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A guide to the establishment of a university satellite program

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A GUIDE TO THE ESTABLISHMENT OF A UNIVERSITY SATELLITE PROGRAM

by

ABBIE MARIE STEWART

A THESIS

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UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN AEROSPACE ENGINEERING

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Approved by

Dr. Henry Pernicka, Advisor

Dr. David Riggins

Dr. Cihan Dagli

ABSTRACT

The UMR SAT team was formed at the University of Missouri–Rolla to design and build microsatellites. This team competed against ten other universities in the Nanosat 4 competition hosted by the Air Force Office of Scientific Research, the Air Force Research Laboratory, and the American Institute of Aeronautics and Astronautics. This document, written by the Chief Engineer, is a description of the process used by the UMR SAT team to develop a successful satellite program. Included in the document are methods based on systems engineering for developing a mission, a discussion of team organization and recruitment, and lessons learned during the 2004 to 2007 years.

ACKNOWLEDGMENTS

The author wishes to acknowledge the Missouri NASA Space Grant consortium, the Boeing Company, the Academy of Mechanical and Aerospace Engineers, and the UMR MAE Department for their financial support of this research. She would also like to thank her advisor, Dr. Henry Pernicka, for his guidance throughout this project along with Dr. David Riggins and Dr. Cihan Dagli, the other members of her committee. The author would also like to recognize the hard work of the UMR SAT team throughout the years of this project. Without their efforts this project would not have been a success. Finally, the author wishes to thank Mom for her excellent editing skills and insightful input.

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1. INTRODUCTION

One of the responsibilities of reputable engineering schools is to provide real-world experiences for the students. These experiences take place in the classroom, in extracurricular activities and in major projects. One such project is the University Nanosat Program (UNP) sponsored by the Air Force Office of Scientific Research (AFOSR), the Air Force Research Laboratory (AFRL), and the American Institute of Aeronautics and Astronautics (AIAA). The purpose of this program is to arrange a competition that provides financial support for universities as they design and build microsatellites that will benefit the Department of Defense (DoD) and the Air Force. In addition to financial support, the UNP provides technical support and industry knowledge for the universities. Ultimately the goal of this program is to create skilled entry level engineers for the workforce.

The purpose of this thesis is to provide prospective universities, who are considering developing a satellite program, a guide for initially organizing the project. The 2004 to 2007 University of Missouri–Rolla satellite, UMR SAT, is used as the model of this process for this thesis, the years during which the author served as Chief Engineer. Included in this thesis are all of the considerations undertaken by the team from its inception to its conclusion including recruitment of team members, development of a mission, organization of the team, specifics relating to the UNP and lessons learned throughout the process.

The purpose of this thesis is not to detail the specific design, hardware development, construction, and integration of the UMR SAT project. This thesis does not describe in detail the full mission of the satellites or the process the team engaged in to acquire hardware and produce the satellite pair. Instead, this document is intended to be a general reference of systems engineering practices that universities establishing a satellite program can adopt.

2. PROJECT DESCRIPTION

2.1. PRIMARY GOAL

The primary goal of the Astronautics faculty of the Aerospace Engineering program of the University of Missouri – Rolla (UMR) is to become skilled at satellite design and satellite construction at the university level. To meet this goal, a laboratory was set up providing a cleanroom and work facilities needed for this project. A team of students was recruited to begin the mission and satellite design process. Integral to the success of the satellite project was compiling ongoing documentation of the process and a plan to mitigate the effects of student turnover. Though most of these original students have graduated, a team of students continues to modify the initial plans developed by the first participants and are building the actual satellite. Through this lengthy design process, valuable experience has been gained in making the next satellite more successful than the first.

2.2. UMR SAT – FIRST ATTEMPT

The original satellite designed by the students of UMR has undergone several modifications during the years since its original conception; however this first attempt at satellite design taught the team many lessons in design and construction. If the knowledge gained in the early stages of the UMR project is implemented into the next satellite design and construction phase, the process should be significantly simpler. UMR SAT is used as an example throughout this thesis to demonstrate both successes and challenges in a university satellite design project. This information should provide other universities with the information needed to start their own satellite projects (1).

2.2.1. UNP Overview and Description. The University Nanosat program (UNP), started in 1999, is currently supported by the Air Force Research Laboratory's Space Vehicles Directorate (AFRL/VS), Air Force Office of Scientific Research (AFOSR) and the American Institute of Aeronautics and Astronautics (AIAA) in order to provide a competition that leads to the launch of one satellite. The program is in the fourth round of university participation. A call for proposals is released two to three months prior to the beginning of a new round. Universities submit microsatellite mission proposals which are reviewed by all of the program supporters, who then choose a certain number to support through the two year program. For Nanosat 4, eleven universities were selected. These universities were given an annual budget for two years which covered less than half of the project budget requiring industry and other forms of financial support to be imperative to the completion of the project. A User's Guide identifies the requirements that each satellite must meet, and any constraints imposed on the satellite designs were also provided. The actual mission and satellite design is left to each university. The schools are also allowed to request outside funding and donations. Throughout the two-year period, five reviews are conducted for each university. The first review, System Concept Review (SCR), occurs shortly after the competing schools are announced and is used to review basic mission plans and system requirements. Four months after this initial review, the Preliminary Design Review (PDR) is held to review the detailed design plan of each university. After approximately one year of designing, each school has a day-long detailed review, Critical Design Review (CDR), where the sponsors of the program visit each school to evaluate their progress as well as facilities for building the satellite. The final review prior to the final competition is the Proto-

Qualification Review, where each team must demonstrate several hardware demonstrations and modify elements of the satellite that cause any concerns for the sponsors. After two years, the Flight Competition Review is held. At this review all the universities deliver a protoflight satellite and after giving a brief presentation, demonstrate the functionality of the satellite. From this competition one or two satellites are chosen to continue through the launch process and be launched into Low Earth Orbit (2).

2.2.2. UMR SAT Overview and Description. The Space Systems Engineering Team at the University of Missouri – Rolla (UMR), in conjunction with a number of faculty and NASA/industry mentors, is working toward the design, construction, and launch of its first satellite, UMR SAT (University of Missouri – Rolla Satellite). The UMR SAT spacecraft was accepted into the Nanosat 4 student competition in 2005. UMR SAT consists of two microsatellites, named MR SAT (Missouri – Rolla Satellite) and MRS SAT (Missouri-Rolla Second Satellite), which will fly in a maintained close formation. The goals of UMR SAT are to test new technologies for Distributed Space Systems missions, including the study of the dynamics of satellites flying in tightly controlled formations, the implementation of a new orbit controller developed at UMR and the development of a low-cost wireless communication link between the satellite pair. Data obtained during the close formation flight phase will be evaluated for the benefit of future missions. As a result of the modest budget that accompanies a university level project, UMR SAT also requires the use of innovative, low-cost solutions to meet the stated objectives. The faculty of UMR were also an invaluable asset to the success of the UMR SAT project. They provided vast design expertise that aided the team of students as they designed and built the first UMR satellites (1).

2.3. CHIEF ENGINEER ROLE

The role of the Chief Engineer of the UMR SAT project is to oversee the entire design and construction of the satellites. The Chief Engineer reviews the requirements given to the team by UNP and ensures that the team's design is in compliance. Internal requirements must also be followed, primarily those of following a strict schedule and a limited budget. In addition, the Chief Engineer monitors students' changing schedules, to insure adequate work was being done at all times. The Chief Engineer's goal for this project was to develop a method for designing and building university satellites while dealing with the many constraints placed on a team.

A top-down approach is the best approach to this type of project. The implementation and specifics of this approach are discussed further throughout this thesis. The UMR SAT project began by assembling a team of qualified student engineers organized as seen in Figure 2.1. This team developed a mission that would be beneficial to the Air Force (the team's customer). A mission statement was written that gave the overall purpose of what the satellites were meant to do. With the UNP requirements, the team was then able to develop mission requirements and organize the team into subsystems.

Within each subsystem, requirements were developed that flowed down from the mission requirements. These requirements defined the hardware selected and the software developed. The goal of these requirements was to define the system precisely to allow for quick decisions throughout the development process.

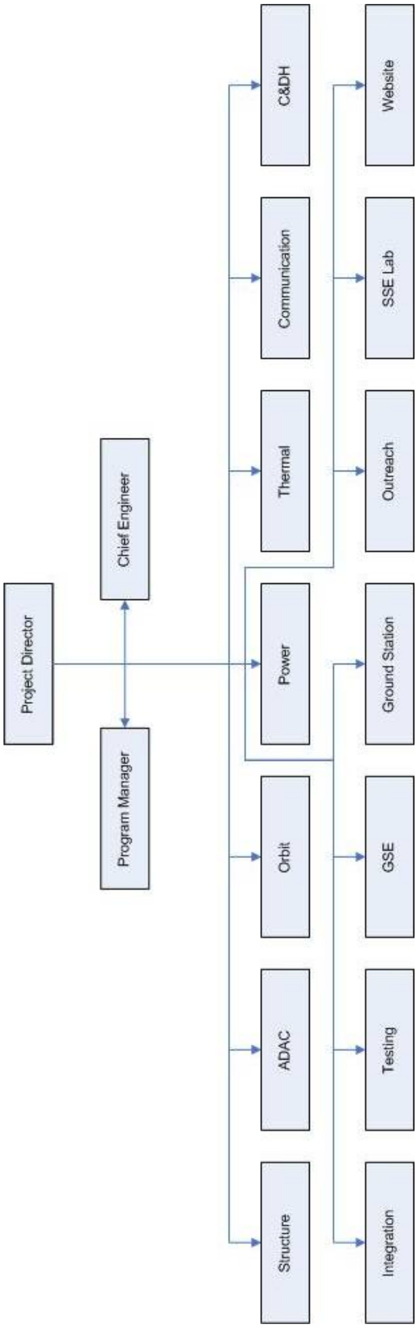


Figure 2.1 Team Organization Chart

3. UNP REQUIREMENTS

Each team in the Nanosat competition is given two main documents when they enter the competition: a User's Guide and a Configuration Management Plan. Both of these documents specified several requirements that were mandatory for all teams to follow. There were also several suggestions to improve the satellites each team designed and built. These requirements were specified to ensure that the winning team would be able to pass all of the launch review boards and be provided a launch into Low Earth Orbit (LEO).

3.1. PHYSICAL REQUIREMENTS

Eight main physical constraints were placed on the satellite teams in the Nanosat Program User's Guide. In addition to the ones listed below, other more detailed requirements are also listed in the User's Guide (3).

- Mass of the satellite system had to be less than 30 kg
- Volume of the satellite system had to fit in a 18.7 in. diameter cylinder, 18.7 in. high
- Center of gravity (CG) must be less than 0.25” from the satellite centerline
- CG must lie less than 12” above the satellite interface plane (SIP)
- Electrical and Mechanical interfaces comply with the Lightband separation system
- Stiffness fundamental frequency above 100 Hz
- Limit load factors on structure plus or minus 20 g along all three axes
- Pressure vessels must have an internal pressure less than 100 psia

The primary reason for these constraints was due to space constraints for secondary payloads on typical launch vehicles. They also increased the overall success of the satellite. Each team was required to use specific batteries which are supplied to the winning team. These Nickel Cadmium (NiCd) batteries have been used in space for years and are proven to be safe. Each team was required to design their power systems making use of these designated batteries. Additionally, these batteries are necessary because they can be fully discharged while on the launch vehicle, assuring any primary satellite on board the launch vehicle that the smaller secondary payload will not harm their satellite by prematurely powering up during ascent.

3.2. ORGANIZATION REQUIREMENTS

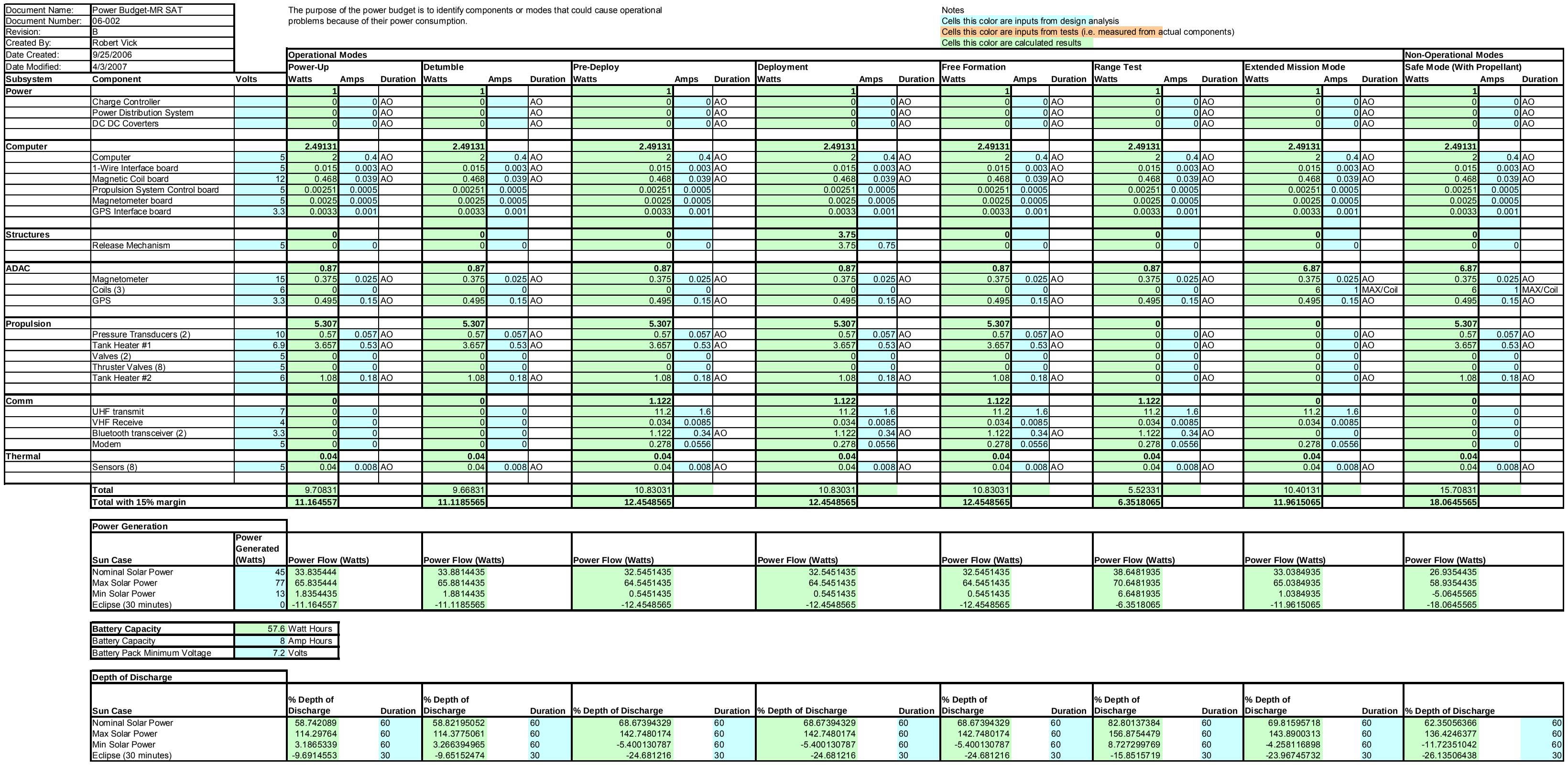
In addition to the User's Guide, the Nanosat Program provided a Configuration Management plan to assist universities in organizing the management of their team. The requirements and suggestions in this document were also considered in the final judging of the projects. These requirements covered the following areas (4):

- Documentation
- Change Management
- Quality Assurance
    - Supplier Integrity
    - Control of Hardware
    - Inspections

The Nanosat Program provided detailed lists of required documents for each review and a date two weeks prior to the review that all documents must be submitted by the universities. These required documents included Mission Objectives, Success Criteria, and Design Requirements, Program Schedule, Subsystem and System Drawings, Mass, Volume, Link, Computing, and Power Budgets, and Structural, Thermal, EMI/EMC, and Pressure Profile Analyses. They provided samples of most of these documents that each team could use to learn the proper method for writing them. Shown below in Figures 3.1, 3.2, 3.3, and 3.4 are UMR SAT examples of several of the required budgets.

UNP also required the teams to develop a management system for their documentation. The UMR SAT team developed a plan where each subsystem was given an identifying number, which was the beginning of each documentation number. Following the subsystem number was a dash and a three digit indicator number which uniquely defined that document. Each document number was then followed by the title of the document. These documents were managed through a wiki system, an online documentation website that tracks all changes made to a document and who made them. The UMR SAT wiki was implemented late in the project. Therefore, the team did not benefit from it as fully as possible. Certain older versions of documents were lost before the wiki was implemented costing the satellite team valuable time as they reproduced and reconfigured documentation.

As part of the Conceptual Design Review midway through the program, the Nanosat managers visited each campus to inspect the available laboratory facilities as well as the hardware control practices being used by the teams. Each team had to demonstrate how they were monitoring and limiting access to their laboratories, hardware, and documentation. With each hardware purchase, the universities were



Document Name:	Power Budget-MR SAT
Document Number:	06-002
Revision:	B
Created By:	Robert Vick
Date Created:	9/25/2006
Date Modified:	4/3/2007

The purpose of the power budget is to identify components or modes that could cause operational problems because of their power consumption.

