NSBESAT 1: Systems Engineering Overview

Christianna Taylor
NSBE Space SIG
Atlanta, GA, USA
Christianna.taylor@gmail.com

Michael McCullar
NSBE Space SIG
Houston, TX, USA
Michael.McCullar-1@nasa.gov

Horace Bussey
NSBE Space SIG
Houston, TX, USA
Horace.L.Bussey@nasa.gov

Abstract - *This paper reviews the system engineering approach for the NSBESAT 1 small satellite concept under development by the NSBE Space Special Interest Group. The approach is unique to the NSBE, because both the customer and contractor are one in the same. By navigating changing requirements and constraints, NSBESAT 1 faces interesting system engineering challenges. A dynamic environment is necessary for the preliminary sizing and subsequent subsystem selection. This paper briefly goes over the history and structure of NSBESAT 1 and explains the systems engineering approach that the NSBE is taking towards developing NSBESAT 1. Preliminary sizing for this small satellite observatory is then established. Subsequent NSBESAT 1 papers report details on specific subsystems.*

Keywords: satellite, NSBESAT 1, systems engineering, satellite sizing, telescope, Design Analysis Cycle.

1 Introduction

In 2006, the NSBE-Alumni Extension's Space Special Interest Group (SIG) put out a Request For Proposals for small satellite concepts. This is one of several technical activities of the NSBE Space SIG aligned with its goals to stimulate the active participation of the community, with focus on the Black community, both within and beyond the engineering profession, in space-related activity [1]. The winning proposal was a small satellite observatory consisting of a telescope and a digital camera, capable of receiving images in the visible spectrum [2]. Ideally, an onboard data storage device will archive images and a transmitter will transmit images to the ground (an Earth-based mission control facility). The observatory payload will consist of off the shelf components that can be bought commercially and modified for use in space. The winning concept was presented at the 2008 NSBE Annual National Convention as the NSBE Small Satellite Initiative for which the first small satellite design was dubbed "NSBESAT 1" [3].

2 Design Analysis Cycles

The NSBE Space SIG developed a general Design Analysis Cycle (DAC) review to accommodate its technical initiatives as defined below.

DAC 1 – Functional Overview
DAC 2 – Reliability Improvements
DAC 3 – Design Details
DAC 4 – Construction Specification

The Functional Overview is covered in this paper and includes investigating the design space to accommodate the best use of NSBE resources to create the NSBE satellite. During this stage, the Space SIG executed an entire parabolic study that shows where the NSBE satellite should stand with respect to each satellite subsystem [4].

3 Payload

The satellite payload is an observatory consisting of a telescope and a digital camera, capable of receiving images in the visible spectrum. An onboard data storage device will archive images and a transmitter will transmit images to the ground. The observatory payload will consist of off the shelf components that can be bought commercially and modified for use in space.

3.1 Telescope

The type of telescope design preferred for NSBESAT 1 would be a Newtonian design (see Fig. 1). The optics for this telescope is mass-produced and commercially available in the sixteen-, eighteen-, and twenty-inch range.

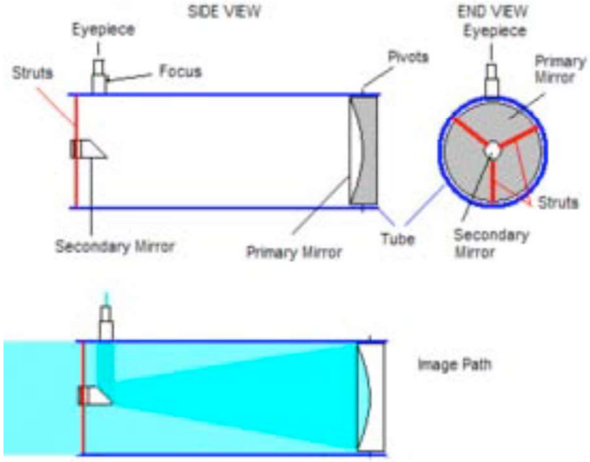

Figure 1. Newtonian Telescope.

