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3-6-2012

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### Recommended Citation

Rose, C. W., & Wirthlin, J. R. (2012). Using M&S to maximize space satellite data collection with multiple ground stations. *Procedia Computer Science*, 8, 124–129. <https://doi.org/10.1016/j.procs.2012.01.024>

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New Challenges in Systems Engineering and Architecting  
Conference on Systems Engineering Research (CSER)  
2012 – St. Louis, MO  
Cihan H. Dagli, Editor in Chief  
Organized by Missouri University of Science and Technology

## Using M&S to maximize space satellite data collection with multiple ground stations

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### Abstract

With the continued operations of FalconSAT-3 well beyond its design life, an opportunity exists to utilize multiple ground stations beyond the original site at the US Air Force Academy (USAFA) to enhance individual training missions at the Air Force Institute of Technology (AFIT), United States Military Academy (USMA), and the Undergraduate Space Training (UST) course at Vandenberg Air Force Base. Using multiple ground stations can enhance FalconSAT-3 experiments beyond the original design. However, with multiple ground stations coordination needs to increase. The problem of distributed files becomes an issue, and all files need to be compiled to maximize experiment analysis. A discrete event simulation of the file distribution was calculated to show how the files are spread across the ground stations. The characteristics of each ground station and available crew rates at the respective stations contribute to the overall ability to download (or miss the opportunity to download) files. The simulation shows the capability of each site to download files and which sites' missed opportunities for file download were caused by crew availability. Implications of downloaded files and missed opportunities can affect the design of the distributed network of ground stations to support FalconSAT-3.

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Keywords: simulation; modeling; ground station architecture

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### 1. Introduction

FalconSAT-3 was built by the cadets and faculty at the US Air Force Academy (USAFA) and launched on 9 March 2007. On board are three experimental payloads: two studying plasma and space weather, and the third as an experimental attitude control pulse plasma thruster. As the original lifetime of the

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spacecraft was only designed for one year, FalconSAT-3 has exceeded expectations as it is still operating well. Since the original science missions are now complete, FalconSAT-3 has the opportunity to become a test asset for additional operations. The Air Force Institute of Technology (AFIT), United States Military Academy (USMA), and the Undergraduate Space Training (UST) course at Vandenberg Air Force Base (AFB) are additional users that would gain from using FalconSAT-3. FalconSAT-3 was never intended to communicate beyond the ground station at USAFA. Expanding FalconSAT-3 operations to additional ground stations will take planning and coordination. One of the concerns about multi-ground station operations is compilation of the downloaded files. The way to circumvent FalconSAT-3's sole ground station operations is to "trick" the satellite into thinking that every ground station is USAFA. Unfortunately, downloaded files are not recorded as to which ground station downloaded them. All of the downloaded data should be compiled into one location in order to maximize analysis of normal housekeeping data, as well as any further experiments. In addition to using multiple ground stations to enhance FalconSAT-3, the satellite can enhance the missions at each ground station. USAFA cadets have been gaining space operations experience since 1997 and their training programs have served as a basis to expand to other organizations for others "learn space by doing space" [1]. USMA cadets are interested in operating FalconSAT-3 for the same experience as USAFA cadets. AFIT students are looking to enhance space operations in preparation for the launch of a satellite in 2012, with other satellites to follow. The UST course at Vandenberg AFB would be enhanced if trainees use a real space asset. Currently, FalconSAT-3 operations have occurred at USAFA and AFIT, with USMA and Vandenberg AFB in the process of establishing their ground station. Using discrete even simulation, the best coordination of ground station operations can be determined, maximizing the potential for downloaded files and opportunities for local mission success.

## 2. Background

A discrete system is "one in which the state variable(s) change only at a discrete set of points in time" [2]. Simulation of the distribution of downloaded FalconSAT-3 files is a prime candidate for discrete event simulation since there are limited (non-continuous) states of being in which the satellite and ground stations exist.

Banks, et al, define a 12 step process to establish a simulation: 1. Problem formulation; 2. Setting of objectives and overall project plan; 3. Model conceptualization; 4. Data collection; 5. Model translation; 6. Verified?; 7. Validated?; 8. Experimental design; 9. Production runs and analysis; 10. More runs?; 11. Documentation and reporting; 12. Implementation [2].

The first phase in building a successful simulation consists of understanding the problem and what needs to be accomplished (steps 1 and 2). The second phase (steps 3-7) involves building and testing the model. The third phase (steps 8-10) entails comprehensively executing the model to satisfy the problem in the first phase. Lastly, the fourth phase is ensuring the knowledge gained by simulating the model is implemented into reality. These steps and phases do occur sequentially, but are not limited to once through. Like many other processes, building a good simulation is an iterative method.