Notes
🟦 Cells this color are inputs from design analysis
🟧 Cells this color are inputs from tests (i.e. measured from actual components)
🟩 Cells this color are calculated results

			Operational Modes											
			Power-Up			Detumble			Pre-Deploy			Deployment		
Subsystem	Component	Volts	Watts	Amps	Duration	Watts	Amps	Duration	Watts	Amps	Duration	Watts	Amps	Duration
Power			**1**			**1**			**1**			**1**		
	Charge Controller		0	0	AO	0		AO	0	0	AO	0	0	AO
	Power Distribution System		0	0	AO	0		AO	0	0	AO	0	0	AO
	DC DC Coverters		0	0	AO	0		AO	0	0	AO	0	0	AO
Computer			**2.49131**			**2.49131**			**2.49131**			**2.49131**		
	Computer	5	2	0.4	AO	2	0.4	AO	2	0.4	AO	2	0.4	AO
	1-Wire Interface board	5	0.015	0.003	AO	0.015	0.003	AO	0.015	0.003	AO	0.015	0.003	AO
	Magnetic Coil board	12	0.468	0.039	AO	0.468	0.039	AO	0.468	0.039	AO	0.468	0.039	AO
	Propulsion System Control board	5	0.00251	0.0005		0.00251	0.0005		0.00251	0.0005		0.00251	0.0005	
	Magnetometer board	5	0.0025	0.0005		0.0025	0.0005		0.0025	0.0005		0.0025	0.0005	
	GPS Interface board	3.3	0.0033	0.001		0.0033	0.001		0.0033	0.001		0.0033	0.001	
Structures			**0**			**0**			**0**			**3.75**		
	Release Mechanism	5	0	0		0	0		0	0		3.75	0.75	
ADAC			**0.87**			**0.87**			**0.87**			**0.87**		
	Magnetometer	15	0.375	0.025	AO	0.375	0.025	AO	0.375	0.025	AO	0.375	0.025	AO
	Coils (3)	6	0	0		0	0		0	0		0	0	
	GPS	3.3	0.495	0.15	AO	0.495	0.15	AO	0.495	0.15	AO	0.495	0.15	AO
Propulsion			**5.307**			**5.307**			**5.307**			**5.307**		
	Pressure Transducers (2)	10	0.57	0.057	AO	0.57	0.057	AO	0.57	0.057	AO	0.57	0.057	AO
	Tank Heater #1	6.9	3.657	0.53	AO	3.657	0.53	AO	3.657	0.53	AO	3.657	0.53	AO
	Valves (2)	5	0	0		0	0		0	0		0	0	
	Thruster Valves (8)	5	0	0		0	0		0	0		0	0	
	Tank Heater #2	6	1.08	0.18	AO	1.08	0.18	AO	1.08	0.18	AO	1.08	0.18	AO
Comm			**0**			**0**			**1.122**			**1.122**		
	UHF transmit	7	0	0		0	0		11.2	1.6		11.2	1.6	
	VHF Receive	4	0	0		0	0		0.034	0.0085		0.034	0.0085	
	Bluetooth transceiver (2)	3.3	0	0		0	0		1.122	0.34	AO	1.122	0.34	AO
	Modem	5	0	0		0	0		0.278	0.0556		0.278	0.0556	
Thermal			**0.04**			**0.04**			**0.04**			**0.04**		
	Sensors (8)	5	0.04	0.008	AO	0.04	0.008	AO	0.04	0.008	AO	0.04	0.008	AO
	Total		9.70831			9.66831			10.83031			10.83031		
	Total with 15% margin		**11.164557**			**11.1185565**			**12.4548565**			**12.4548565**		

			Operational Modes									Non-Operational Modes		
			Free Formation			Range Test			Extended Mission Mode			Safe Mode (With Propellant)		
Subsystem	Component	Volts	Watts	Amps	Duration	Watts	Amps	Duration	Watts	Amps	Duration	Watts	Amps	Duration
Power			**1**			**1**			**1**			**1**		
	Charge Controller		0	0	AO	0	0	AO	0	0	AO	0	0	AO
	Power Distribution System		0	0	AO	0	0	AO	0	0	AO	0	0	AO
	DC DC Coverters		0	0	AO	0	0	AO	0	0	AO	0	0	AO
Computer			**2.49131**			**2.49131**			**2.49131**			**2.49131**		
	Computer	5	2	0.4	AO	2	0.4	AO	2	0.4	AO	2	0.4	AO
	1-Wire Interface board	5	0.015	0.003	AO	0.015	0.003	AO	0.015	0.003	AO	0.015	0.003	AO
	Magnetic Coil board	12	0.468	0.039	AO	0.468	0.039	AO	0.468	0.039	AO	0.468	0.039	AO
	Propulsion System Control board	5	0.00251	0.0005		0.00251	0.0005		0.00251	0.0005		0.00251	0.0005	
	Magnetometer board	5	0.0025	0.0005		0.0025	0.0005		0.0025	0.0005		0.0025	0.0005	
	GPS Interface board	3.3	0.0033	0.001		0.0033	0.001		0.0033	0.001		0.0033	0.001	
Structures			**0**			**0**			**0**			**0**		
	Release Mechanism	5	0	0		0	0		0	0		0	0	
ADAC			**0.87**			**0.87**			**6.87**			**6.87**		
	Magnetometer	15	0.375	0.025	AO	0.375	0.025	AO	0.375	0.025	AO	0.375	0.025	AO
	Coils (3)	6	0	0		0	0		6	1	MAX/Coil	6	1	MAX/Coil
	GPS	3.3	0.495	0.15	AO	0.495	0.15	AO	0.495	0.15	AO	0.495	0.15	AO
Propulsion			**5.307**			**0**			**0**			**5.307**		
	Pressure Transducers (2)	10	0.57	0.057	AO	0	0	AO	0	0	AO	0.57	0.057	AO
	Tank Heater #1	6.9	3.657	0.53	AO	0	0	AO	0	0	AO	3.657	0.53	AO
	Valves (2)	5	0	0		0	0		0	0		0	0	
	Thruster Valves (8)	5	0	0		0	0		0	0		0	0	
	Tank Heater #2	6	1.08	0.18	AO	0	0	AO	0	0	AO	1.08	0.18	AO
Comm			**1.122**			**1.122**			**0**			**0**		
	UHF transmit	7	11.2	1.6		11.2	1.6		11.2	1.6		0	0	
	VHF Receive	4	0.034	0.0085		0.034	0.0085		0.034	0.0085		0	0	
	Bluetooth transceiver (2)	3.3	1.122	0.34	AO	1.122	0.34	AO	0	0		0	0	
	Modem	5	0.278	0.0556		0.278	0.0556		0.278	0.0556		0	0	
Thermal			**0.04**			**0.04**			**0.04**			**0.04**		
	Sensors (8)	5	0.04	0.008	AO	0.04	0.008	AO	0.04	0.008	AO	0.04	0.008	AO
	Total		10.83031			5.52331			10.40131			15.70831		
	Total with 15% margin		**12.4548565**			**6.3518065**			**11.9615065**			**18.0645565**		

Power Generation

Sun Case	Power Generated (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)	Power Flow (Watts)
Nominal Solar Power	45	33.835444	33.8814435	32.5451435	32.5451435	32.5451435	38.6481935	33.0384935	26.9354435
Max Solar Power	77	65.835444	65.8814435	64.5451435	64.5451435	64.5451435	70.6481935	65.0384935	58.9354435
Min Solar Power	13	1.8354435	1.8814435	0.5451435	0.5451435	0.5451435	6.6481935	1.0384935	-5.0645565
Eclipse (30 minutes)	0	-11.164557	-11.1185565	-12.4548565	-12.4548565	-12.4548565	-6.3518065	-11.9615065	-18.0645565

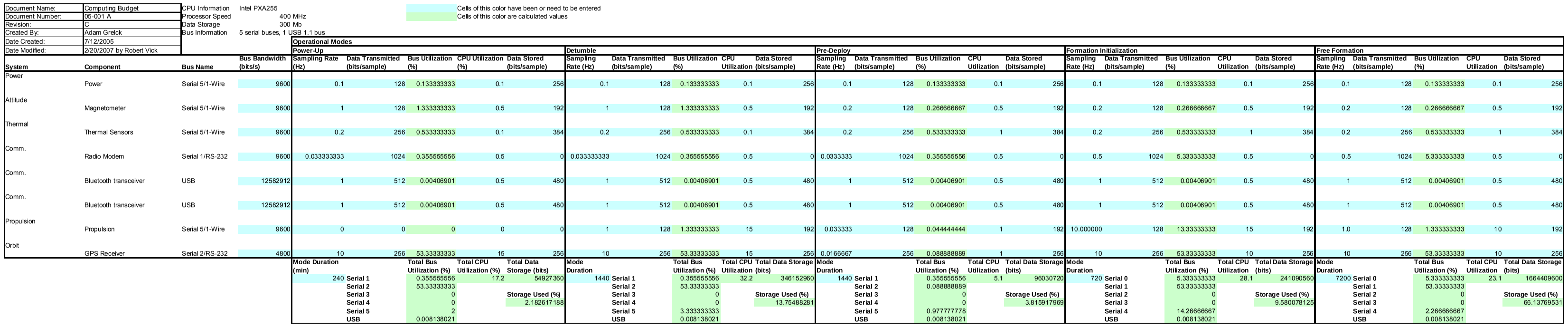
Battery Capacity	57.6	Watt Hours
Battery Capacity	8	Amp Hours
Battery Pack Minimum Voltage	7.2	Volts

Depth of Discharge

Sun Case	% Depth of Discharge	Duration	% Depth of Discharge	Duration	% Depth of Discharge	Duration	% Depth of Discharge	Duration
Nominal Solar Power	58.742089	60	58.82195052	60	68.67394329	60	68.67394329	60
Max Solar Power	114.29764	60	114.3775061	60	142.7480174	60	142.7480174	60
Min Solar Power	3.1865339	60	3.266394965	60	-5.400130787	60	-5.400130787	60
Eclipse (30 minutes)	-9.6914553	30	-9.65152474	30	-24.681216	30	-24.681216	30

Sun Case	% Depth of Discharge	Duration	% Depth of Discharge	Duration	% Depth of Discharge	Duration	% Depth of Discharge	
Nominal Solar Power	68.67394329	60	82.80137384	60	69.81595718	60	62.35056366	60
Max Solar Power	142.7480174	60	156.8754479	60	143.8900313	60	136.4246377	60
Min Solar Power	-5.400130787	60	8.727299769	60	-4.258116898	60	-11.72351042	60
Eclipse (30 minutes)	-24.681216	30	-15.8515719	30	-23.96745732	30	-26.13506438	30

Figure 3.1 UMR SAT Power Budget (5)



Document Name:	Computing Budget
Document Number:	05-001 A
Revision:	C
Created By:	Adam Grelck
Date Created:	7/12/2005
Date Modified:	2/20/2007 by Robert Vick

CPU Information	Intel PXA255
Processor Speed	400 MHz
Data Storage	300 Mb
Bus Information	5 serial buses, 1 USB 1.1 bus

🟦 Cells of this color have been or need to be entered

🟩 Cells of this color are calculated values

System	Component	Bus Name	Bus Bandwidth (bits/s)
Power	Power	Serial 5/1-Wire	9600
Attitude	Magnetometer	Serial 5/1-Wire	9600
Thermal	Thermal Sensors	Serial 5/1-Wire	9600
Comm.	Radio Modem	Serial 1/RS-232	9600
Comm.	Bluetooth transceiver	USB	12582912
Comm.	Bluetooth transceiver	USB	12582912
Propulsion	Propulsion	Serial 5/1-Wire	9600
Orbit	GPS Receiver	Serial 2/RS-232	4800

Operational Modes

Power-Up

Component	Sampling Rate (Hz)	Data Transmitted (bits/sample)	Bus Utilization (%)	CPU Utilization (%)	Data Stored (bits/sample)
Power	0.1	128	0.133333333	0.1	256
Magnetometer	1	128	1.333333333	0.5	192
Thermal Sensors	0.2	256	0.533333333	0.1	384
Radio Modem	0.033333333	1024	0.355555556	0.5	0
Bluetooth transceiver	1	512	0.00406901	0.5	480
Bluetooth transceiver	1	512	0.00406901	0.5	480
Propulsion	0	0	0	0	0
GPS Receiver	10	256	53.33333333	15	256

Mode Duration (min)		Total Bus Utilization (%)	Total CPU Utilization (%)	Total Data Storage (bits)
240	Serial 1	0.355555556	17.2	54927360
	Serial 2	53.33333333		
	Serial 3	0		Storage Used (%)
	Serial 4	0		2.182617188
	Serial 5	2		
	USB	0.008138021		

Detumble

Component	Sampling Rate (Hz)	Data Transmitted (bits/sample)	Bus Utilization (%)	CPU Utilization	Data Stored (bits/sample)
Power	0.1	128	0.133333333	0.1	256
Magnetometer	1	128	1.333333333	0.5	192
Thermal Sensors	0.2	256	0.533333333	0.1	384
Radio Modem	0.033333333	1024	0.355555556	0.5	0
Bluetooth transceiver	1	512	0.00406901	0.5	480
Bluetooth transceiver	1	512	0.00406901	0.5	480
Propulsion	1	128	1.333333333	15	192
GPS Receiver	10	256	53.33333333	15	256

Mode Duration		Total Bus Utilization (%)	Total CPU Utilization	Total Data Storage (bits)
1440	Serial 1	0.355555556	32.2	346152960
	Serial 2	53.33333333		
	Serial 3	0		Storage Used (%)
	Serial 4	0		13.75488281
	Serial 5	3.333333333		
	USB	0.008138021		

Pre-Deploy

Component	Sampling Rate (Hz)	Data Transmitted (bits/sample)	Bus Utilization (%)	CPU Utilization	Data Stored (bits/sample)
Power	0.1	128	0.133333333	0.1	256
Magnetometer	0.2	128	0.266666667	0.5	192
Thermal Sensors	0.2	256	0.533333333	1	384
Radio Modem	0.0333333	1024	0.355555556	0.5	0
Bluetooth transceiver	1	512	0.00406901	0.5	480
Bluetooth transceiver	1	512	0.00406901	0.5	480
Propulsion	0.033333	128	0.044444444	1	192
GPS Receiver	0.0166667	256	0.088888889	1	256

Mode Duration		Total Bus Utilization (%)	Total CPU Utilization	Total Data Storage (bits)
1440	Serial 1	0.355555556	5.1	96030720
	Serial 2	0.088888889		
	Serial 3	0		Storage Used (%)
	Serial 4	0		3.815917969
	Serial 5	0.977777778		
	USB	0.008138021		

Formation Initialization

Component	Sampling Rate (Hz)	Data Transmitted (bits/sample)	Bus Utilization (%)	CPU Utilization	Data Stored (bits/sample)
Power	0.1	128	0.133333333	0.1	256
Magnetometer	0.2	128	0.266666667	0.5	192
Thermal Sensors	0.2	256	0.533333333	1	384
Radio Modem	0.5	1024	5.333333333	0.5	0
Bluetooth transceiver	1	512	0.00406901	0.5	480
Bluetooth transceiver	1	512	0.00406901	0.5	480
Propulsion	10.000000	128	13.33333333	15	192
GPS Receiver	10	256	53.33333333	10	256

Mode Duration		Total Bus Utilization (%)	Total CPU Utilization	Total Data Storage (bits)
720	Serial 0	5.333333333	28.1	241090560
	Serial 1	53.33333333		
	Serial 2	0		Storage Used (%)
	Serial 3	0		9.580078125
	Serial 4	14.26666667		
	USB	0.008138021		

Free Formation

Component	Sampling Rate (Hz)	Data Transmitted (bits/sample)	Bus Utilization (%)	CPU Utilization	Data Stored (bits/sample)
Power	0.1	128	0.133333333	0.1	256
Magnetometer	0.2	128	0.266666667	0.5	192
Thermal Sensors	0.2	256	0.533333333	1	384
Radio Modem	0.5	1024	5.333333333	0.5	0
Bluetooth transceiver	1	512	0.00406901	0.5	480
Bluetooth transceiver	1	512	0.00406901	0.5	480
Propulsion	1.0	128	1.333333333	10	192
GPS Receiver	10	256	53.33333333	10	256

Mode Duration		Total Bus Utilization (%)	Total CPU Utilization	Total Data Storage (bits)
7200	Serial 0	5.333333333	23.1	1664409600
	Serial 1	53.33333333		
	Serial 2	0		Storage Used (%)
	Serial 3	0		66.13769531
	Serial 4	2.266666667		
	USB	0.008138021		

Figure 3.2 UMR SAT Computing Budget (6)

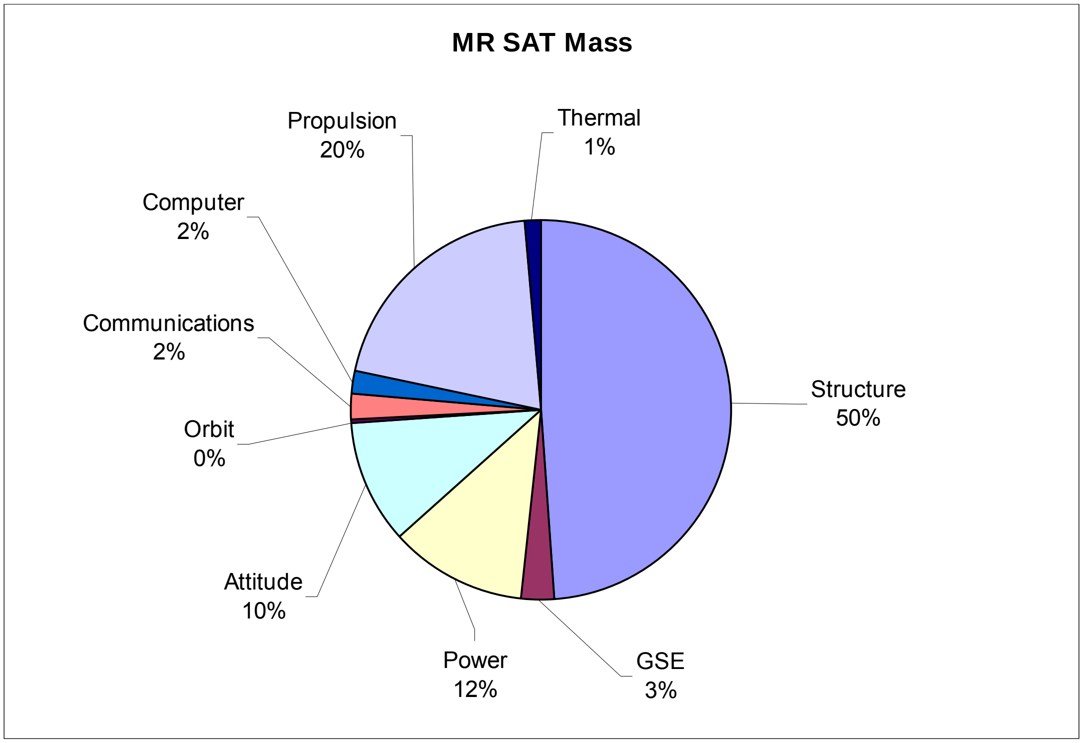


Figure 3.3 UMR SAT Mass Budget Pie Chart (7)