The Newtonian design is simple and has the least number of optical components. A typical Newtonian has a parabolic mirror and a flat secondary mirror. It is not compact since the focal length is not folded. This design requires the telescope tube to be long and narrow.

3.1.1 Resolving Power:

The resolving power of the telescope depends on the size of the mirror and the wavelength of light. A good approximation is given by

$$\alpha = \frac{\lambda}{4D} \tag{1}$$

where λ is the wavelength in micrometers, *D* is the mirror diameter, and α is the resolving power in arc seconds.

3.2 Mirror

Of particular interest are mirrors with thin film coatings or actual thin film mirrors. A Newtonian telescope is another form of reflector telescope which uses mirrors to collect light into a smaller area for astronomical imaging. While other telescopes with more complex optics are more compact, they have more expensive optical components. A standard Newtonian telescope has a parabolic primary single mirror and flat elliptical 45° secondary mirror. Since an imaging device will be used at prime focus this makes the secondary unnecessary. Although this design will make the telescope long and narrow, it has the simplest optics —but it does suffer from some chromatic aberration. The camera, filter, and magnifier assembly will have to fit in a tube-like housing suspended on spider supports above the main mirror. The diameter of this housing must be as small as possible to maximize the light gathering ability of the telescope. If the camera diameter is one half the diameter of the mirror, this would reduce the mirror area down to 75% [2].

3.3 Telescope Body

A closed tube is required for the telescope body and must be very rigid, inflexible, and lightweight. This suggests the use of a carbon composite material — fiberglass or aluminum would be too heavy. An *f*/6, 20'' mirror would have a focal length of 120''. Materials reviews will determine the best material that not only has the rigidity and thermal properties desired, but also satisfies the requirement that it must not out-gas any substance that would cloud the telescope mirrors.

3.4 Camera

The imaging capability of the telescope depends on the size (i.e., area) and resolution of the imaging sensor chip being used. Parts and electronics from a digital camera could be used for this project. Most commercially available digital cameras have small imaging sensors and do not have the proper spectral response for astronomical imaging. However, some digital cameras have been adapted for astronomical use. One of these is the Canon EOS20Da. This camera has an APS (active pixel sensor) which is 22.5 x 15.0 mm in area. This sensor has a maximum resolution of 3504 x 2336 pixels – about 156 pixels per millimeter. For photometric use, the five standard UBVRI filters can be placed in an off-axis rotating turret in front of the image sensor. The filters would have to be at least the same size as the imaging sensor. Six 25 mm filters can be arranged in a hexagonal turret about 3 inches in diameter. The complete assembly would have to move forward and aft to adjust the focus. Figure 2 shows a sketch of the satellite payload components.

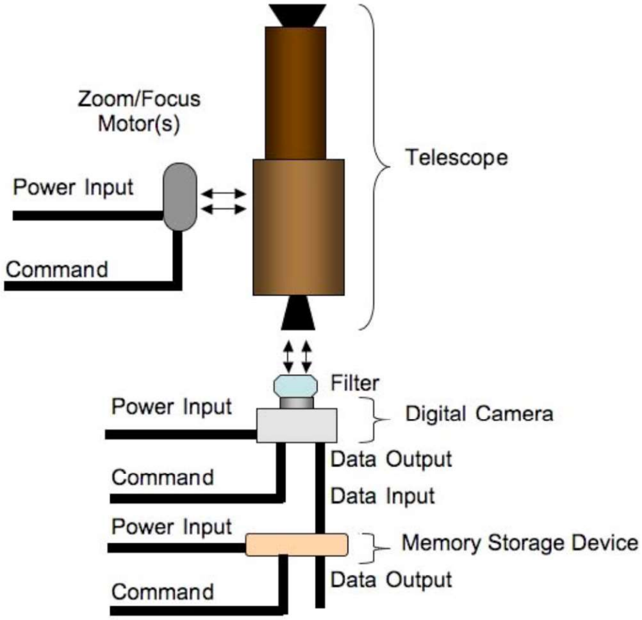

Figure 2. NSBESAT 1 telescope system schematic.