Discrete even simulation of FalconSAT-3's downloaded files is captured with Imagine That, Inc.'s ExtendSim software [3]. Although the idea is to always have a model transgress into the fourth phase, the model that simulates file distribution for FalconSAT-3 is still in the third phase. In order to exhaustively understand the implications of the file distribution, some further specifics need to be explored to confidently express the results of the simulation. The groundwork for the model has been constructed, but additional refining of values will make the model more robust, which will improve the overall operation of FalconSAT-3 over multiple ground stations once completed.

### 3. Methodology

Determining the flow of the FalconSAT-3 during a pass is established with current operations by USAFA. Determining the use of multiple ground stations, and when each ground station is most appropriate, is key to simulating the file distribution. As FalconSAT-3 flies over the US, one of the four ground stations will have the best and longest view time to download files. To determine the optimal ground stations for communication with FalconSAT-3, calculations were based on the process shown in figure 1.

FalconSAT-3 is on a defined orbit. With no onboard propulsion system, the main influences to FalconSAT-3's orbit are gravitational perturbations from the Earth and other celestial bodies, atmospheric drag, and solar radiation pressure. These forces slightly affect FalconSAT-3's orbit, but not significantly to radically change the orbit over the simulation. The orbital elements used in this study were from May 2011.

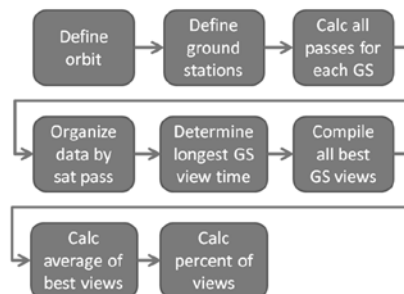


Figure 1: Process for determining optimal ground station passes

Defining ground stations requires knowing the latitude and longitude of the ground station antenna. For this study, the individual local antenna patterns were not calculated, but an optimal 5 degree above the horizon view was used as the basis for each ground station. Using an orbit determination software such as Analytical Graphics, Inc.'s Satellite Tool Kit (AGI's STK) [4], the number of passes and characteristics of each pass can be calculated given the satellite orbit and ground station information. For this study, FalconSAT-3's orbit (and subsequent views by each ground station) was calculated over the entire 2011 calendar year. In 2011, there are approximately 3,428 FalconSAT-3 passes visible to one or more of the ground stations studied. Organizing the pass information by ground station is the next step. Once the data elements are organized, a side by side comparison can be made to determine which ground station has the longest view during that pass. Compiling all of these best view times create a greater understanding of the ground stations role in downloading files. Then, determining the total number of best passes for each ground station divided by the total number of passes calculated shows what percentage of views should go to each ground station to optimize satellite passes. Using this methodology, it is determined that Vandenberg is the best location of the four ground stations. Vandenberg is the best site during 47.3% of all passes. AFIT is second with 19.6%. USMA is the best site for 19.4% and USAFA is 13.7% of the passes. These percentages are used in simulating the choice of which site is the best ground station for a random pass.

Besides physical location of the ground station, crew manning contributes to file downloads. If a crew is not available to take advantage of the FalconSAT-3 pass, there is a wasted opportunity to download files. This wasted opportunity could translate to fewer data elements collected over the course of an experiment (FalconSAT-3's onboard hard drive could reach capacity). Manning rates were determined based up organizational goal and size, as well as competing resources/events that would cause a crew not to operate a satellite pass. USAFA was given a crew manning rate of 80% since there are a relatively large number of cadets that can operate their ground station. Vandenberg was assigned a crew

rate of 25% due to the space training occurring on site, but with limited hours that a student crew can perform a satellite pass due to the training environment. USMA was assigned a crew rate of 50%. Similar to USAFA, USMA has a large cadet pool but with a smaller space operations program. AFIT was assigned a crew rate of 20%. AFIT has the fewest available operators compared to the other organizations.

Furthermore, a Chi Squared distribution was established as the number of files that a ground station would download during their pass. This distribution is based off of a download history of FalconSAT-3 at USAFA. All of the aforementioned characteristics of ground stations and FalconSAT-3 combine into the model shown in figure 2.