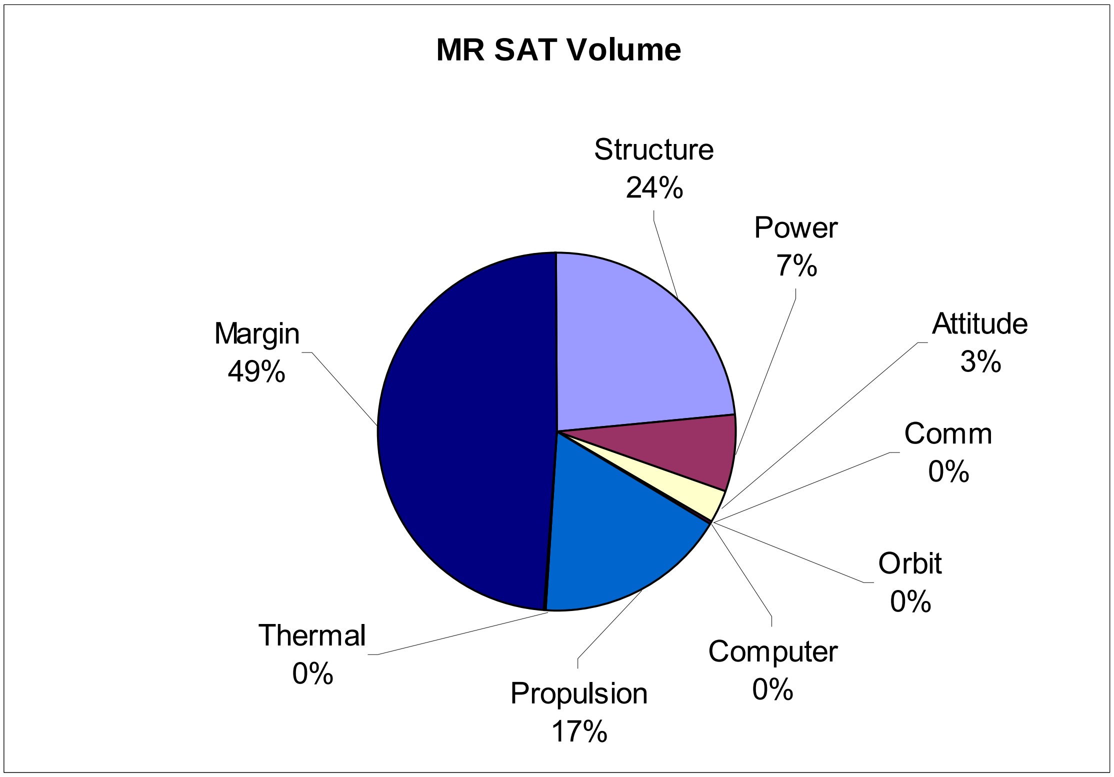


Figure 3.4 UMR SAT Volume Budget Pie Chart (8)

required to obtain a Certificate of Compliance (C of C) and a materials list that would be given to the Nanosat managers. Ultimately this information will be provided to the launch vehicle provider. The Nanosat Program established rules requiring no less than two team members to work on any item of hardware and one additional person for every 25 pounds lifted. This Configuration Management Plan also provides several sample copies of C of C's, deviation and waiver forms, and other forms that teams will need to use during the building phase of the project. Examples of these can be found in Appendix A (4).

3.3. TEAM MEMBER REQUIREMENTS

Although the Nanosat program did not specify detailed requirements for the composition of each team, there were several suggestions given by the Nanosat leadership that would be considered during the final competition. These suggestions included (3):

- Multi-disciplinary
- Several grade levels

The multi-disciplinary requirement encouraged teams to recruit workers from outside the aerospace discipline. For the satellite project to be successful, many different areas of expertise were necessary such as Computer, Electrical, Mechanical Engineering and Computer Science. Including students in several grade levels guaranteed that experienced workers would always be on the team, regardless of some team members graduating or leaving the project. Also, by encouraging upperclassmen and graduate students to be on the team, there was a high level of knowledge gained from coursework in the earlier years of college. The only specific requirement stated by the Nanosat Program, that truly was a requirement and not a suggestion, was that each team was required to have only United States citizens or citizens of friendly countries to the United States. This requirement stemmed from the use of Air Force documentation and facilities for the competition.

4. TEAM ORGANIZATION

4.1. PURPOSE FOR HAVING AN ORGANIZATION

A clearly defined team organization is necessary for project success. Without a clear chain of command and one or two people designated to make final decisions the project will not be able to meet the necessary deadlines. Organization also ensures that the entire team is working toward the same goal and working together to achieve that goal. The team organization should include student leaders, student participants and professors. Though the project may be considered a student design project it is necessary to include a professor on the project who has industry knowledge and experience to bring to the team.

4.2. LEVELS OF ORGANIZATION

After creating a team organization, it is necessary to define each person's role on the team and to clearly create a chain of command. In UMR SAT's organization, the final authority on any major decision is the advising professor, especially when the budget is concerned. The professor oversees the entire budget and must sign off on every purchase made by the team. This is a role defined by the university and cannot be altered. Other than budgetary concerns, the professor assists students in making other decisions where the students can benefit from the professor's industry experience. The highest level of student leadership is shared by the Chief Engineer and the Program Manager. It is the Chief Engineer's job to guarantee the project is remaining on schedule and is meeting all requirements given by the customer. The Chief Engineer must keep the subsystems on task and communicating with one another. The ultimate goal of the

Chief Engineer is to get the project finished correctly and on time. The Program Manager ensures that the team has a sufficient number of team members and that they are evenly divided into subsystems. The Program Manager runs the meetings each week and monitors the business side of the project. He/She runs the weekly meetings where the entire team gathers together, allowing each subsystem to update the other subsystems on their progress and discuss cross-subsystem issues. Each subsystem also has a separate weekly 15-minute meeting with the Chief Engineer, Program Manager and Professor each week to ensure that the details of the subsystem are being covered and that they do not interfere with any other subsystem design. Organizing presentations and displays, recruitment, and publicity all fall under the duties of the Program Manager. The next tier of student leaders is the subsystem leaders. These leaders focus their energy on the productiveness of their subsystem. They are in charge of knowing the needs and requirements of the customer by their subsystem. They oversee the detailed design of the subsystem and make sure every item in the plan is being covered by someone. Below the subsystem leaders are the subsystem members. The subsystem members make up the largest part of the team, and are responsible for the majority of the actual designing and building each component of the satellite. Though they may not be completely concerned with the satellite as a whole, it is their job to make sure that their one component meets the requirements defined by their subsystem leader and that the component functions the way the team needs for the final satellite. Below is a more detailed list of the roles of each member of the organization.

From UNP Guidelines (9):

Professor

- "head of state"
- Technical mentorship
- Executes expenditures
- Administrative support
- Must empower students to:
    - Complete tasks
    - Make design decisions
    - Productivity self-policing
- Step in only when necessary

Students/Student PI

- "head of government"
- Technical execution
- Financial decisions
- Administrative awareness
- MUST advise professor on
    - Technical progress
    - Group morale
    - Facility needs
- Prevent the need for the professor to "step in"

Role of Chief Engineer vs. Program Manager:

Chief Engineer

- Oversees project from satellite design/construction perspective
- Guarantees hardware being purchased meets requirements
- Ensures satellites produced on time and to all specifications
- Facilitates subsystem communication to confirm satellite successful when completed
- Makes purchases that cross subsystem lines

Program Manager

- Manages/organizes team
- Shifts team members when necessary
- Oversees documentation production and presentations
- Runs team meetings

4.3. SUBSYSTEM DIVISION

The mission concept should already be developed at the point the team begins to divide into subsystems. The mission plan will make the necessary subsystems evident. The following subsystems will be necessary for most every satellite mission.

Main subsystems:

- Structure
- Thermal
- Communication
- Power

- Attitude Determination and Control
- Orbit Determination and Control
- Command and Data Handling
- Payload

Each mission also may require several additional subsystems depending on the type of mission. The following subsystems are possible additional subsystems that might be needed.

Additional subsystems:

- Propulsion
- Integration
- Payload specific needs may produce several other subsystems

The Integration subsystem was included in the UMR SAT team organization because the Structure and other subsystems were occupied with their individual components to devote close attention to the overall system integration. The Integration subsystem focused on the assembly procedures of each subsystem and the overall satellite systems, as well as all drawings for the satellites. These procedures were mainly created by the subsystems where as the drawings were almost entirely completed by the Integration subsystem. Both the procedures and the drawings were approved by the subsystems, the Integration subsystem leader and the Chief Engineer. More details of the integration subsystem and processes for UMR SAT can be found in Reference 10.

Once the subsystems have been created it is necessary to populate them with students. Though it is preferable to allow students to choose the subsystem they wish to work in, this is not always possible. Every subsystem must have team members working in it and therefore it may, on occasion, be necessary to place a team member in a subsystem that was not his/her first choice. The method for subsystem division employed by UMR SAT has each team member provide the three most favorable subsystem choices and one least favorite subsystem to the Program Manager and the Chief Engineer. They then divide the team up as evenly as possible, while still trying to accommodate as many preferences as possible.

5. MISSION DESIGN

Designing the mission is the first step in the actual production of a satellite. Following the careful recruitment of a team, the next step is to define the goal of the team, and what product the team is striving to create. This is not a trivial step in creating a university satellite. Determining the mission will set the tone for the rest of the project. The mission must be clearly defined yet leave room for some necessary changes later. If the mission is poorly defined in the beginning, the program will immediately fall behind and become misdirected. Time will be wasted on ideas that do not address what the team is truly trying to accomplish. The well-defined mission is best developed by a team of people dedicated to the project and its success. The team needs to consist of several students who have the vision for new and innovative solutions, as well as a few faculty advisors who have the industrial experience to advise on the feasibility of ideas. This team will need to go through several steps to fully design the satellite mission. This section further explores the steps the design team will need to take to fully design the satellite mission in a detailed manner in order to more effectively ensure success of the project. In each of these steps it is advised that team members recognize that the first design may not be the final design.

5.1. DETERMINING THE MISSION

When defining a mission for a spacecraft, four basic questions need to be answered:

- For whom is the spacecraft being built, or who is your customer?
- What does that customer need the spacecraft to do?

- What resources and personnel are available for the project?
- What time frame and budget are available to complete the project?

Without a clear answer to these four questions, it is very difficult to define a useful, attainable mission. Defining the customer is the simplest task. It is only necessary to determine who the end- user of the spacecraft will be. In the case of UMR SAT, the Nanosat competition is operated by the Air Force Research Laboratory (AFRL) and the Department of Defense (DoD) who will provide the launch for the winner. Therefore, the customer for all the competing universities is AFRL and the DoD. With this information, it is then necessary to conduct research into the interests of the customer. What do they hope to accomplish in future spacecraft? What Technology Readiness Levels (TRLs) do they most want to improve? Every technology is given a TRL value that indicates how developed and tested that product is. TRL values range from the lowest number indicating the beginning of research to the highest number indicating fully flight proven technology. Both the DoD and NASA versions of TRLs can be found in Appendix B. In the case of the Nanosat competition, a list of DoD interests in space was provided to each competing university. The UMR SAT team chose to pursue “Novel approaches for the autonomous control of distributed spacecraft.” Choosing this topic stemmed from answering the next question, “what resources and capabilities are available?”

The UMR SAT team considered the resources available to them. The supervising professor over the UMR SAT project has experience working with distributed spacecraft in industry. Also by testing distributed spacecraft, constructing multiple smaller spacecraft would be necessary. While the university laboratory might prove to be a hindrance in building a single larger spacecraft, the smaller laboratory facilities of UMR would be adequate for building smaller spacecraft. The laboratory at UMR includes a small Class 100 cleanroom. For this project, only a Class 100,000 cleanroom was necessary which means that a particle counter only finds 100,000 particles in one square foot of air inside the cleanroom. The laboratory also was required to be equipped with an Electrostatic Discharge (ESD) safe work bench where students and hardware could be grounded at all times. For any university to participate in a satellite project, these facilities will be necessary to build a flight-worthy satellite. The testing facilities available for the project must also be considered in response to this question. Any satellite that wishes to launch will need to go through several tests before a launch provider will accept them including Structural Strength, Stiffness, Random Vibration/Acoustic, Shock, Mass properties, Thermal Vacuum, Pressure Profile, Bake out, Envelop Verification, EMI/EMC, and Electrical System Aliveness and Functional Tests (3). Each of these tests will need detailed plans developed prior to performing the tests so the team follows specific procedures and seeks the desired result. At UMR, vibration, EMC, and vacuum chambers are available. However, for thermal vacuum or any further testing, the UMR SAT team was required to locate off-campus facilities. Manufacturing facilities are also necessary such as machine shops, Computer Numerical Control (CNC) machining facilities and rapid prototyping facilities. UMR has access to all of these facilities, as well as waterjetting capabilities. However other universities may not, and would need to consider what is needed for their spacecraft and how it can be manufactured in a reasonable timeframe. Another consideration is the personnel involved. Even with all of these facilities available to the UMR SAT team, lack of experience on the part of student personnel caused several setbacks throughout the project.

The final question is possibly the most vital. Even if the spacecraft is exactly what the customer wants and the facilities and knowledge are in place to create the spacecraft, if it cannot be completed in the timeframe and budget given by the customer, the spacecraft becomes obsolete and useless. For UMR SAT, UNP gave a two-year timeframe with a budget of $110,000 for the competition. If a complete protoflight spacecraft was not delivered in two-years, the team would have no hope of winning the launch into Low Earth Orbit (LEO).

5.2. CREATING A MISSION STATEMENT

The mission statement is a vital part to mission planning. It lays the groundwork for the rest of the project. Because all mission, system, and subsystem requirements flow down from this one statement, it is imperative to have a well-written mission statement. It needs to be clear and specific without constricting or limiting the mission goals or objectives. The mission statement needs to contain no justification and does not need to specify the requirements for the following steps. Two poorly written statements follow. The first is too general and the second is poorly written because it is overly specific. The last mission statement is an example of a well written mission statement (9).

(1) The purpose of Program X is to learn about magnetic-molecular chemistry effects in the upper atmosphere by using microsatellites.

(2) Chemical reactions between oxygenated molecules in the upper atmosphere are theorized to have a strong effect on weather patterns over large bodies of water such

as the oceans. As such, the purpose of Program X is to investigate the effect on Earth’s magnetic field on atomic oxygen and ozone reactions in the F1 and F2 layers of the ionosphere; this will be achieved by taking data with a novel dual-band antenna sensing device attached to a micorsatellite not to exceed 50 cm cubed in size and 50 kg in mass. The data must be returned to the ground within 12 hours of capture so that it can be processed using the revolutionary “Technique B.”

(3) The purpose of Program X is to investigate the effects of Earth’s magnetic field on molecular chemical reactions in the upper ionosphere; this will be achieved by taking data on orbit with a novel dual-band antenna sensing device, after which the data will be returned to the ground for processing.

A design team is destined for failure without a properly constructed mission statement.

UMR SAT went through several revisions of its mission statement before one was developed that followed all the concepts listed above and precisely stated what the team wanted for the mission. Below are several of the mission statements that the team developed before it settled on the final one (11).

(1a) The primary purpose of the MR SAT project is to investigate the autonomous control of distributed spacecraft flying in close formation.

(1b) The mission will be accomplished by orbiting two satellites (MR SAT and MRS SAT) on a short tether (Phase I) followed by free formation flight (Phase II) to compare modes of formation control. (MS2)

(2a) The primary purpose of the MR SAT project is to investigate the autonomous control of distributed spacecraft flying in close formation.

(2b) The mission will be accomplished by orbiting two satellites (MR SAT and MRS SAT) on a short tether (Phase I) followed by free formation flight (Phase II) to compare modes of formation control.

(3a) The purpose of the MR SAT project is to investigate the autonomous control of distributed spacecraft flying in close formation.

(3b) The mission will be accomplished by orbiting two satellites (MR SAT and MRS SAT) in free formation flight.

(4a) The purpose of the UMR SAT project is to investigate the autonomous control of distributed spacecraft flying in close formation.

(4b) The mission will be accomplished by orbiting two satellites (MR SAT and MRS SAT) in free formation flight.

As is obvious, some revisions were merely cosmetic, while other changes altered the entire course of the project.

5.3. DEVELOPING MISSION REQUIREMENTS

Each level of a mission and its system must have requirements which flow directly from the requirements the level above them. If a requirement is created that can not be directly linked to the level above, it should be reevaluated. For this reason all of the mission level requirements should be directly linked to the mission statement. The requirements begin to list how the mission statement will be fulfilled. They need to be clear specific statements that describe the goals and deliverables of the mission. Every goal that is listed needs to also have minimum success criteria so that the team has a predictor for the remainder of the project. It is imperative that mission requirements do not become system requirements. These are not requirements on the actual satellite system, but more on the mission that the satellite will perform. Finally, a requirement at any level must not be either too vague or too specific. The requirements need to be specific enough to place a boundary on your mission and system, without so limiting the design that it is not feasible to successfully complete the project.

UMR SAT's requirements evolved as the team learned more about how to write good requirements. Some requirements placed excessively narrow parameters on the work, while others were too broad to provide necessary direction. The team would have had a more successful beginning if there had been a better understanding of how to write requirements before the project started. Below are the final mission level requirements created by the UMR SAT team (11).