4 Orbit Characteristics

Two possible launch vehicle studies were used to determine two different orbits for NSBESAT 1 in Low Earth Orbit (LEO). The selected orbit characteristics are given in Table 1 below. The Falcon-1 resulted in a required spacecraft delta-velocity (ΔV) capability of ~800 km/s for all 4 years of the Mission Duration. This information affected the propellant mass associated with the satellite. Comparing the possible values of ΔV with the possible operations maneuvers reveals the design space for putting together various combinations for operations protocols. This will be utilized in later DACs.

In order to make the best use of NSBE resources each study will provide input to an overall objective function to make satellite system decisions. The NSBE Sat is expected to be a secondary payload. This means that the launch vehicle or the orbit is still to be determined in later DACs. The choices presented here serve only as the base model for possible LEO selection.

Table 1. Orbit Inputs for Two Launch Vehicles.

Name	*Falcon-1*	*Ares-1*
Inclination	9.3467°	51.97990°
Altitude	330.5km	350km
Eccentricity	0	.0003229
Number of Orbits per Day	15.89177	15.79876
Mission Duration	4 yrs	4 yrs

5 Modeling and Simulation

The traditional Space Mission Analysis and Design (SMAD) tool created by Wertz and Larson [5] was used for DAC-1. The orbit selection was provided as input into the model to help create the preliminary sizing which took into account the payload mass and power projected percentages [6]. Two constraints were given from the proposal. The definition of a small satellite is that it must be less than 500 kg and the proposal gave prospective payload mass and power ranges. This simulation only provides ranges for each subsystem mass and power budget; however, the SMAD tool will be used further for subsequent subsystem approximations.

5.1 Parabolic Study

A parabolic study of the preliminary sizing aspects was conducted with respect to the mass and power budgets. Nine inputs were varied on three levels to produce a full factorial as shown below in Table 2. This resulted in 19,683 cases. This Design of Experiments was chosen because it was relatively small. This study would benchmark NSBESAT 1 with respect to other small satellites. This information was used to assess the current operation plans and payload variables in accordance to the submitted proposal.

Table 2. Input Variables for Sizing Study.

Variable	***Lower Bound***	***Upper Bound***
Payload Mass	30kg	85kg
Payload Mass %	15%	20%
Payload Mass Margin %	0%	10%
Payload Power	5W	25W
Payload Power %	15%	30%
Payload Power Margin %	0%	10%
Attitude Control %	5%	10%
Propellant Margin %	0%	10%
Residual %	0%	5%

Table 2 corresponds to the first parabolic study conducted. This data was then used to make subsequent reductions and determine ranges for subsystem components.

6 Results

The data was condensed to show relevant combinations. Every finished design that did not meet the 500 kg constraint was thrown out. This reduced the data from 19,683 to 10,854, which translates into a 45% decrease in design space possibilities. Each combination gave possible mass and power margins to each subsystem. To further reduce this information the data utilized Jacob's Math Project (JMP) to show possible preliminary sizing combinations and where the NSBE Space SIG may reduce discrepancies. These results are shown in Figure for the Falcon-1 Launch Vehicle.

