piece parts as used here include semiconductors and discreet parts but not mechanical parts or solar cells. The number of electronic piece parts is used as an index of complexity.) In other words it ought to be about as complex as two or three largesat components. The development schedule is not as easy to scale, but if we equate the cheapsat schedule to that of a largesat component, we might surmise a development schedule of 2 years. The cost would imply an average labor base of 25 people.

The actual cost numbers are quite different. Development cost for a 50 kg cheapsat is closer to \$1 M assuming that all labor is actually paid for. Cost offsets such as volunteer labor reduce this cost even further. To match this total cost, the cheapsat must be produced (designed, constructed and tested) by an expenditure of less than 10 person years. This would imply a level of 5-10 equivalent full time people for a period of 1-2 years.

• • • Published cheapsat block diagrams show a component or module count of 10-30 per spacecraft. In the largesat world, the term component refers to a black box or physical unit. In the cheapsat world, this term is not so well defined and some of the functional units that I refer to as components may be more properly called modules. The limited schematic and photograph data indicates that most cheapsat components(modules) have fewer than 200 piece parts. Based on these data our typical spacecraft might consist of a structure subsystem and 5 electronic subsystems. The electronics would employ 20 components with an average part count of 100 electronic parts per component.

Assuming that 60% of the cost of the spacecraft is applied to subsystem design and construction, one arrives at a labor expenditure of a person year per subsystem. Assuming that material costs are less than \$50,000 (5% of program cost) or the equivalent to one-half of a person year, the remaining 31/2 person years within the cost envelope is devoted to integration and test, system engineering and program management.

## <u>Schedule</u>

Published cheapsat schedule information shows spans of between one<sup>4</sup> and three<sup>3,8</sup> years. These data confirm

4

the reasonableness of the 2 year estimate obtained from largesat component spans.

#### <u>Material</u>

Although material cost has been dismissed as a major consideration in the previous paragraphs, some discussion of materials and piece parts and their effect on cost is worthwhile. Structural materials, (aluminum, stainless steel, copper, etc.) are generally available and inexpensive as are common plastic materials (teflon, mylar, kapton, and phenalics). Even integration parts, high quality threaded fasteners and the like, are readily available and inexpensive.

Adhesives, conformal coatings and paints generally are available in commercial equivalent form but the designers must pay attention to their suitability for use in space (principally outgassing characteristics).

The most common structural approach for cheapsats is the milled aluminum housing/slice method. Isogrid panels are sometimes used. Honeycomb panels and truss construction are infrequent.

As far as electronic piece parts are concerned, cost and procurement lead time excludes substantially all hi-rel and rad-hard items from consideration unless they can be obtained by donation or through surplus. Solar cells and sealed battery cells are available at moderate cost.

The use of commercial components has proven particularly beneficial in cheapsat construction. Amateur radio components are the backbone of the communications subsystems. A recent search for reaction wheels has led Weber State designers to look at surplus aircraft gyroscopes. Reference 10 describes use of a commercial CCD camera as a prime payload component. Clearly if a commercial component is available in the cost range of a few hundred to a few thousand dollars and can be modified (toughened) for space use by expenditure of a few person months, this approach should be used.

#### Labor, Labor Categories, and Facilities

The costing of conventional spacecraft programs involves several labor categories and cost pools. Typically these include engineers (sometimes several engineering categories), secretarial, technicians, drafters, machinists, etc. For a cheapsat program these labor categories may also be appropriate, but it is more probable that individuals cross category lines. The engineer probably makes his own drawings and may construct his own hardware. University engineering laboratories and shops generally are equipped so students can build hardware suitable for space flight. Most of these labs also have machinists and technicians to support the students if the fabrication is beyond their capability. Items that cannot be handled by available shop facilities (multi-layer circuit boards for instance) can be farmed out at reasonable cost.

Unfortunately, environmental test facilities (shakers and vacuum chambers) are not usually found on the University campuses. Such equipment is available in industry and can be rented but the cost may be prohibitive. The use of government facilities is also possible.

## Cost Offsets

19 ar 18

Techniques for offsetting material costs are summarized in Table 4. Methods of offsetting labor costs are presented in Table 5.

It should be observed that a student class of 15 people will provide a little more than 1000 person hours (approximately 1/2 person year) in a single semester for a normal 3 semesterhour class. I believe that a good undergraduate engineering design class can design and construct a simple cheapsat subsystem or a complex component in a semester. Graduate students are even more competent but they generally cost money. Although the student stipend is usually low, there are a number of added costs such as health benefits, overhead, and professorial supervision that raise the wrap cost to a significant fraction of \$100K per person year.

## Table 4 Material Cost Offsets

Use commercial parts/components Donation Surplus

Table 5 Labor Cost OffsetsVolunteersStudent labor-class projectsStudent labor-graduate research

## **Conclusions**

The principal conclusions of this study are presented in Table 6.

Table 6 Summary of Conclusions		
Cheapsat	Mass 50 kg, size 0.3-0.7 m, power 10-50 w	
Characteristics	Subsystems/Components	
	Number of subsystems ~5 of components (modules)10-30	
	Complexity ~100 piece parts/component	
	Construction standards Conventional circuit boards, some	
	multilayer	
	Part pedigree commercial	
	Extensive use of "toughened" terrestrial components	
	Structural approach Milled housings/slice	
Cost	Total cost ~ \$1M	
	Material < \$50K	
	Labor ~\$950K which equates to 9.5 person years direct	
	~1 person year/ subsystem	
Schedule	2 years	
Cost Offsets	Material: Commercial parts/components, donation, surplus	
	Labor: Volunteers, students	

## **References**

1. Lee, Sung, and Choi, Experimental Multimission Microsatellites-Kitsat Series, 7th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 Sept. 1993

2. Seversike, L. K., Iowa Satellite Project, 7th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 Sept. 1993

3. Milne G. W. et al, SUNSAT Stellenbosch University and SA-AMSAT Remote Sensing and Packet Communications Microsatellite, 7th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 Sept. 1993

4. Meerman, M. J. M., Overall Programmes at the University of Surrey, 7th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 Sept. 1993

5. Davidoff, M. R., The Satellite Experimenter's Handbook, American Radio Relay League 1985

 Larson, W. J. and Wertz, J. R., Space Mission Analysis and Design, Kluwer Academic Publishers, 1991 ibid. Fleeter, R. and Warner, R, Chapter 22 Design of Low-Cost Spacecraft

7. Larson, W. J. and Wertz, J. R., Space Mission Analysis and Design, Kluwer Academic Publishers, 1991 ibid. Reeves,
E. I., Chapter 12 Spacecraft Manufacture and Test

 Liefer, R. K. and Twiggs, R. J., JAWSAT, A Unique Low Cost Educational Satellite, 6th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 Sept. 1992

9. King, J. A., McGwier, R., Price, H., White, J., The In-Orbit Performance of Four Microsat Spacecraft, 4th Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan Utah 84322 August 1990

10 Bonsall, C. A. Editor, Webersat Users Handbook, Weber State University, 1993