M-1 Formation flight will be conducted with two spacecraft (MR SAT and MRS SAT)

M-2 Control of the formation will be conducted autonomously and monitored by UMR Ground Station

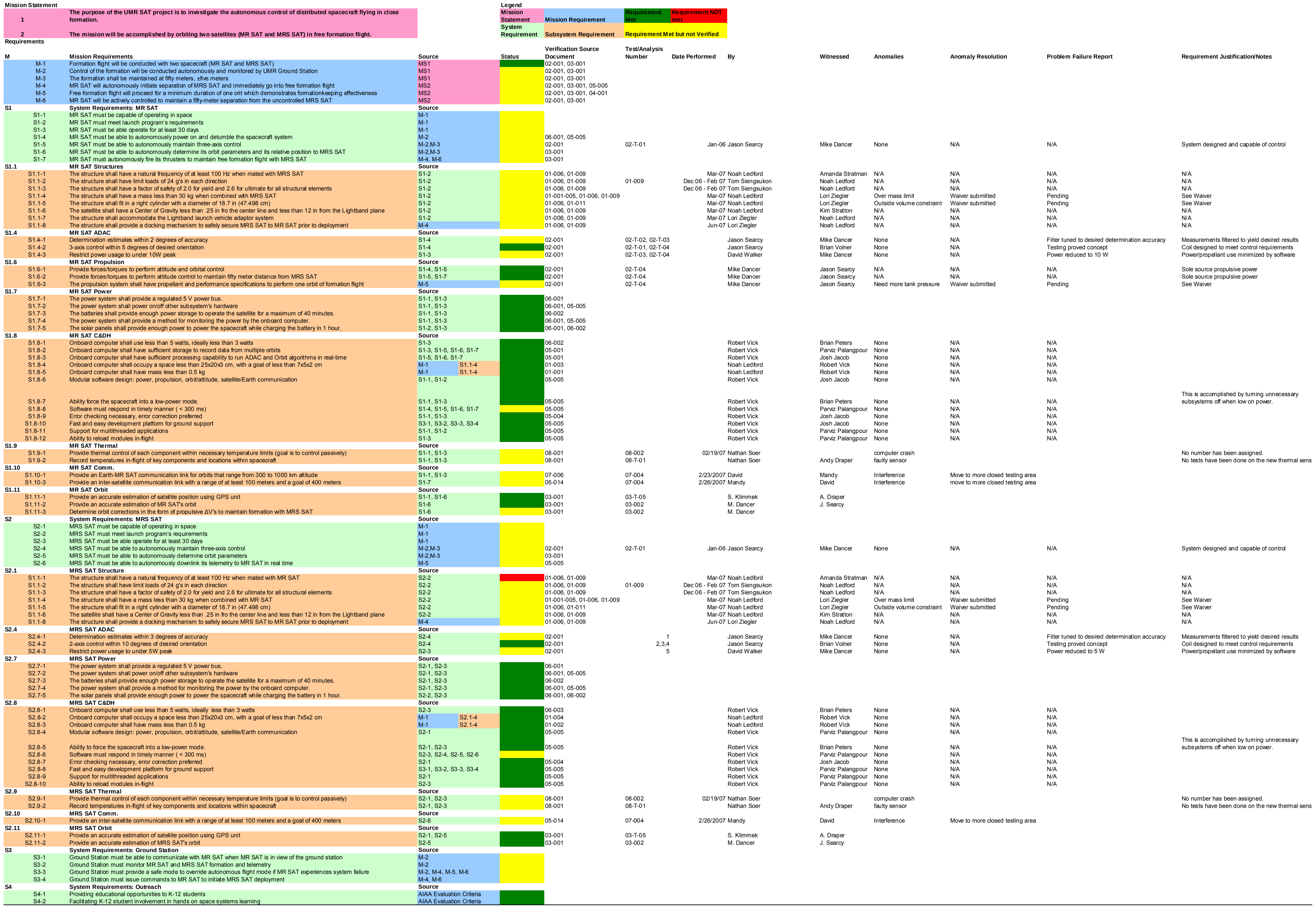
M-3 The formation shall be maintained at fifty meters, ±five meters

M-4 MR SAT will autonomously initiate separation of MRS SAT and immediately go into free formation flight

M-5 Free formation flight will proceed for a minimum duration of one orbit which demonstrates formationkeeping effectiveness

M-6 MR SAT will be actively controlled to maintain a fifty-meter separation from the uncontrolled MRS SAT

These requirements, added to the mission statement, system requirements and subsystem requirements were combined in to one document called the Requirements



Mission Statement

1	**The purpose of the UMR SAT project is to investigate the autonomous control of distributed spacecraft flying in close formation.**
2	**The mission will be accomplished by orbiting two satellites (MR SAT and MRS SAT) in free formation flight.**

Legend

Mission Statement	Mission Requirement	🟩 Requirement Met	🟥 Requirement NOT met
System Requirement	Subsystem Requirement	🟨 Requirement Met but not Verified	

Requirements

M	Mission Requirements	Source	Status	Verification Source Document	Test/Analysis Number	Date Performed	By	Witnessed	Anomalies	Anomaly Resolution	Problem Failure Report	Requirement Justification/Notes
M-1	Formation flight will be conducted with two spacecraft (MR SAT and MRS SAT)	MS1	🟩	02-001, 03-001								
M-2	Control of the formation will be conducted autonomously and monitored by UMR Ground Station	MS1	🟨	02-001, 03-001								
M-3	The formation shall be maintained at fifty meters, ±five meters	MS1	🟨	02-001, 03-001								
M-4	MR SAT will autonomously initiate separation of MRS SAT and immediately go into free formation flight	MS2	🟨	02-001, 03-001, 05-005								
M-5	Free formation flight will proceed for a minimum duration of one orit which demonstrates formationkeeping effectiveness	MS2	🟨	02-001, 03-001, 04-001								
M-6	MR SAT will be actively controlled to maintain a fifty-meter separation from the uncontrolled MRS SAT	MS2	🟨	02-001, 03-001								
S1	**System Requirements: MR SAT**	**Source**										
S1-1	MR SAT must be capable of operating in space	M-1	🟨									
S1-2	MR SAT must meet launch program's requirements	M-1	🟨									
S1-3	MR SAT must be able operate for at least 30 days	M-1	🟨									
S1-4	MR SAT must be able to autonomously power on and detumble the spacecraft system	M-2	🟨	06-001, 05-005								
S1-5	MR SAT must be able to autonomously maintain three-axis control	M-2,M-3	🟨	02-001	02-T-01	Jan-06	Jason Searcy	Mike Dancer	None	N/A	N/A	System designed and capable of control
S1-6	MR SAT must be able to autonomously determine its orbit parameters and its relative position to MRS SAT	M-2,M-3	🟨	03-001								
S1-7	MR SAT must autonomously fire its thrusters to maintain free formation flight with MRS SAT	M-4, M-6	🟨	03-001								
S1.1	**MR SAT Structures**	**Source**										
S1.1-1	The structure shall have a natural frequency of at least 100 Hz when mated with MRS SAT	S1-2	🟨	01-006, 01-009		Mar-07	Noah Ledford	Amanda Stratman	N/A	N/A	N/A	N/A
S1.1-2	The structure shall have limit loads of 24 g's in each direction	S1-2	🟨	01-006, 01-009	01-009	Dec 06 - Feb 07	Tom Siengsukon	Noah Ledford	N/A	N/A	N/A	N/A
S1.1-3	The structure shall have a factor of safety of 2.0 for yield and 2.6 for ultimate for all structural elements	S1-2	🟨	01-006, 01-009		Dec 06 - Feb 07	Tom Siengsukon	Noah Ledford	N/A	N/A	N/A	N/A
S1.1-4	The structure shall have a mass less than 30 kg when combined with MRS SAT	S1-2	🟨	01-001-005, 01-006, 01-009		Mar-07	Noah Ledford	Lori Ziegler	Over mass limit	Waiver submitted	Pending	See Waiver
S1.1-5	The structure shall fit in a right cylinder with a diameter of 18.7 in (47.498 cm)	S1-2	🟨	01-006, 01-011		Mar-07	Noah Ledford	Lori Ziegler	Outside volume constraint	Waiver submitted	Pending	See Waiver
S1.1-6	The satellite shall have a Center of Gravity less than .25 in fro the center line and less than 12 in from the Lightband plane	S1-2	🟨	01-006, 01-009		Mar-07	Noah Ledford	Kim Stratton	N/A	N/A	N/A	N/A
S1.1-7	The structure shall accommodate the Lightband launch vehicle adaptor system	S1-2	🟨	01-006, 01-009		Mar-07	Lori Ziegler	Noah Ledford	N/A	N/A	N/A	N/A
S1.1-8	The structure shall provide a docking mechanism to safely secure MRS SAT to MR SAT prior to deployment	M-4	🟨	01-006, 01-009		Jun-07	Lori Ziegler	Noah Ledford	N/A	N/A	N/A	N/A
S1.4	**MR SAT ADAC**	**Source**										
S1.4-1	Determination estimates within 2 degrees of accuracy	S1-4	🟨	02-001	02-T-02, 02-T-03		Jason Searcy	Mike Dancer	None	N/A	Filter tuned to desired determination accuracy	Measurements filtered to yield desired results
S1.4-2	3-axis control within 5 degrees of desired orientation	S1-4	🟩	02-001	02-T-01, 02-T-04		Jason Searcy	Brian Volner	None	N/A	Testing proved concept	Coil designed to meet control requirements
S1.4-3	Restrict power usage to under 10W peak	S1-3	🟨	02-001	02-T-03, 02-T-04		David Walker	Mike Dancer	None	N/A	Power reduced to 10 W	Power/propellant use minimized by software
S1.6	**MR SAT Propulsion**	**Source**										
S1.6-1	Provide forces/torques to perform attitude and orbital control	S1-4, S1-5	🟩	02-001	02-T-04		Mike Dancer	Jason Searcy	N/A	N/A	N/A	Sole source propulsive power
S1.6-2	Provide forces/torques to perform attitude control to maintain fifty meter distance from MRS SAT	S1-5, S1-7	🟩	02-001	02-T-04		Mike Dancer	Jason Searcy	N/A	N/A	N/A	Sole source propulsive power
S1.6-3	The propulsion system shall have propellant and performance specifications to perform one orbit of formation flight	M-5	🟨	02-001	02-T-04		Mike Dancer	Jason Searcy	Need more tank pressure	Waiver submitted	Pending	See Waiver
S1.7	**MR SAT Power**	**Source**										
S1.7-1	The power system shall provide a regulated 5 V power bus.	S1-1, S1-3	🟩	06-001								
S1.7-2	The power system shall power on/off other subsystem's hardware	S1-1, S1-3	🟩	06-001, 05-005								
S1.7-3	The batteries shall provide enough power storage to operate the satellite for a maximum of 40 minutes.	S1-1, S1-3	🟩	06-002								
S1.7-4	The power system shall provide a method for monitoring the power by the onboard computer.	S1-1, S1-3	🟩	06-001, 05-005								
S1.7-5	The solar panels shall provide enough power to power the spacecraft while charging the battery in 1 hour.	S1-2, S1-3	🟩	06-001, 06-002								
S1.8	**MR SAT C&DH**	**Source**										
S1.8-1	Onboard computer shall use less than 5 watts, ideally less than 3 watts	S1-3	🟩	06-002			Robert Vick	Brian Peters	None	N/A	N/A	
S1.8-2	Onboard computer shall have sufficient storage to record data from multiple orbits	S1-3, S1-5, S1-6, S1-7	🟩	05-001			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S1.8-3	Onboard computer shall have sufficient processing capability to run ADAC and Orbit algorithms in real-time	S1-5, S1-6, S1-7	🟩	05-001			Robert Vick	Josh Jacob	None	N/A	N/A	
S1.8-4	Onboard computer shall occupy a space less than 25x20x3 cm, with a goal of less than 7x5x2 cm	M-1 S1.1-4	🟩	01-003			Noah Ledford	Robert Vick	None	N/A	N/A	
S1.8-5	Onboard computer shall have mass less than 0.5 kg	M-1 S1.1-4	🟩	01-001			Noah Ledford	Robert Vick	None	N/A	N/A	
S1.8-6	Modular software design: power, propulsion, orbit/attitude, satellite/Earth communication	S1-1, S1-2	🟩	05-005			Robert Vick	Josh Jacob	None	N/A	N/A	
S1.8-7	Ability force the spacecraft into a low-power mode.	S1-1, S1-3	🟩	05-005			Robert Vick	Brian Peters	None	N/A	N/A	This is accomplished by turning unnecessary subsystems off when low on power.
S1.8-8	Software must respond in timely manner (< 300 ms)	S1-4, S1-5, S1-6, S1-7	🟨	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S1.8-9	Error checking necessary, error correction preferred	S1-1, S1-3	🟩	05-004			Robert Vick	Josh Jacob	None	N/A	N/A	
S1.8-10	Fast and easy development platform for ground support	S3-1, S3-2, S3-3, S3-4	🟩	05-005			Robert Vick	Josh Jacob	None	N/A	N/A	
S1.8-11	Support for multithreaded applications	S1-1, S1-2	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S1.8-12	Ability to reload modules in-flight	S1-3	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S1.9	**MR SAT Thermal**	**Source**										
S1.9-1	Provide thermal control of each component within necessary temperature limits (goal is to control passively)	S1-1, S1-3	🟨	08-001	08-002	02/19/07	Nathan Soer		computer crash			No number has been assigned.
S1.9-2	Record temperatures in-flight of key components and locations within spacecraft	S1-1, S1-3	🟨	08-001	08-T-01		Nathan Soer	Andy Draper	faulty sensor			No tests have been done on the new thermal sens
S1.10	**MR SAT Comm.**	**Source**										
S1.10-1	Provide an Earth-MR SAT communication link for orbits that range from 300 to 1000 km altitude	S1-1, S1-3	🟨	07-006	07-004	2/23/2007	David	Mandy	Interference	Move to more closed testing area		
S1.10-3	Provide an inter-satellite communication link with a range of at least 100 meters and a goal of 400 meters	S1-7	🟨	05-014	07-004	2/26/2007	Mandy	David	Interference	move to more closed testing area		
S1.11	**MR SAT Orbit**	**Source**										
S1.11-1	Provide an accurate estimation of satellite position using GPS unit	S1-1, S1-6	🟩	03-001	03-T-05		S. Klimmek	A. Draper				
S1.11-2	Provide an accurate estimation of MR SAT's orbit	S1-6	🟩	03-001	03-002		M. Dancer	J. Searcy				
S1.11-3	Determine orbit corrections in the form of propulsive ΔV's to maintain formation with MRS SAT	S1-6	🟨	03-001	03-002		M. Dancer					
S2	**System Requirements: MRS SAT**	**Source**										
S2-1	MRS SAT must be capable of operating in space	M-1	🟨									
S2-2	MRS SAT must meet launch program's requirements	M-1	🟨									
S2-3	MRS SAT must be able operate for at least 30 days	M-1	🟨									
S2-4	MRS SAT must be able to autonomously maintain three-axis control	M-2,M-3	🟨	02-001	02-T-01	Jan-06	Jason Searcy	Mike Dancer	None	N/A	N/A	System designed and capable of control
S2-5	MRS SAT must be able to autonomously determine orbit parameters	M-2,M-3	🟨	03-001								
S2-6	MRS SAT must be able to autonomously downlink its telemetry to MR SAT in real time	M-5	🟨	05-005								
S2.1	**MRS SAT Structure**	**Source**										
S1.1-1	The structure shall have a natural frequency of at least 100 Hz when mated with MR SAT	S2-2	🟥	01-006, 01-009		Mar-07	Noah Ledford	Amanda Stratman	N/A	N/A	N/A	N/A
S1.1-2	The structure shall have limit loads of 24 g's in each direction	S2-2	🟨	01-006, 01-009	01-009	Dec 06 - Feb 07	Tom Siengsukon	Noah Ledford	N/A	N/A	N/A	N/A
S1.1-3	The structure shall have a factor of safety of 2.0 for yield and 2.6 for ultimate for all structural elements	S2-2	🟨	01-006, 01-009		Dec 06 - Feb 07	Tom Siengsukon	Noah Ledford	N/A	N/A	N/A	N/A
S1.1-4	The structure shall have a mass less than 30 kg when combined with MR SAT	S2-2	🟨	01-001-005, 01-006, 01-009		Mar-07	Noah Ledford	Lori Ziegler	Over mass limit	Waiver submitted	Pending	See Waiver
S1.1-5	The structure shall fit in a right cylinder with a diameter of 18.7 in (47.498 cm)	S2-2	🟨	01-006, 01-011		Mar-07	Noah Ledford	Lori Ziegler	Outside volume constraint	Waiver submitted	Pending	See Waiver
S1.1-6	The satellite shall have a Center of Gravity less than .25 in fro the center line and less than 12 in from the Lightband plane	S2-2	🟨	01-006, 01-009		Mar-07	Noah Ledford	Kim Stratton	N/A	N/A	N/A	N/A
S1.1-8	The structure shall provide a docking mechanism to safely secure MRS SAT to MR SAT prior to deployment	M-4	🟨	01-006, 01-009		Jun-07	Lori Ziegler	Noah Ledford	N/A	N/A	N/A	N/A
S2.4	**MRS SAT ADAC**	**Source**										
S2.4-1	Determination estimates within 3 degrees of accuracy	S2-4	🟨	02-001	1		Jason Searcy	Mike Dancer	None	N/A	Filter tuned to desired determination accuracy	Measurements filtered to yield desired results
S2.4-2	2-axis control within 10 degrees of desired orientation	S2-4	🟩	02-001	2,3,4		Jason Searcy	Brian Volner	None	N/A	Testing proved concept	Coil designed to meet control requirements
S2.4-3	Restrict power usage to under 5W peak	S2-3	🟨	02-001	5		David Walker	Mike Dancer	None	N/A	Power reduced to 5 W	Power/propellant use minimized by software
S2.7	**MRS SAT Power**	**Source**										
S2.7-1	The power system shall provide a regulated 5 V power bus.	S2-1, S2-3	🟩	06-001								
S2.7-2	The power system shall power on/off other subsystem's hardware	S2-1, S2-3	🟩	06-001, 05-005								
S2.7-3	The batteries shall provide enough power storage to operate the satellite for a maximum of 40 minutes.	S2-1, S2-3	🟩	06-002								
S2.7-4	The power system shall provide a method for monitoring the power by the onboard computer.	S2-1, S2-3	🟩	06-001, 05-005								
S2.7-5	The solar panels shall provide enough power to power the spacecraft while charging the battery in 1 hour.	S2-2, S2-3	🟩	06-001, 06-002								
S2.8	**MRS SAT C&DH**	**Source**										
S2.8-1	Onboard computer shall use less than 5 watts, ideally less than 3 watts	S2-3	🟩	06-003			Robert Vick	Brian Peters	None	N/A	N/A	
S2.8-2	Onboard computer shall occupy a space less than 25x20x3 cm, with a goal of less than 7x5x2 cm	M-1 S2.1-4	🟩	01-004			Noah Ledford	Robert Vick	None	N/A	N/A	
S2.8-3	Onboard computer shall have mass less than 0.5 kg	M-1 S2.1-4	🟩	01-002			Noah Ledford	Robert Vick	None	N/A	N/A	
S2.8-4	Modular software design: power, propulsion, orbit/attitude, satellite/Earth communication	S2-1	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S2.8-5	Ability to force the spacecraft into a low-power mode.	S2-1, S2-3	🟩	05-005			Robert Vick	Brian Peters	None	N/A	N/A	This is accomplished by turning unnecessary subsystems off when low on power.
S2.8-6	Software must respond in timely manner (< 300 ms)	S2-3, S2-4, S2-5, S2-6	🟨				Robert Vick	Parviz Palangpour	None	N/A	N/A	
S2.8-7	Error checking necessary, error correction preferred	S2-1	🟩	05-004			Robert Vick	Josh Jacob	None	N/A	N/A	
S2.8-8	Fast and easy development platform for ground support	S3-1, S3-2, S3-3, S3-4	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S2.8-9	Support for multithreaded applications	S2-1	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S2.8-10	Ability to reload modules in-flight	S2-3	🟩	05-005			Robert Vick	Parviz Palangpour	None	N/A	N/A	
S2.9	**MRS SAT Thermal**	**Source**										
S2.9-1	Provide thermal control of each component within necessary temperature limits (goal is to control passively)	S2-1, S2-3	🟨	08-001	08-002	02/19/07	Nathan Soer		computer crash			No number has been assigned.
S2.9-2	Record temperatures in-flight of key components and locations within spacecraft	S2-1, S2-3	🟨	08-001	08-T-01		Nathan Soer	Andy Draper	faulty sensor			No tests have been done on the new thermal sens
S2.10	**MRS SAT Comm.**	**Source**										
S2.10-1	Provide an inter-satellite communication link with a range of at least 100 meters and a goal of 400 meters	S2-6	🟨	05-014	07-004	2/26/2007	Mandy	David	Interference	Move to more closed testing area		
S2.11	**MRS SAT Orbit**	**Source**										
S2.11-1	Provide an accurate estimation of satellite position using GPS unit	S2-1, S2-5	🟩	03-001	03-T-05		S. Klimmek	A. Draper				
S2.11-2	Provide an accurate estimation of MRS SAT's orbit	S2-5	🟩	03-001	03-002		M. Dancer	J. Searcy				
S3	**System Requirements: Ground Station**	**Source**										
S3-1	Ground Station must be able to communicate with MR SAT when MR SAT is in view of the ground station	M-2	🟨									
S3-2	Ground Station must monitor MR SAT and MRS SAT formation and telemetry	M-2	🟨									
S3-3	Ground Station must provide a safe mode to override autonomous flight mode if MR SAT experiences system failure	M-2, M-4, M-5, M-6	🟨									
S3-4	Ground Station must issue commands to MR SAT to initiate MRS SAT deployment	M-4, M-6	🟨									
S4	**System Requirements: Outreach**	**Source**										
S4-1	Providing educational opportunities to K-12 students	AIAA Evaluation Criteria	🟩									
S4-2	Facilitating K-12 student involvement in hands on space systems learning	AIAA Evaluation Criteria	🟩									