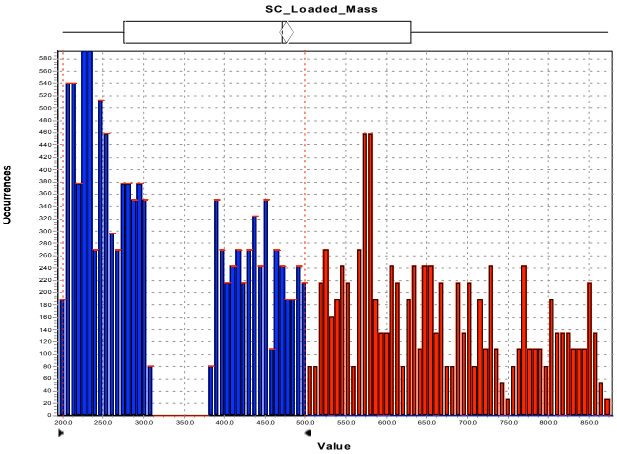

Figure 3. Spacecraft Mass Histogram.

Each one of these combinations has a complete subsystem mass and power range associated with them. Figure 3 shows that there is a division in the spacecraft class. This is shown by the apparent gap around 300kg. This suggests that the design space originally searched was too large since 45% of the design points were excluded. Taking this information into account means that another design space must be searched. The design space used a Pareto Plot to find which variables contributed the most to the loaded mass as seen below in Figure 4. It shows that the payload mass contributed 61% to the loaded mass design points studied here.

Figure 4 shows that the payload mass has the largest effect on the loaded spacecraft mass. Therefore this is the variable that must be changed in order to have the largest effects on the system. Table 2 shows that the largest payload mass considered was 85 kg. It also shows that the largest payload mass percentage is 20%, which would leave the rest of the spacecraft to be 425 kg, which has a final loaded weight of at least 510 kg. This value already exceeds the small spacecraft mass constraint. If the largest payload percentage is 20%, but there is a clear second class of spacecraft under 300 kg as shown from Figure 3, then a revised upper bound of 300 kg could be used which, at a payload mass of 20%, would yield a new maximum payload mass of 60 kg (See Table 3).

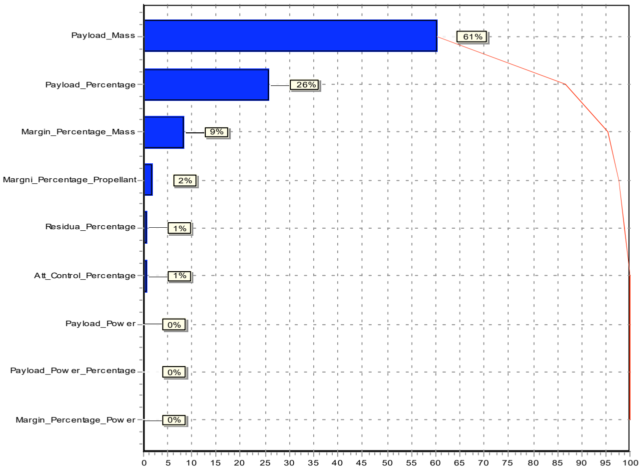

Figure 4. Pareto Plot of Loaded Mass Variable Contributions.

Table 3. Revised upper bound on spacecraft constraints.

Name	Original Upper Bound	Revised Upper Bound
Loaded Mass	*500kg*	*300kg*
Dry Mass	*400kg*	*220kg*
Propellant Mass	*100kg*	*80kg*
Payload Mass	*85kg*	*60kg*

Reducing this maximum payload mass to 60 kg changed the design space. These constraints were re-ran with the new limits and resulted in Figure . Figure shows that there is no longer a gap as compared to Figure . Both figures show the 500 kg constraint placed upon the design space. The simple change of lowering the upper bound of the payload mass opened up the design space. It should be noted that while the maximum payload percentage would have resulted in a maximum loaded mass of 300 kg, the information was not combined with the other subsystem configurations. That is why there are configurations that result in loaded masses over 500 kg as shown in Figure .

Continuing with this design space leads to the spacecraft dry mass, propellant mass, each subsystem mass and power requirements. A sample of this information is given in Figure through Figure 8.