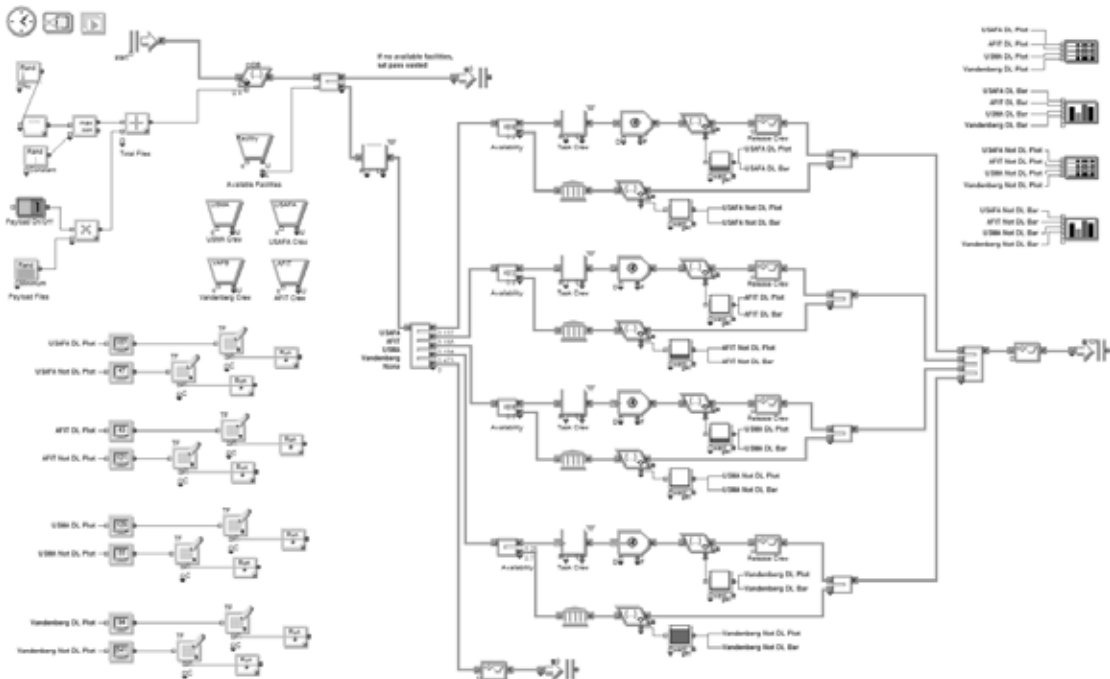


Figure 2: Model of FalconSAT-3 download file distribution in ExtendSim (for illustrative purposes)

## Results

Using the model described in section 3, various outputs were created to determine how to best posture the ground stations to maximize file downloads. From predicted crew rates, missed opportunities for file downloads were also calculated. Figures 3 and 4 show a plot of files downloaded or missed over the course of many passes.

Over the course of 100 calculated simulation runs, an average of 455 files were downloaded in each simulation by all ground stations. During those same passes, 773 files were not downloaded that could have been based upon crew availability rates. Table 1 shows the percentages of total files that each ground station downloaded and did not download.

Table 1 shows that about 31% of the downloaded files will be initially stored at Vandenberg. Table 2 shows the overall number of files that were downloaded or not downloaded (missed opportunity) at each site, as well as the total numbers. The percentages in table 1 were calculated from table 2.

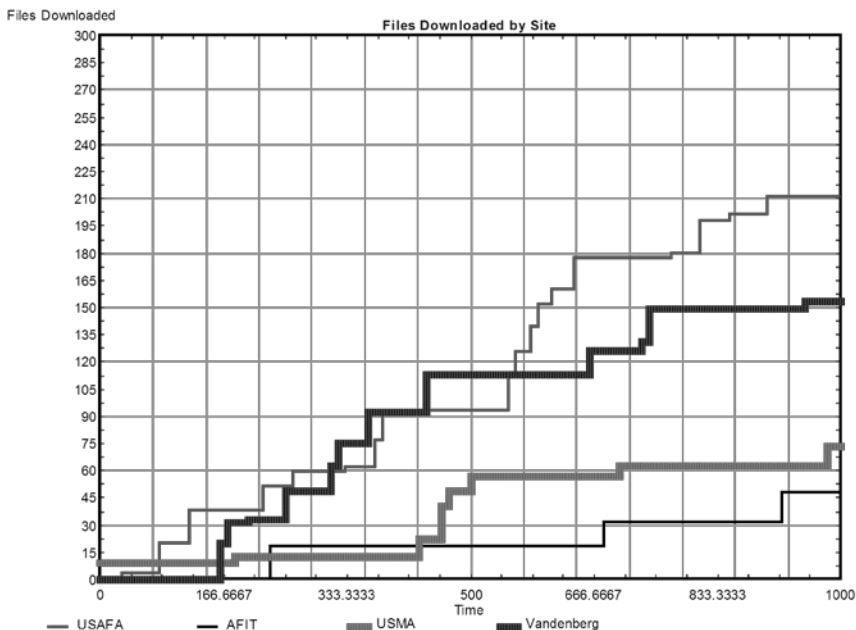


Figure 3. Files downloaded by each ground station during one simulation run.