Figure 5.1 UMR SAT RVM (11)

Verification Matrix (RVM) shown in Figure 5.1. A sample of an RVM was provided to UMR SAT by AFRL. It was then modified to be of the most benefit to UMR SAT and is included below.

5.4. FLOW DOWN REQUIREMENTS

System requirements and operational requirements should directly support mission goals. These are more specific to the satellite being designed than what was stated in the mission statement. It is only necessary to include the numbers directly specified by the customer, such as mass and volume constraints. Specifying numbers in the requirements at this point in the design could be limiting for the team later in the build process. Below are examples of UMR SAT’s system requirements for the MR SAT spacecraft system (11).

S1-1 MR SAT must be capable of operating in space

Source: M-1

S1-2 MR SAT must meet launch program’s requirements

Source: M-1

S1-3 MR SAT must be able to operate for a minimum of one orbit

Source: M-1

S1-4 MR SAT must be able to autonomously power on and detumble the spacecraft system

Source: M-2

S1-5 MR SAT must be able to autonomously maintain three-axis control

Source: M-2, M-3

S1-6 MR SAT must be able to autonomously determine its orbit parameters and its relative position to MRS SAT

Source: M-2, M-3

S1-7 MR SAT must autonomously fire its thrusters to maintain free formation flight with MRS SAT

Source: M-4, M-6

In the same way that the system requirements support the mission requirements, the subsystem requirements should directly support system requirements, and again, should not be so specific that they unnecessarily limit subsystem design. As an example, the requirements for the UMR SAT Structure subsystem are included below:

S1.1-1 The structure shall have a natural frequency of at least 100 Hz when mated with MRS SAT

Source: S1-2

S1.1-2 The structure shall have limit loads of 24 g's in each direction

Source: S1-2

S1.1-3 The structure shall have a factor of safety of 2.0 yield and 2.6 for ultimate for all structural elements

Source: S1-2

S1.1-4 The structure shall have a mass less than 30 kg when combined with MRS SAT

Source: S1-2

S1.1-5 The structure shall fit in a right cylinder with a diameter of 18.7 in. (47.498 cm)

Source: S1-2

S1.1-6 The structure shall have a Center of Gravity less than 0.25 in from the center line and less than 12 in. from the Lightband plane

Source: S1-2

S1.1-7 The structure shall accommodate the Lightband launch vehicle adaptor system

Source: S1-2

S1.1-8 The structure shall provide a docking mechanism to safely secure MRS SAT to MR SAT prior to deployment

Source: M-4

5.5. GLEANING USEFUL INFORMATION FROM CUSTOMER INFORMATION

Customers often place unnecessary requirements or constraints on a team believing those requirements will lead to a more successful design. It is important for the design team to understand the final goal of the customer and where the final product will be used. If the team understands the process that the entire product will be subjected to after it leaves the university, it can better determine which requirements imposed by the customer can be questioned or may have some degree of flexibility. This process will ultimately make designing the satellite simpler. A good example of this is in the mass and volume requirements the University Nanosat Program (UNP) placed on the UMR SAT team. The constraints were much tighter than necessary to fit the satellites on the launch vehicle because the UNP wanted to ensure that the universities would not design their satellites excessively large. After discussing the team’s designs with the UNP, it was quickly explained that with a simple waiver the team could exceed the mass and volume requirements listed in the User’s Guide. This is not to say there was not an upper limit because it was still necessary to fit the satellites within a launch vehicle’s payload envelope, but the requirement was not as hard as was originally thought by the UMR SAT team.

6. TEAM SUCCESSES AND CHALLENGES

Throughout the UMR SAT project several lessons were learned that should help other universities as they begin to develop a satellite project. This section details some of the successes and challenges encountered by the UMR SAT team.

6.1. SUCCESSES

The following are considered successes because they helped in the completion of the final product and with the accomplishments of the team. Several other aspects went into the overall success of the project, though the two listed below are the most significant.

6.1.1. Modes of Operation. The Modes of Operation for the UMR SAT microsatellites describe the chronological events and processes associated with the satellite pair. Each mode describes a different period in the life of the satellite pair that will either prepare them for a technology demonstration or perform the desired technology demonstration. The modes identify events that are performed autonomously as well as those directed by the ground station at UMR. Section 6.1.1.2 describes and shows an example of a top level mode performed by the UMR SAT satellite pair developed in Microsoft Visio. Section 6.1.1.3 includes detailed steps to perform each activity in the example mode. All Modes of Operation used for UMR SAT are included in Appendix C.

6.1.1.1 Purpose. The Modes of Operation outline how the system will work when it is operational in space giving the entire team a unified goal to work toward. By detailing these modes, the team is, in a sense, writing an outline of the work that they will need to do in order to complete the project. They also bring the team to a consensus on what the system will be doing and what each individual team member needs to accomplish to make the system successful. These modes fully define how the team wants the final mission to proceed. Several team meetings were held for the team to review the Modes of Operation. The team's input was necessary to ensure the Modes followed correctly from one command to the next and to ensure that no steps were left out.

6.1.1.2 Top level modes. The Initialization Mode, shown in Figure 6.1, begins by first moving the satellite pair into Power-Up Mode. Once this mode is complete, the Initialization Mode will go through a diagnostic check on all major subsystems to ensure that the satellite is performing properly. After this diagnostic check is completed, the satellite pair will transition to Pre-Deploy Mode (12).

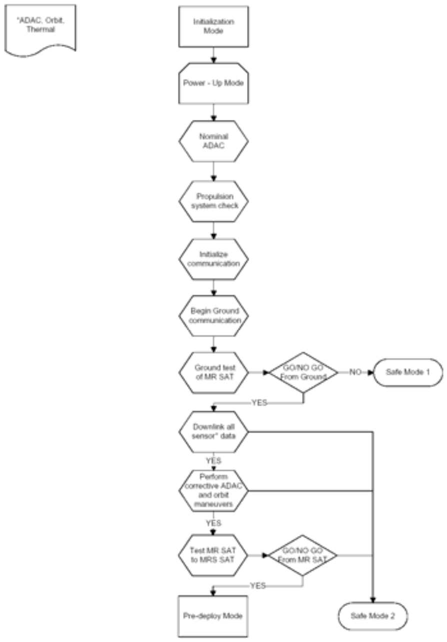


Figure 6.1 Sample Mode: Initialization Mode

The block to the left of the main chart is a note explaining what sensor data will be down linked. Since the blocks in the main chart were not large enough to list these specifics they were simply called sensors in the main block followed by an asterisk to lead the reader to the side block where the sensors are listed.

6.1.1.3 Detailed modes done by subsystems. The following information was developed within each subsystem to further explain in detail each block of the Initialization Mode. Each mode was detailed in the manner to ensure the team knew exactly what steps the satellites would go through to accomplish the mission.

“Nominal ADAC”

- Check to see that satellite attitude is within mission requirements
- Transmit ADAC and Orbit data to ground

“Propulsion system check”

- Activate Propulsion board
- Check tank temperature and pressure
    - If above threshold -> Safe Mode 1
- Check line temperature and pressure
    - If above threshold -> Safe Mode 1
- Check if heater works based on power draw

“Initialize communication”

- Computer when powered up will turn on modem/transmitter/receiver

“Begin ground communication”

- MR SAT sends a sample packet of information to the ground station

“Ground test of MR SAT”

- Ground request basic signal from MR SAT

“GO/NO GO from Ground”

- Receive signal from MR SAT
    - Signal received – proceed
    - Signal not received – Safe Mode 2
- Test of the quality of data received.
    - Quality of signal good – proceed to next step
    - Quality of signal bad – Safe Mode 2

“Downlink all sensor data”

- Once the Ground Station has successfully made contact with the satellite, MR SAT will begin an automatic downlink of all telemetry and sensor data as prioritized by the flight software

“Perform corrective ADAC and orbit maneuvers”

- Perform maneuvers if necessary

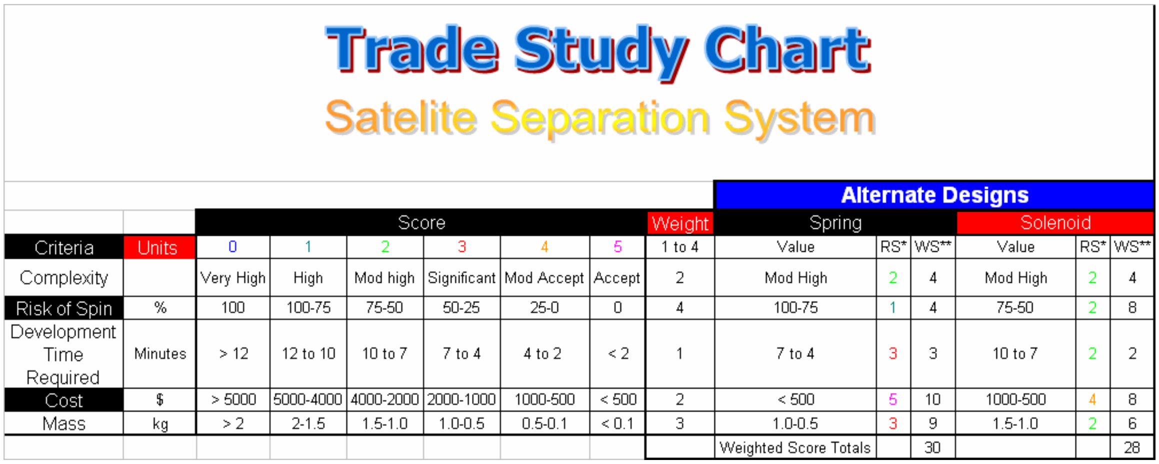
“Test MR SAT to MRS SAT”

- Computer checks to make sure everything is functioning properly and then tells the modem to send the information to ground station

6.1.2. Conferences. UMR SAT team members presented several papers at conferences throughout the project. These papers focused on a wide range of topics including the autonomous controller, propulsion system, and systems design. With each presentation, the team received invaluable feedback from the conference attendees about technical relevance of the project and other improvement ideas. The presentations and papers also severed as excellent publicity for the team. Involvement at these conferences led to partnership with the industry mentors that aided the team with low cost hardware purchases and technical expertise. The experience of presenting in a technical forum was also beneficial to the team members’ education and preparation for future industry work. Many students were recruited by potential employers after presenting at a conference. The UMR SAT team members attended and/or presented at many conferences throughout the two-year Nanosat program, including the Small Satellite Conference, SPACE, and several AIAA/AAS conferences.

6.1.3. Trade Studies. In several instances during the UMR SAT project it became necessary to perform a trade study to evaluate how to proceed on a certain aspect of the project. The original design of the satellite had a tether connecting the smaller satellite to the larger one. When this was still part of the design three trade studies were done to determine the best design for separating the two satellites, deploying the smaller satellite on the tether, and disconnecting the tether. Later a trade study was performed to determine if the tether concept should be included in the final design of the satellite pair.

Trade studies were also used in the communication and power subsystems. The benefit in using trade studies is their ability to quantify a decision that seems unquantifiable. They place a numerical value on each option in a decision and then allow the team to make a decision based on those values. When developing a trade study, criteria should be determined that will be used to examine the designs in question. These criteria should then be given a weighted value based on their importance to the overall mission and the decision at hand. A scoring range should also be developed corresponding to each criterion. Then for each design a raw score (RS) for the criteria listed should be determined. This raw score is multiplied with the criterion weight to determine the weighted score (WS) for that criterion. The final step is to add all of the weighted scores for a design concept to determine its final weighted score which can be compared to the other design concepts. An example of a UMR SAT trade study is in Figure 6.2.



Trade Study Chart

Satelite Separation System

									Alternate Designs					
		Score						Weight	Spring			Solenoid		
Criteria	Units	0	1	2	3	4	5	1 to 4	Value	RS*	WS**	Value	RS*	WS**
Complexity		Very High	High	Mod high	Significant	Mod Accept	Accept	2	Mod High	2	4	Mod High	2	4
Risk of Spin	%	100	100-75	75-50	50-25	25-0	0	4	100-75	1	4	75-50	2	8
Development Time Required	Minutes	> 12	12 to 10	10 to 7	7 to 4	4 to 2	< 2	1	7 to 4	3	3	10 to 7	2	2
Cost	$	> 5000	5000-4000	4000-2000	2000-1000	1000-500	< 500	2	< 500	5	10	1000-500	4	8
Mass	kg	> 2	2-1.5	1.5-1.0	1.0-0.5	0.5-0.1	< 0.1	3	1.0-0.5	3	9	1.5-1.0	2	6
									Weighted Score Totals		30			28

Figure 6.2 Trade Study Chart: Satellite Separation System

6.2. PARTIAL SUCCESSES

6.2.1. Scheduling. Scheduling for UMR SAT was done in Microsoft Project Gantt charts. Each subsystem created their own Gantt charts and updated them a minimum of once a semester. The Chief Engineer also developed an overall system level Gantt chart that the team followed. The key to any scheduling system is to adhere to the schedule as completely as possible. It is helpful to have the charts posted in the laboratory where they will be referenced frequently. The reason scheduling is listed only as a partial success is because the UMR SAT team made very detailed schedules, but did not follow them after they were made, causing the end of the project to be extremely rushed. Several key components were not ordered properly or with enough lead time to have them in before the final competition.

6.2.1.1 Purpose. A schedule’s obvious purpose is to keep the team on track for the timely completion of the project. It also is a good tool for motivating the team when time gets constrained. The schedule also provides a “to-do” list for each subsystem where they can clearly see the progress they are making.

6.2.1.2 Implementation. The key is to treat schedules as nonnegotiable. After one or two revisions, the team should not be allowed to update the dates of the tasks any longer. If something is past a due date, then it is simply marked “late” until it is completed. The UMR SAT team employed a color scheme in the Gantt charts to more quickly identify tasks that were complete or past due. A task that was complete was colored green, one that was in progress was blue, one that was not late but had not started was black, and one that was late starting or late finishing was red. This helped the team to see in a single glance how far behind they were on the project.