Each histogram gives the design space combinations that dictate the total mass or power of each system. This information is summarized below in Table 4, which lists the upper limits for the mass and power budgets. These are the current working budgets, but each requires analysis to find the minimum values for each subsystem. Further analysis for individual subsystems is beyond the scope of this paper; however, future work will investigate each subsystem separately. This will be the subject of future work by the NSBE Space SIG. However, what this analysis does do is provide a working budget and a set of parameters that physical systems may be based upon.

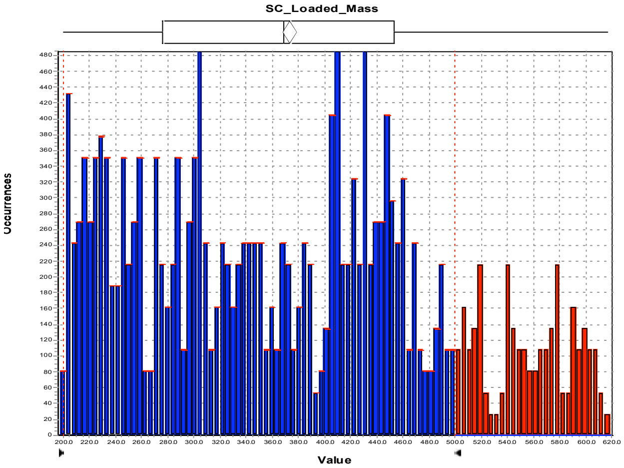

Figure 5. Spacecraft Loaded Mass Histogram.

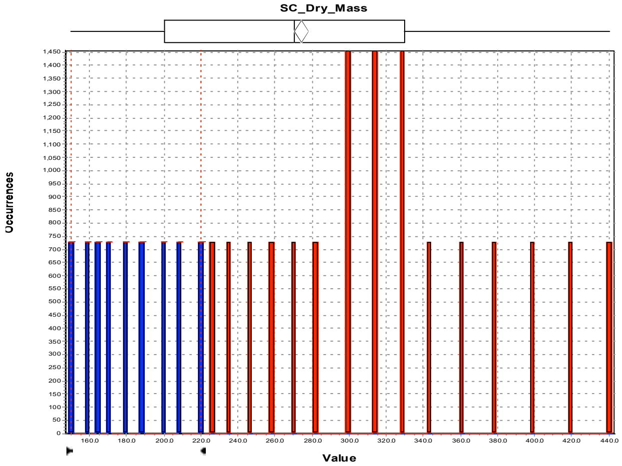

Figure 6. Spacecraft Dry Mass Histogram.

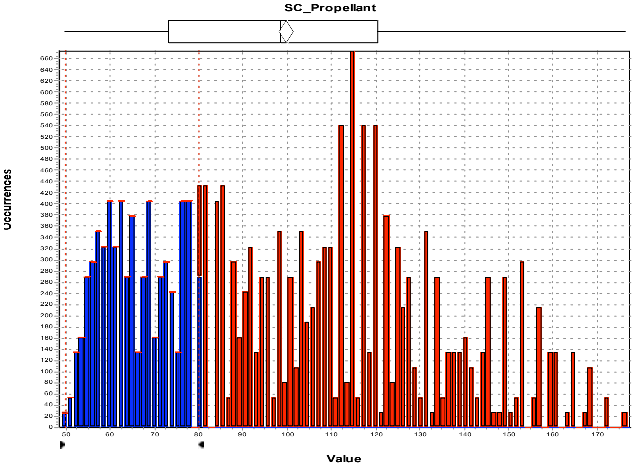

Figure 7. Spacecraft Propellant Mass Histogram.