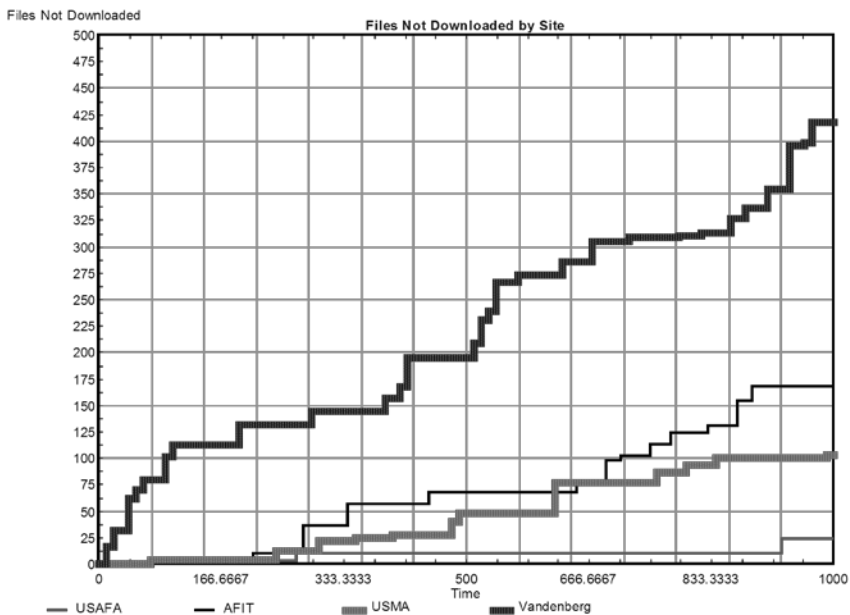


Figure 4. Files not downloaded (missed) by each ground station during one simulation run.

Table 1. Percentages of files downloaded or not downloaded for all ground stations

% of files	USAFA	AFIT	USMA	VAFB
Downloaded	30.8412	11.5396	26.5999	31.0193
Missed	4.3238	25.3178	14.6876	55.6708

Table 2. Average number of files downloaded or not downloaded for all ground stations during simulation

USAFA		AFIT		USMA		Vandenberg		Total	
DL	Missed	DL	Missed	DL	Missed	DL	Missed	DL	Missed
140.34	33.43	52.51	195.75	121.04	113.56	141.15	430.43	455.04	773.17

## Conclusions and Future Research

Files downloaded from FalconSAT-3 will be sufficiently spread across the US to cause significant gaps in data if the files are not compiled back together for analysis. Vandenberg AFB is a significant contributor to enhanced FalconSAT-3 operations. When determining a file storage solution, storing the files at Vandenberg could reduce the overall file transfer.

Looking at the data generated in section 4, about 25% of missed files could be reduced by implementing an automatic satellite communications program at AFIT. Due to AFIT's smaller available crew numbers, and interest in automation for future AFIT satellite missions, an automated solution for FalconSAT-3 would significantly increase downloaded files. Vandenberg, the site with the most missed files, would prefer to operate passes manually for their training mission. Missed files would not directly equate to an experiment's demise. The next ground station operation would have the opportunity to download the missed files. Missed files would likely equate to a lack of realization of FalconSAT-3's full potential. Leadership at each of the sites would have to buy in to maximize the operations of FalconSAT-3. With other existing priorities, FalconSAT-3's full potential may never be met, but it is important that leadership is informed of the capabilities available by FalconSAT-3.

To increase accuracy of the simulation, the exact antenna pattern at each ground station can be used. Furthermore, a study could be done to determine more accurate crew availability rates. For example, the UST course will use FalconSAT-3, but it has yet to be determined exactly how much the course will utilize the asset. Additional simulation runs can also be added to enhance any trends that have not yet fully developed in the output data. More ground stations can also be added to help leadership decide if there will be any value added for adding further ground stations (at the US Naval Academy or the Naval Postgraduate School, for example).

Understanding how files are distributed using FalconSAT-3's setup can affect the next generation of satellites developed by AFIT (and others). The file storage system on a satellite can be designed to communicate with an expandable number of ground stations and could either allow multiple downloads of the same file, or create a log of which ground station downloaded a particular file.

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