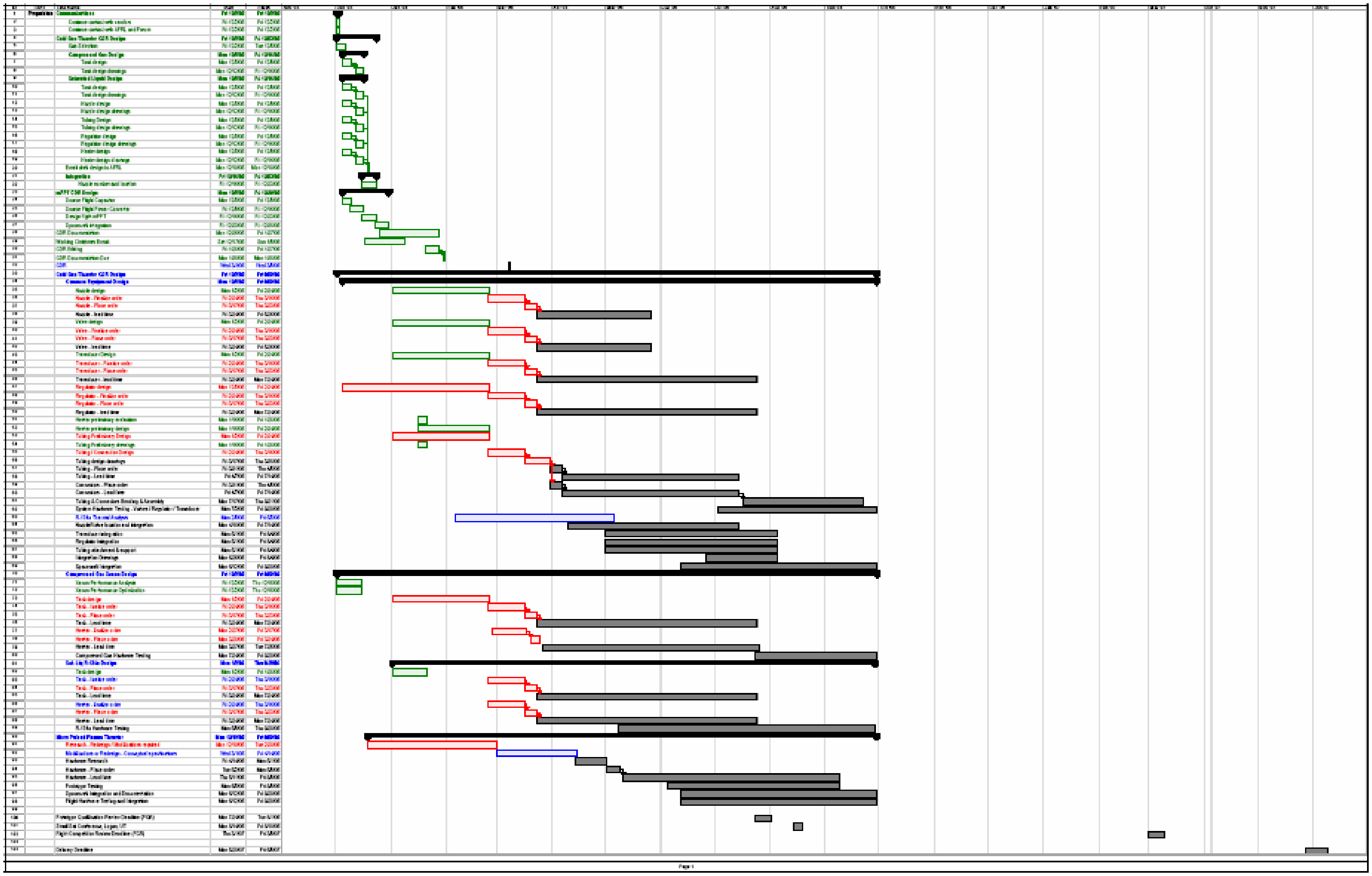
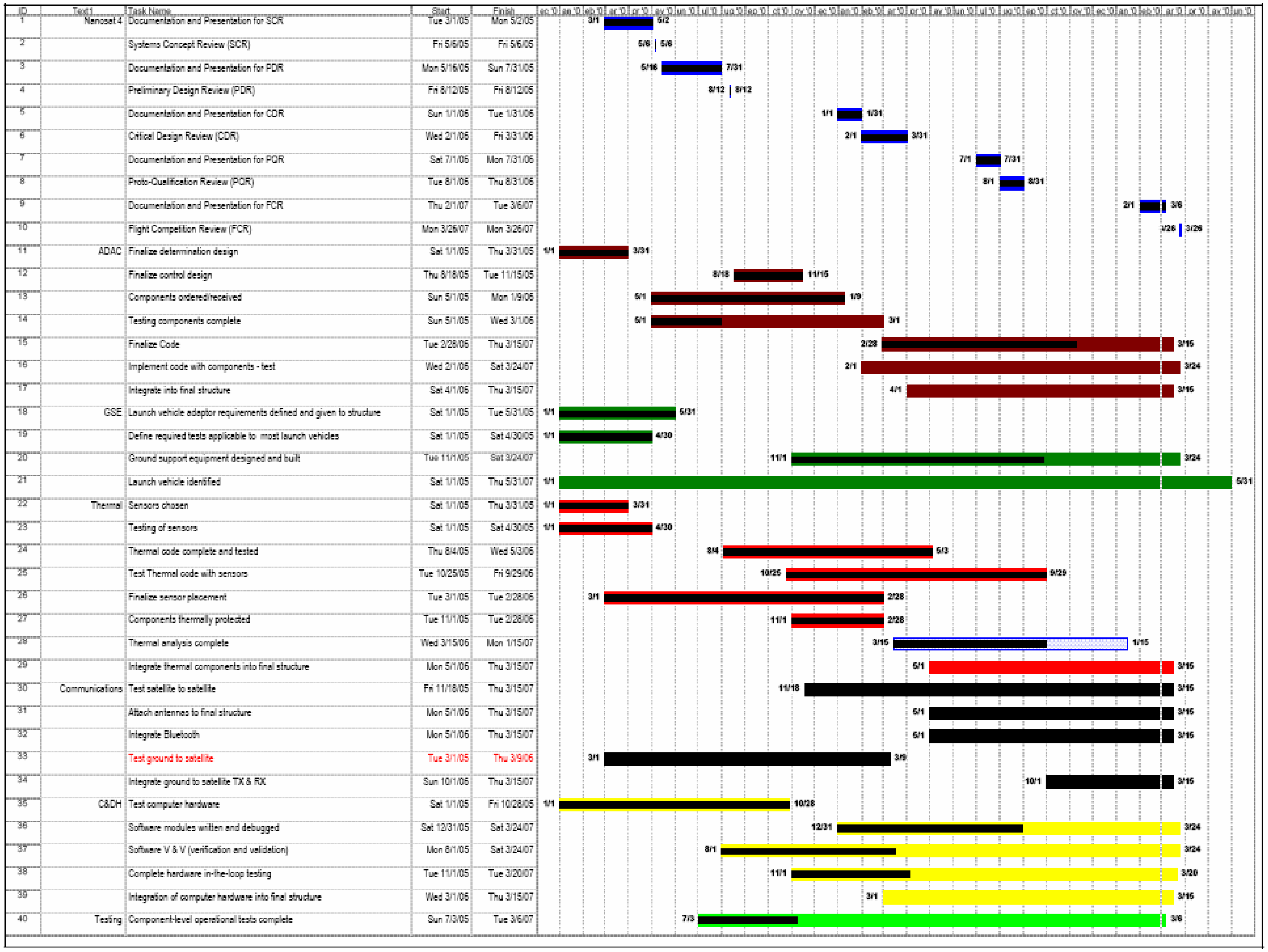
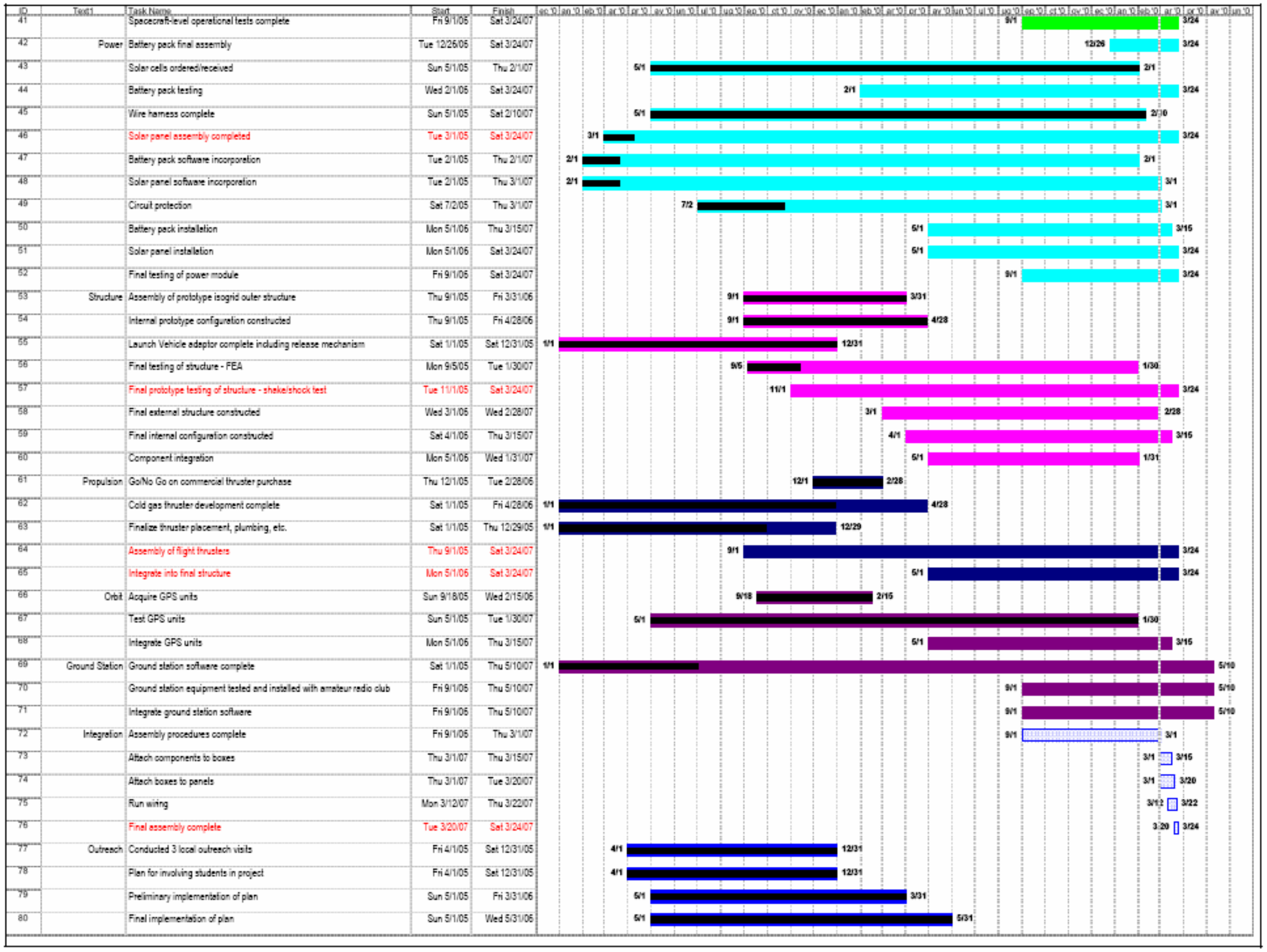


Figure 6.3 Propulsion Subsystem Gantt Chart



ID	Text1	Task Name	Start	Finish
1	Nanosat 4	Documentation and Presentation for SCR	Tue 3/1/05	Mon 5/2/05
2		Systems Concept Review (SCR)	Fri 5/6/05	Fri 5/6/05
3		Documentation and Presentation for PDR	Mon 5/16/05	Sun 7/31/05
4		Preliminary Design Review (PDR)	Fri 8/12/05	Fri 8/12/05
5		Documentation and Presentation for CDR	Sun 1/1/06	Tue 1/31/06
6		Critical Design Review (CDR)	Wed 2/1/06	Fri 3/31/06
7		Documentation and Presentation for PQR	Sat 7/1/06	Mon 7/31/06
8		Proto-Qualification Review (PQR)	Tue 8/1/06	Thu 8/31/06
9		Documentation and Presentation for FCR	Thu 2/1/07	Tue 3/6/07
10		Flight Competition Review (FCR)	Mon 3/26/07	Mon 3/26/07
11	ADAC	Finalize determination design	Sat 1/1/05	Thu 3/31/05
12		Finalize control design	Thu 8/18/05	Tue 11/15/05
13		Components ordered/received	Sun 5/1/05	Mon 1/9/06
14		Testing components complete	Sun 5/1/05	Wed 3/1/06
15		Finalize Code	Tue 2/28/06	Thu 3/15/07
16		Implement code with components - test	Wed 2/1/06	Sat 3/24/07
17		Integrate into final structure	Sat 4/1/06	Thu 3/15/07
18	GSE	Launch vehicle adaptor requirements defined and given to structure	Sat 1/1/05	Tue 5/31/05
19		Define required tests applicable to most launch vehicles	Sat 1/1/05	Sat 4/30/05
20		Ground support equipment designed and built	Tue 11/1/05	Sat 3/24/07
21		Launch vehicle identified	Sat 1/1/05	Thu 5/31/07
22	Thermal	Sensors chosen	Sat 1/1/05	Thu 3/31/05
23		Testing of sensors	Sat 1/1/05	Sat 4/30/05
24		Thermal code complete and tested	Thu 8/4/05	Wed 5/3/06
25		Test Thermal code with sensors	Tue 10/25/05	Fri 9/29/06
26		Finalize sensor placement	Tue 3/1/05	Tue 2/28/06
27		Components thermally protected	Tue 11/1/05	Tue 2/28/06
28		Thermal analysis complete	Wed 3/15/06	Mon 1/15/07
29		Integrate thermal components into final structure	Mon 5/1/06	Thu 3/15/07
30	Communications	Test satellite to satellite	Fri 11/18/05	Thu 3/15/07
31		Attach antennas to final structure	Mon 5/1/06	Thu 3/15/07
32		Integrate Bluetooth	Mon 5/1/06	Thu 3/15/07
33		Test ground to satellite	Tue 3/1/05	Thu 3/9/06
34		Integrate ground to satellite TX & RX	Sun 10/1/06	Thu 3/15/07
35	C&DH	Test computer hardware	Sat 1/1/05	Fri 10/28/05
36		Software modules written and debugged	Sat 12/31/05	Sat 3/24/07
37		Software V & V (verification and validation)	Mon 8/1/05	Sat 3/24/07
38		Complete hardware in-the-loop testing	Tue 11/1/05	Tue 3/20/07
39		Integration of computer hardware into final structure	Wed 3/1/06	Thu 3/15/07
40	Testing	Component-level operational tests complete	Sun 7/3/05	Tue 3/6/07

Figure 6.4 Overall Gantt Chart Part 1 (13)



ID	Text1	Task Name	Start	Finish
41		Spacecraft-level operational tests complete	Fri 9/1/06	Sat 3/24/07
42	Power	Battery pack final assembly	Tue 12/26/06	Sat 3/24/07
43		Solar cells ordered/received	Sun 5/1/05	Thu 2/1/07
44		Battery pack testing	Wed 2/1/06	Sat 3/24/07
45		Wire harness complete	Sun 5/1/05	Sat 2/10/07
46		Solar panel assembly completed	Tue 3/1/05	Sat 3/24/07
47		Battery pack software incorporation	Tue 2/1/05	Thu 2/1/07
48		Solar panel software incorporation	Tue 2/1/05	Thu 3/1/07
49		Circuit protection	Sat 7/2/05	Thu 3/1/07
50		Battery pack installation	Mon 5/1/06	Thu 3/15/07
51		Solar panel installation	Mon 5/1/06	Sat 3/24/07
52		Final testing of power module	Fri 9/1/06	Sat 3/24/07
53	Structure	Assembly of prototype isogrid outer structure	Thu 9/1/05	Fri 3/31/06
54		Internal prototype configuration constructed	Thu 9/1/05	Fri 4/28/06
55		Launch Vehicle adaptor complete including release mechanism	Sat 1/1/05	Sat 12/31/05
56		Final testing of structure - FEA	Mon 9/5/05	Tue 1/30/07
57		Final prototype testing of structure - shake/shock test	Tue 11/1/05	Sat 3/24/07
58		Final external structure constructed	Wed 3/1/06	Wed 2/28/07
59		Final internal configuration constructed	Sat 4/1/06	Thu 3/15/07
60		Component integration	Mon 5/1/06	Wed 1/31/07
61	Propulsion	Go/No Go on commercial thruster purchase	Thu 12/1/05	Tue 2/28/06
62		Cold gas thruster development complete	Sat 1/1/05	Fri 4/28/06
63		Finalize thruster placement, plumbing, etc.	Sat 1/1/05	Thu 12/29/05
64		Assembly of flight thrusters	Thu 9/1/05	Sat 3/24/07
65		Integrate into final structure	Mon 5/1/06	Sat 3/24/07
66	Orbit	Acquire GPS units	Sun 9/18/05	Wed 2/15/06
67		Test GPS units	Sun 5/1/05	Tue 1/30/07
68		Integrate GPS units	Mon 5/1/06	Thu 3/15/07
69	Ground Station	Ground station software complete	Sat 1/1/05	Thu 5/10/07
70		Ground station equipment tested and installed with amateur radio club	Fri 9/1/06	Thu 5/10/07
71		Integrate ground station software	Fri 9/1/06	Thu 5/10/07
72	Integration	Assembly procedures complete	Fri 9/1/06	Thu 3/1/07
73		Attach components to boxes	Thu 3/1/07	Thu 3/15/07
74		Attach boxes to panels	Thu 3/1/07	Tue 3/20/07
75		Run wiring	Mon 3/12/07	Thu 3/22/07
76		Final assembly complete	Tue 3/20/07	Sat 3/24/07
77	Outreach	Conducted 3 local outreach visits	Fri 4/1/05	Sat 12/31/05
78		Plan for involving students in project	Fri 4/1/05	Sat 12/31/05
79		Preliminary implementation of plan	Sun 5/1/05	Fri 3/31/06
80		Final implementation of plan	Sun 5/1/05	Wed 5/31/06

Figure 6.5 Overall Gantt Chart Part 2 (13)

6.2.1.3 UMR SAT example. Several subsystem Gantt chart examples are included in Appendix D. An example of the Propulsion subsystem's Gantt chart as well as an overall Gantt chart is shown below in Figures 6.3, 6.4, and 6.5.

6.2.2. Division of Tasks. The UMR SAT project went through three Program Managers while retaining the same Chief Engineer throughout the entire time. Since the Program Manager's job description was not clearly specified before the first Program Manager took the job, each successor had a limited understanding of what his responsibilities were. It was not until the final Program Manager took over that the job was clearly described as given in Section 4. This confusion caused work that would normally be part of the Program Manager's job to fall on the Chief Engineer, and in the long run, it slowed the project down. If the job had been detailed at the start of the program, the transfer from one Program Manager to the next would have gone smoothly without delaying the overall project and without unduly burdening the Chief Engineer.

6.3. CHALLENGES

6.3.1. Team Turnover. Several challenges arose at the end of each school year when the team would lose several graduating members and gain new, younger members. Departing members created little documentation of their work and what was created was poorly executed leaving the new members with a limited view of where to begin working. Many team members claimed to be working on documentation where in actuality, no documentation was being produced. Often documentation created by the former team members would make assumptions about what the new team members would understand and would leave out the necessary explanation to prevent overlap and confusion in work. Ill-informed new members, who often neglected to request assistance, caused the team to back track several times, rediscovering the same solutions or problems each semester. Since the new members were disinclined to ask questions, the continuing members of the team often made assumptions about the level of understanding held by new members, and inappropriate work assignments would be made. For all these reasons, the team lost several weeks at the beginning of each school year to confusion and unnecessary rework. If the proper information had been passed along to all the new team members and they had been encouraged to ask questions, this valuable work time would not have been lost. In order to prevent this problem a standardized document could have been created that each team member would need to fill in prior to leaving. This internal document may not be an official document that the team would turn in to the customer, but it would be formatted specifically for new members. It should include a section that details what work was done prior to current member's work, a section detailing the work accomplished by the current member, and a section about what the current member feels the new member needs to do next. The document should explain exactly where the subsystem has been and where the current member feels it needs to go in order to finish the project.