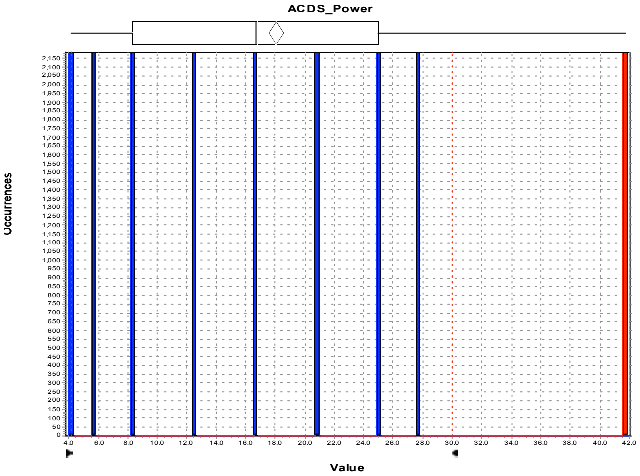

Figure 8. ACDS Power Histogram.

Table 4. Subsystem upper and lower constraints for preliminary sizing.

Name	**Mass Upper Limit (kg)**	**Power Upper limit (W)**
Payload	*60*	*30*
ADCS	*30*	*30*
C&DH	*22*	*10*
Power	*75*	*15*
Propulsion	*30*	*10*
Structure	*70*	*0*
Thermal	*10*	*0*
TT&C (Comm)	*15*	*30*
Propellant	*80*	*0*
Total	**422**	**95**

7 Conclusions and Future Work

NSBESAT 1 started out with the goal of building a small satellite for the National Society of Black Engineers. The first Design Analysis Cycle presented herein provides a preliminary sizing for mass and power budgets for what NSBESAT 1 will adhere too. The opinion is that a good payload mass would approximately be 35 kg in order to remain in the lower class of small satellites. This information allows for further analysis to determine the amount of maneuvers that may be performed in the required 3 year time period that NSBESAT 1 will operate and, more importantly, how donated subsystems may fit into the satellite operations.

This preliminary work lays the groundwork for separate NSBE chapters to work on different subsystems to concurrently build NSBESAT 1. This preliminary information is important as a common baseline parameter set for engineers and engineering students in each chapter to adhere to as they become involved in designing and building different subsystems. The last phase of DAC-1 will investigate each subsystem of NSBESAT 1 in order to create specific subsystem parameters so that DAC-2 may allow chapters to actually start building the desired subsystems.

The application of the NSBESAT DAC-1 builds requirements and boundaries on each subsystem and preliminary sizing. As the process moves forward each subsystem will be resized and bounded down within these requirements. At the moment, the NSBESAT will have the preliminary system sizing presented here and the final sizing for each subsequent subsystem is planned to be presented at the 2010 NSBE Annual National Convention. By that time the NSBESAT team will set up a system to allow NSBE collegiate chapters to work on designing and building each subsystem of the NSBESAT 1 with plans to move forward on NSBESAT 2 [7]. This project presents the design space required for a small satellite, which will be utilized for future satellite projects. Since this design study has already been done, DAC-1 for NSBESAT 2 and beyond will be able to reference it for subsequent preliminary design analyses.

References

[1] NSBE Space Special Interest Group, http://www.nsbe-hsc.org/space/.

[2] H. Bussey and D. Griffin, "Observer satellite mission," NSBESAT Mission Proposal to NSBE Space Special Interest Group Small Satellites Project, 2007.

[3] E. Tunstel and R. Howard, "Small satellites: NSBESAT 1 mission payload," presented at the 34th NSBE Annual National Convention, 12th Technical Professional Conference, Orlando, FL, 2008.

[4] C. Taylor, "NSBESAT DAC-1.1 update: A parabolic study design document," NSBE Space Special Interest Group, Small Satellites Project, 2008.

[5] J. R. Wertz and W.J. Larson, eds., *Space Mission Analysis and Design*, (3rd Edition), Microcosm/Kluwer Academic Publishers, 1999.

[6] C. Taylor, "NSBESAT proposed methodology – preliminary sizing," Design Document, NSBE Space Special Interest Group, Small Satellites Project, 2007.

[7] C. Taylor and M. McCullar, "NSBE SmallSat: National Convention update," presented at the 35th NSBE Annual National Convention, 13th Technical Professional Conference, Las Vegas, NV, 2009.