In order to have successful team turnover, the current team must create detailed, well-written documentation prior to leaving the team. This documentation needs to be reviewed by several people and edited prior to the current team members leaving. Among the most necessary documents that should be included in a list of task items that the current team members believe the new team members need to accomplish to complete the project. The new team members also need to meet with the former team members to discuss any questions or concerns they might have about the project or the subsystem. It is helpful if the new team member has read the documentation prior to the meeting so that they might have questions to be answered. Finally, the system leaders should obtain good contact information for all leaving team members in case questions arise later in the project.

6.3.2. The Human Factor. As in any project, the inclusion of humans adds a certain degree of uncertainty. Sometimes there are team members who appear to be good leaders but when put in a leadership position, are unable to handle the pressure of the job. Design teams also have problems with students being enthusiastic about the project at first and then losing interest as the school year progresses, especially when classes and other projects become demanding. The need for dependable leaders in each subsystem cannot be overemphasized. A lack of consistent leadership can easily be the single cause of failure in any part of the project. Specifically, in the UMR SAT project, the team had little success securing a Power subsystem leader that was able to accomplish the design and construction of the subsystem. At the end of the project this became a major hindrance to the completion of the satellites. It is necessary to carefully choose team leaders and team members in order to guarantee the work not only gets completed, but gets completed correctly and on time. It might be advisable to employ a tool such as a Myers-Briggs type test to better understand the people on the team and where they would best serve the team.

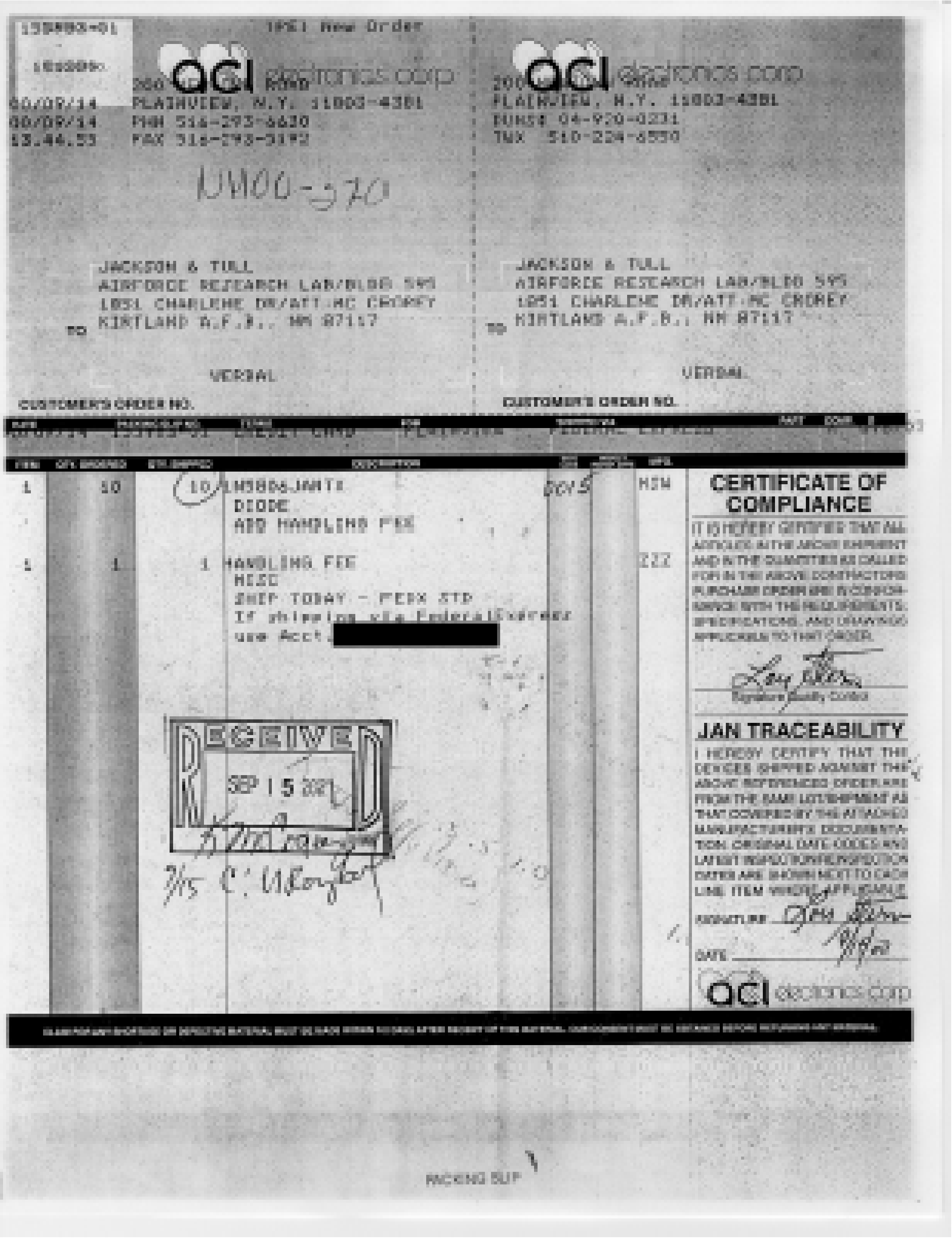
7. CONCLUSION

This document describes the process used by the UMR SAT team to organize, facilitate, and produce a competitive satellite in the Nanosat program. The processes described in this paper will hopefully aid other universities who wish to establish a satellite program. The success of these processes is evident in the results obtained by the UMR SAT team in final judging by the Nanosat program.

The UMR SAT team successfully completed the Nanosat 4 Competition in March 2007. The team delivered two protoflight satellites to the Final Competition Review in Albuquerque, New Mexico where they received 3rd place out of the 11 teams competing, along with being recognized as the most improved team. The team successfully delivered the required hardware and documentation to AFRL by the specified date. Though the UMR SAT team was in its first competition in the Nanosat program, it was able to succeed at a high level due, in large part, to the techniques described in this thesis.

APPENDIX A

UNP REFERENCE DOCUMENTS (4)



1961 New Order

aci electronics corp
PLAINVIEW, N.Y. 11803-4381
PHN 516-293-6620
FAX 516-293-9192

00/09/14
00/09/14
13.46.53

NM00-370

TO JACKSON & TULL
AIRFORCE RESEARCH LAB/BLDG 595
1851 CHARLENE DR/ATT:MC CRORFY
KIRTLAND A.F.B., NM 87117

VERBAL

CUSTOMER'S ORDER NO.

aci electronics corp
PLAINVIEW, N.Y. 11803-4381
DUNS# 04-920-0231
TWX 510-224-6550

TO JACKSON & TULL
AIRFORCE RESEARCH LAB/BLDG 595
1851 CHARLENE DR/ATT:MC CRORFY
KIRTLAND A.F.B., NM 87117

VERBAL

CUSTOMER'S ORDER NO.

1	10	10	1N5806JANTX DIODE ADD HANDLING FEE	0015	MSM
1	1	1	HANDLING FEE MISC SHIP TODAY - FEDX STD If shipping via Federal Express use Acct. [redacted]		ZZZ

RECEIVED
SEP 15 2021

7/15 C. Ulrongbert

CERTIFICATE OF COMPLIANCE

IT IS HEREBY CERTIFIED THAT ALL ARTICLES IN THE ABOVE SHIPMENT AND IN THE QUANTITIES AS CALLED FOR IN THE ABOVE CONTRACTOR'S PURCHASE ORDER ARE IN CONFORMANCE WITH THE REQUIREMENTS, SPECIFICATIONS, AND DRAWINGS APPLICABLE TO THAT ORDER.

Signature Quality Control

JAN TRACEABILITY

I HEREBY CERTIFY THAT THE DEVICES SHIPPED AGAINST THE ABOVE REFERENCED ORDER ARE FROM THE SAME LOT/SHIPMENT AS THAT COVERED BY THE ATTACHED MANUFACTURER'S DOCUMENTATION. ORIGINAL DATE CODES AND LATEST INSPECTION/REINSPECTION DATES ARE SHOWN NEXT TO EACH LINE ITEM WHERE APPLICABLE.

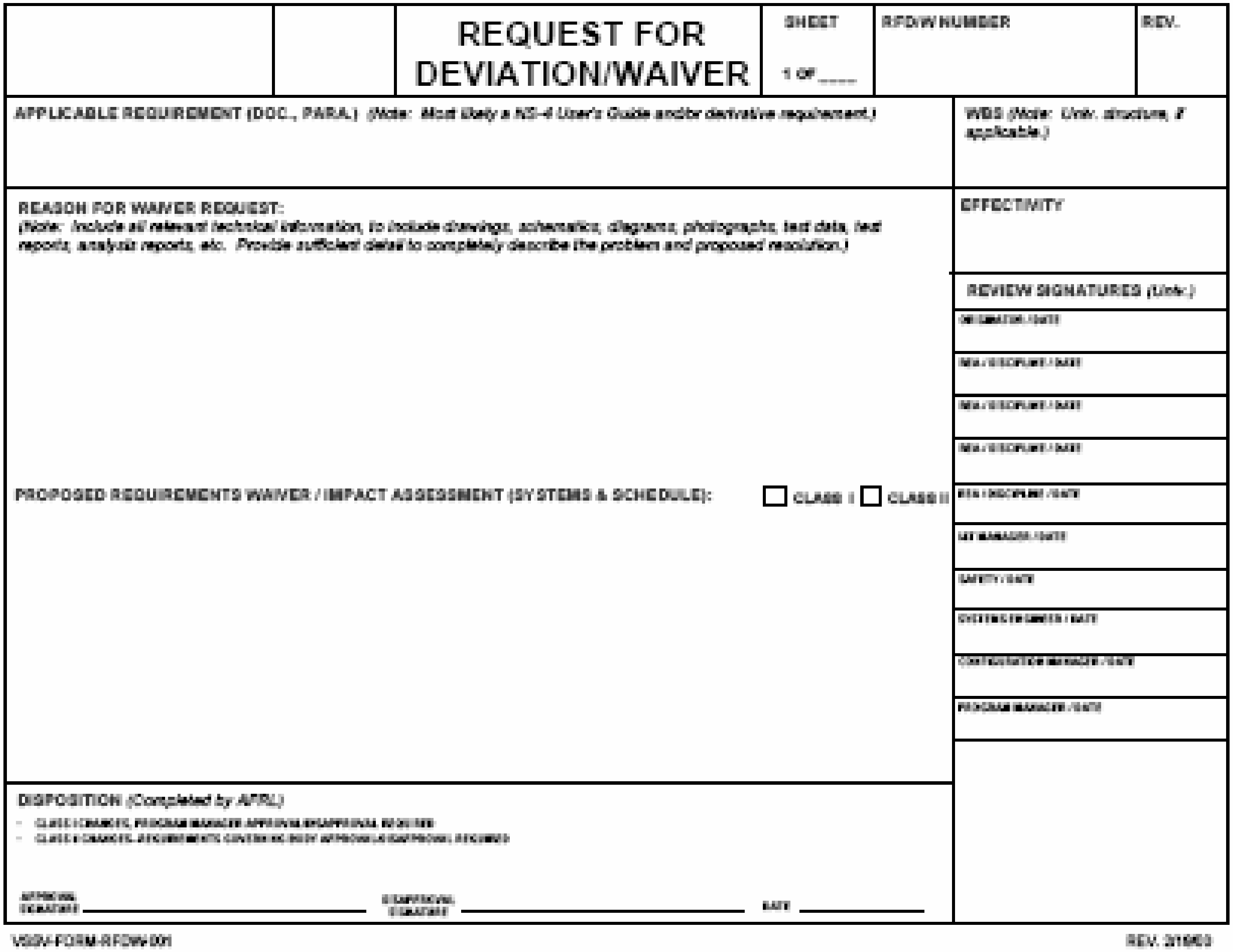
SIGNATURE

DATE

aci electronics corp

PACKING SLIP

Figure A. 1 Sample Certificate of Compliance



		REQUEST FOR DEVIATION/WAIVER	SHEET 1 OF ____	RFD/W NUMBER	REV.

APPLICABLE REQUIREMENT (DOC., PARA.) *(Note: Most likely a NS-4 User's Guide and/or derivative requirement.)*

WBS *(Note: Univ. structure, if applicable.)*

REASON FOR WAIVER REQUEST:
(Note: Include all relevant technical information, to include drawings, schematics, diagrams, photographs, test data, test reports, analysis reports, etc. Provide sufficient detail to completely describe the problem and proposed resolution.)

EFFECTIVITY

REVIEW SIGNATURES *(Univ.)*

ORIGINATOR / DATE

[illegible] / DISCIPLINE / DATE

[illegible] / DISCIPLINE / DATE

[illegible] / DISCIPLINE / DATE

[illegible] / DISCIPLINE / DATE

[illegible] MANAGER / DATE

SAFETY / DATE

SYSTEMS ENGINEER / DATE

CONFIGURATION MANAGER / DATE

PROGRAM MANAGER / DATE

PROPOSED REQUIREMENTS WAIVER / IMPACT ASSESSMENT (SYSTEMS & SCHEDULE): ☐ CLASS I ☐ CLASS II

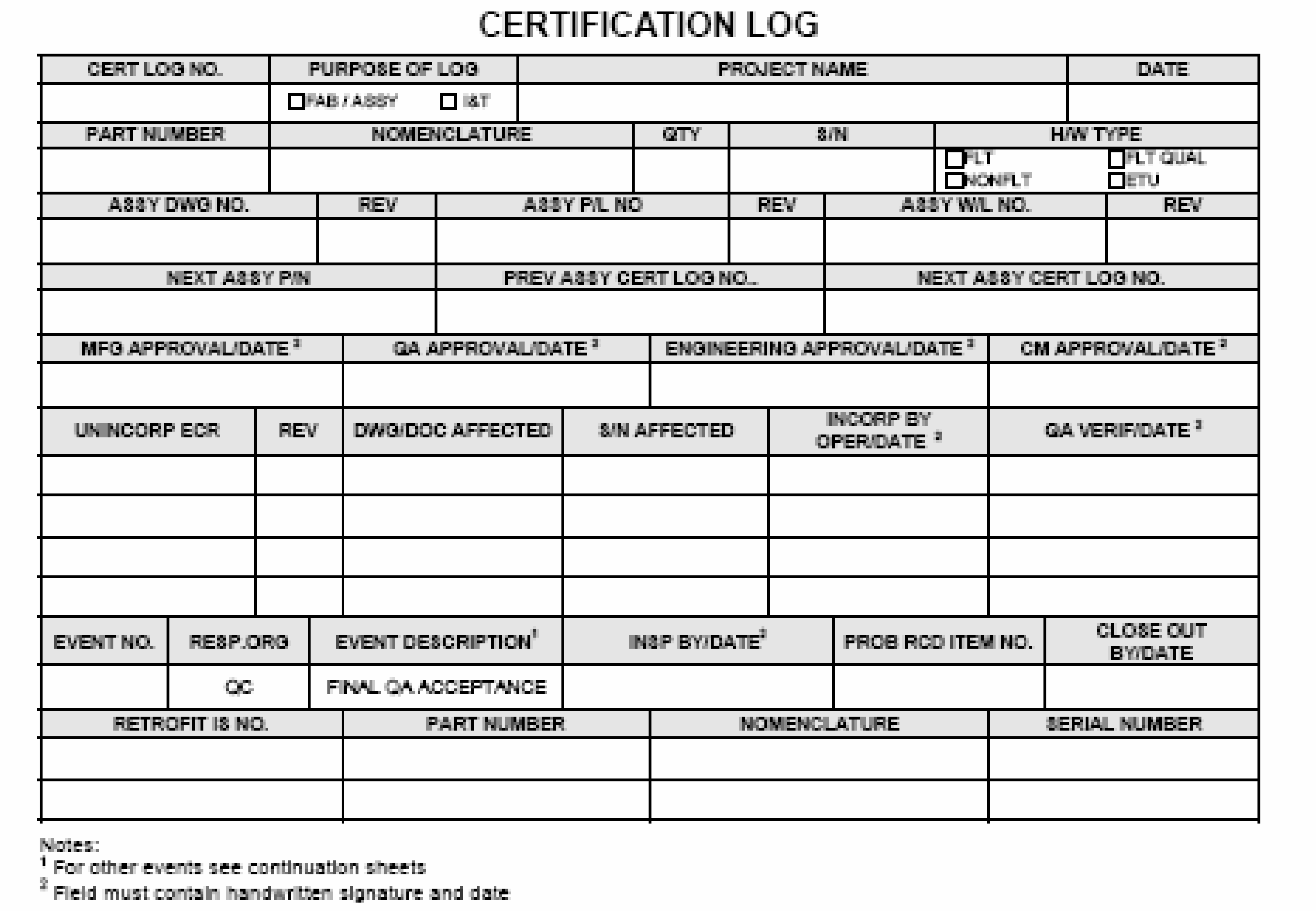
DISPOSITION *(Completed by AFRL)*

APPROVAL SIGNATURE ____________ DISAPPROVAL SIGNATURE ____________ DATE ________

VSSV-FORM-RFDW-001

REV. 3/18/03

Figure A. 2 Sample Request for Deviation/Waiver



CERTIFICATION LOG

CERT LOG NO.	PURPOSE OF LOG	PROJECT NAME	DATE
	☐ FAB / ASSY ☐ I&T		

PART NUMBER	NOMENCLATURE	QTY	S/N	H/W TYPE
				☐ FLT ☐ FLT QUAL ☐ NONFLT ☐ ETU

ASSY DWG NO.	REV	ASSY P/L NO	REV	ASSY W/L NO.	REV

NEXT ASSY P/N	PREV ASSY CERT LOG NO..	NEXT ASSY CERT LOG NO.

MFG APPROVAL/DATE [2]	QA APPROVAL/DATE [2]	ENGINEERING APPROVAL/DATE [2]	CM APPROVAL/DATE [2]

UNINCORP ECR	REV	DWG/DOC AFFECTED	S/N AFFECTED	INCORP BY OPER/DATE [2]	QA VERIF/DATE [2]

EVENT NO.	RESP.ORG	EVENT DESCRIPTION[1]	INSP BY/DATE[2]	PROB RCD ITEM NO.	CLOSE OUT BY/DATE
	QC	FINAL QA ACCEPTANCE			

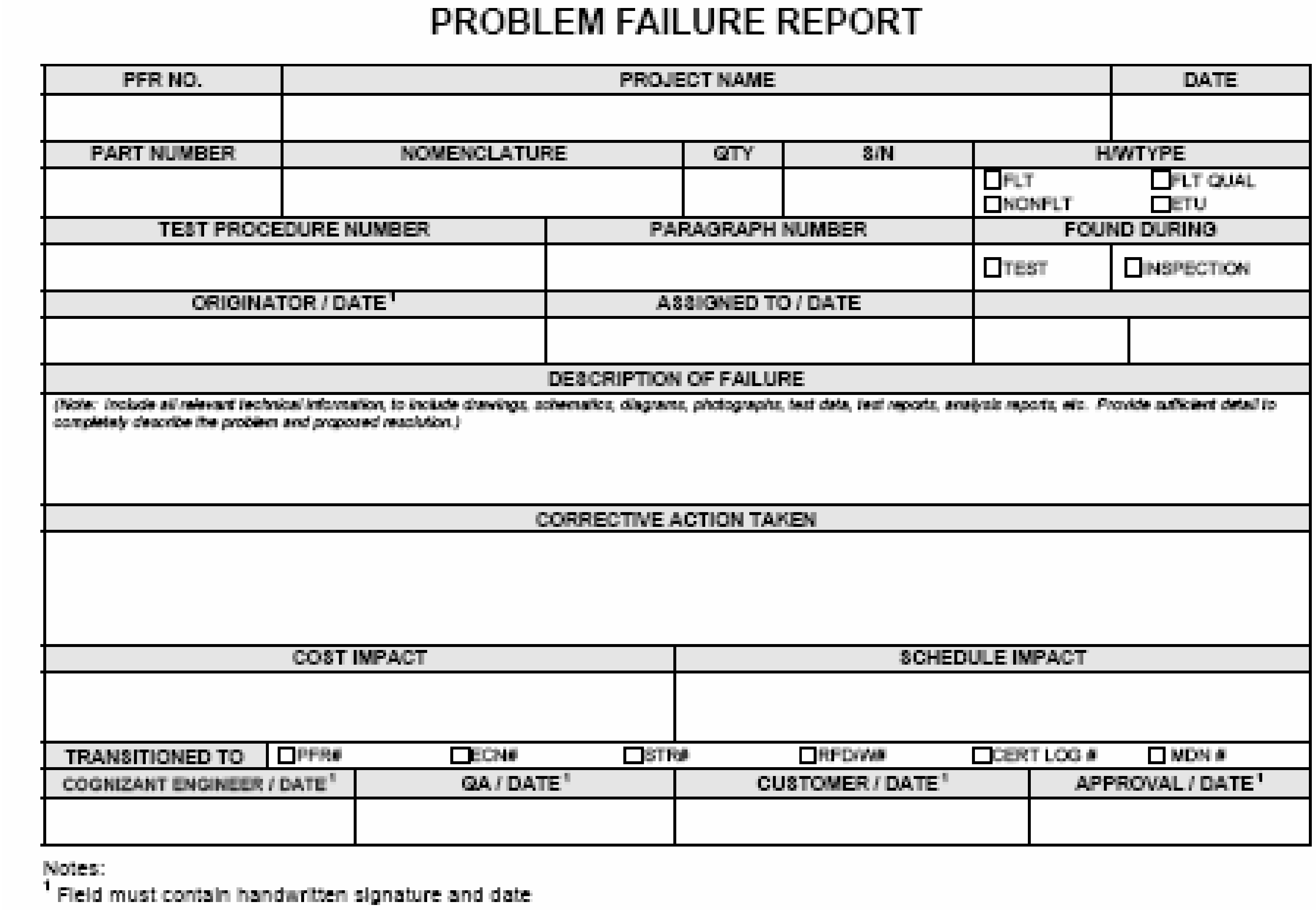
RETROFIT IS NO.	PART NUMBER	NOMENCLATURE	SERIAL NUMBER

Notes:

[1] For other events see continuation sheets

[2] Field must contain handwritten signature and date

Figure A. 3 Sample Certification Log



PROBLEM FAILURE REPORT

PFR NO.	PROJECT NAME				DATE
PART NUMBER	NOMENCLATURE	QTY	S/N	H/WTYPE	
				☐ FLT ☐ NONFLT	☐ FLT QUAL ☐ ETU
TEST PROCEDURE NUMBER	PARAGRAPH NUMBER			FOUND DURING	
				☐ TEST	☐ INSPECTION
ORIGINATOR / DATE[1]	ASSIGNED TO / DATE				

DESCRIPTION OF FAILURE

(Note: Include all relevant technical information, to include drawings, schematics, diagrams, photographs, test data, test reports, analysis reports, etc. Provide sufficient detail to completely describe the problem and proposed resolution.)

CORRECTIVE ACTION TAKEN

COST IMPACT	SCHEDULE IMPACT

TRANSITIONED TO ☐ PFR# ☐ ECN# ☐ STR# ☐ RFD/W# ☐ CERT LOG # ☐ MDN #

COGNIZANT ENGINEER / DATE[1]	QA / DATE[1]	CUSTOMER / DATE[1]	APPROVAL / DATE[1]

Notes:

[1] Field must contain handwritten signature and date

Figure A. 4 Sample Problem Failure Report

APPENDIX B

TECHNOLOGY READINESS LEVELS (14)

Technology Readiness Levels in the Department of Defense (DOD)
(Source: DOD (2004), *DODI 5000.2 Acquisition System Guidebook*)

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.

7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and 'flight qualified' through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system 'flight proven' through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Technology Readiness Levels in the National Aeronautics and Space Administration(NASA)

(Source: Mankins (1995), *Technology Readiness Levels: A White Paper*)

Technology Readiness Level	Description
1. Basic principles observed and reported	This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development.
2. Technology concept and/or application formulated	Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be 'invented' or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.
3. Analytical and experimental critical function and/or characteristic proof of concept	At this step in the maturation process, active research and development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2.
4. Component and/or breadboard validation in laboratory environment	Following successful "proof-of-concept" work, basic technological elements must be integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is relatively "low-fidelity" compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory.

5. Component and/or breadboard validation in relevant environment	At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a 'simulated' or somewhat realistic environment.
6. System/subsystem model or prototype demonstration in a relevant environment (ground or space)	A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system - which would go well beyond ad hoc, 'patch-cord' or discrete component level breadboarding - would be tested in a relevant environment. At this level, if the only 'relevant environment' is the environment of space, then the model/prototype must be demonstrated in space.
7. System prototype demonstration in a space environment	TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system and the demonstration must take place in space.
8. Actual system completed and 'flight qualified' through test and demonstration (ground or space)	In almost all cases, this level is the end of true 'system development' for most technology elements. This might include integration of new technology into an existing system.
9. Actual system 'flight proven' through successful mission operations	In almost all cases, the end of last 'bug fixing' aspects of true 'system development'. This might include integration of new technology into an existing system. This TRL does *not* include planned product improvement of ongoing or reusable systems.

APPENDIX C

MODES OF OPERATION (12)

Test Mode

The Test Mode takes both satellites through environmental and operational testing that will be preformed prior to the satellites' initial storage and transportation for launch.

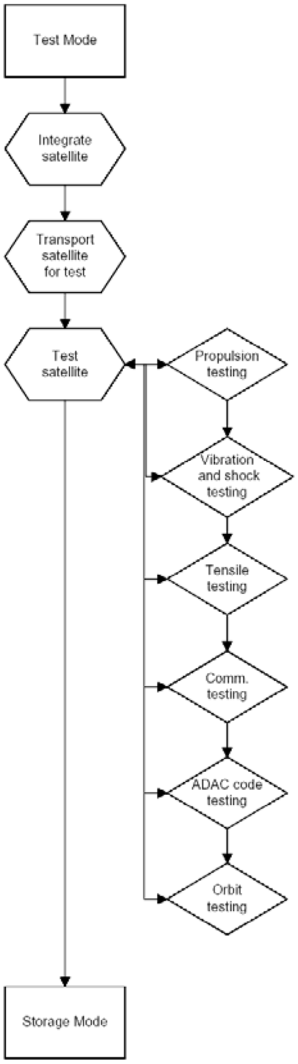


Figure C. 1 Test Mode

Detailed Steps

"Integrate satellite"

- See all Assembly Procedures

“Test satellite”

“Propulsion testing”

- Check all sensors and propellant conditions
- Test each thruster independently
- Test thruster in flight scenarios
- Check all sensors and propellant conditions

“Vibration/Shock testing”

- Attach assembled satellite to shock table in the Civil Engineering laboratory
  - Make sure the satellite is torqued down
- Turn on shock table and use equipment to determine the natural frequency response of the satellite
- Also use necessary equipment to determine the amount of load or frequency is being applied.
- See user guide Section 8.1.3

“Tensile testing”

- Attach individual panel to tensile tester located in the Civil Engineering laboratory
- Activate the machine and measure the stress/strain
- A panel attached to a plate with our bolts attaching the two
  - This testing will have 6 different loading cases. One in each principal direction, X, Y, Z as we define them

“Communication testing”

- Transmitter Tests
    - Communication Test
        - Purpose: This test will be performed to ensure that a data link can be established between the satellite transmitter and a ground based receiver.
        - Procedure: The transmitter will be attached to the computer and to the antenna. Test packets of data will be sent from the computer to the transmitter and sent to the ground based receiver. A computer will take the data from the receiver, and it will be compared to the test packet originally sent. If the data matches, the test will be repeated to prove reliability.
    - Range Test
        - Purpose: This test will be performed to measure the transmission range of the transmitter.
        - Procedure: The transmitter will be placed as high as possible, ideally in an aircraft in order to simulate orbit altitude. Once in position, the transmitter will send test packets of data to the ground station. The received packets will then be compared to the originals. If the data matches, the test will be repeated to prove reliability.
- Receiver Tests
    - Communication Test

        - Purpose: This test will be performed to ensure that a data link can be established between a ground based transmitter and the satellite receiver.
        - Procedure: The receiver will be attached to the computer and to the antenna. Test packets of data will be sent from the computer to the ground based transmitter and sent to the receiver. A computer will take the data from the receiver and it will be compared to the test packet originally sent. If the data matches, the test will be repeated to prove reliability.
    - Range Test
        - Purpose: This test will be performed to ensure that the receiver can accurately receive information in orbit.
        - Procedure: The receiver will be placed as high as possible, ideally in an aircraft in order to simulate orbit altitude. Once in position, the ground based transmitter will send test packets of data to the receiver. The received packets will then be compared to the originals. If the data matches, the test will be repeated to prove reliability.
- Wireless Connection Tests
    - Communication Test
        - Purpose: This test will be performed to ensure that a reliable data link can be established between MR SAT and MRS SAT.

    - Procedure: The WT11 Bluetooth units will be mounted in mockups of the satellites and connected to the antennas. The computers will then attempt to establish a network connection between the satellites. If the connection is successfully established, test packets will be sent to determine the quality of the link.
- Throughput Test
    - Purpose: This test will be performed to determine the maximum amount of data that can be transmitted between the satellites.
    - Procedure: The two units will transmit files of increasing size to each other. The quality of the transmission will be evaluated to determine what the bandwidth should be throttled to.
- Range Test
    - Purpose: This test will be performed to determine the maximum distance apart that will still allow the satellites to communicate.
    - Procedure: This test will consist of two parts performed concurrently. The first part will be a horizontal range test. For this part, one satellite will be stationary and the other will be moved horizontally away from it. The second portion will be a vertical range test. As the second satellite is moved away from the first, it will be placed at different heights above and below the stationary satellite. This will allow us to determine the maximum vertical separation the satellites can undergo.

“Attitude code testing”

- Log into computer
- Load MATLAB™ program
- Change directory to S:/minerfiles.umr.edu/dfs/users/mrsat/ADAC
- Run software
- Make certain results meet all requirements for the attitude control of the UMR SAT project
- Close MATLAB
- Log off computer

“Orbit testing”

- Supply power to the breadboard and the laptop
- Verify that the voltage converter is working properly
- Plug the pin connectors from the Engineering Unit into the correct holes on the breadboard
- Attach the active antenna to the Engineering Unit
- Turn on the laptop and start Starview
- Attach the serial cable from the breadboard to the computer
- Take the setup outside to an open view area (batteries are used to supply power to the unit and the laptop)
- In Starview, click “File/Port”, then “Auto Connect”, then “Start”
- View the screen for desired information

Storage Mode

Storage Mode steps through the process of properly packaging and storing the two satellites so that no harm will come to any component on the satellites or people working on or near them.

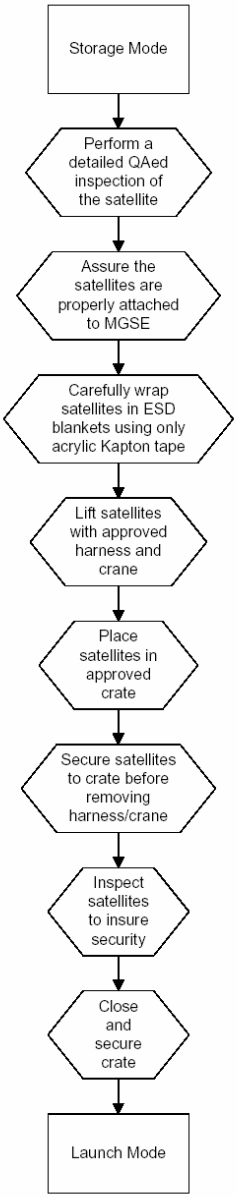


Figure C. 2 Storage Mode

Detailed Steps

“Assure the satellites are properly attached to MGSE”

- Slide (lower) tabs into MGSE catch
- Bolt to platform with specified torque

“Carefully wrap satellites in ESD blankets using only acrylic Kapton tape”

- Measure ESD blanket and cut slits for GSE tabs
- Cut blanket to length
- Wrap satellite 2-5 times
- Secure using Kapton tape

“Lift satellites with approved harness and crane”

- Attach harness to satellites with bolts and tighten to specified torque
- Unscrew bolts attaching satellite to platform
- Raise harness to reduce slack
- If necessary, lift satellite over MGSE platform and lower slowly until cable is carrying the weight

“Place satellites in approved crate”

- Lower satellite into crate
- Bolt

“Secure satellites to crate before removing harness/crane”

- Attach satellite to crate using satellite tabs

“Inspect satellites to insure security”

- Inspect satellite for rips or opening in ESD blanket
- Check torque on bolts attaching satellite to crate

“Remove cable harness”

- Unbolt satellite from crane

“Close and secure crate”

- Raise crane harness carefully
- Raise sides and screw
- Screw together
- Place lid on top and screw into place

Launch Mode

Launch Mode spans the time from satellite integration into the launch vehicle to the time the pintail connectors indicate the system is separated from the launch vehicle. When the pigtail connectors indicate separation, the microswitches will transition the satellite pair into Initialization Mode. Throughout the entirety of Launch Mode the two satellites are in a stacked configuration.

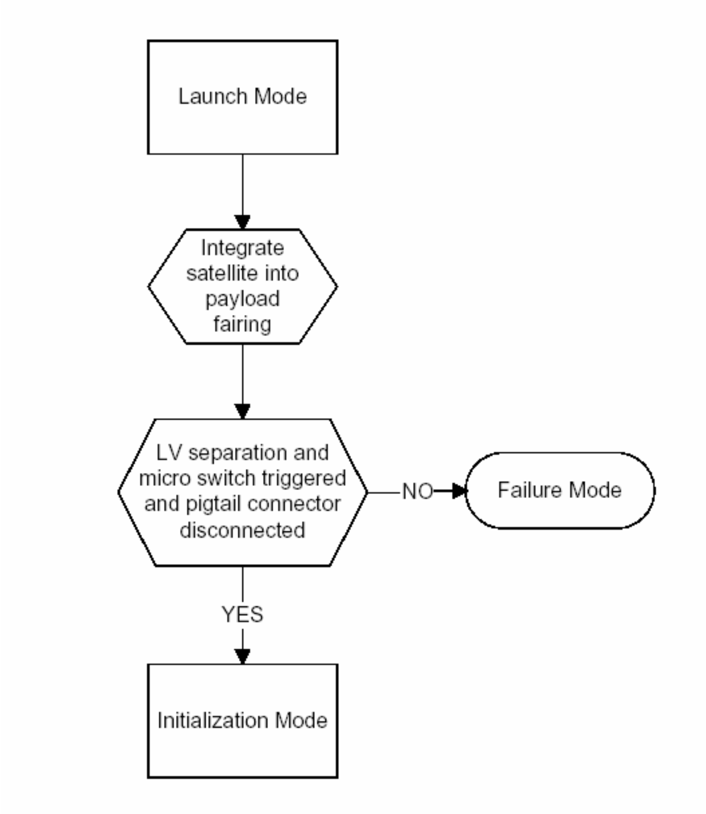


Figure C. 3 Launch Mode

Detailed Steps

“Integrate satellite into payload fairing”

- Unscrew lid from MRS SAT crate
- Unscrew sides of MRS SAT crate and lower gently
- Bolt crane harness to MRS SAT, torque bolts to specification
- Unscrew lid to MR SAT crate
- Unscrew sides of MR SAT crate and lower gently
- Unbolt MRS SAT from crate
- Raise MRS SAT
- Lower MRS SAT onto MR SAT

- Bolt Qwknut as specified
- Unbolt crane from MRS SAT
- Bolt crane to MR SAT using specifications
- Unbolt MR/MRS SAT combination from MR SAT crate
- Attach Lightband to fairing as specified
- Unbolt satellite from crane

"LV separation and micro switch triggered and pigtail connector disconnected"

- Handling of the LV separation is done automatically by the electromechanical relays (inhibits) located on the power board. The microswitches on the LV will trigger the relays and they will let the satellite begin to charge the batteries.
- Failure to separate from the LV or if the micro-switch fails to trigger, then the spacecraft inhibits never get released and thus the satellite never turns on.

Initialization Mode

The Initialization Mode begins by first moving the satellite pair into Power-Up Mode. Once this mode is complete, the Initialization Mode will go through a diagnostic check on all major subsystems to ensure the satellite is performing properly. After this diagnostic check is completed the satellite pair will transition to Pre-Deploy Mode.

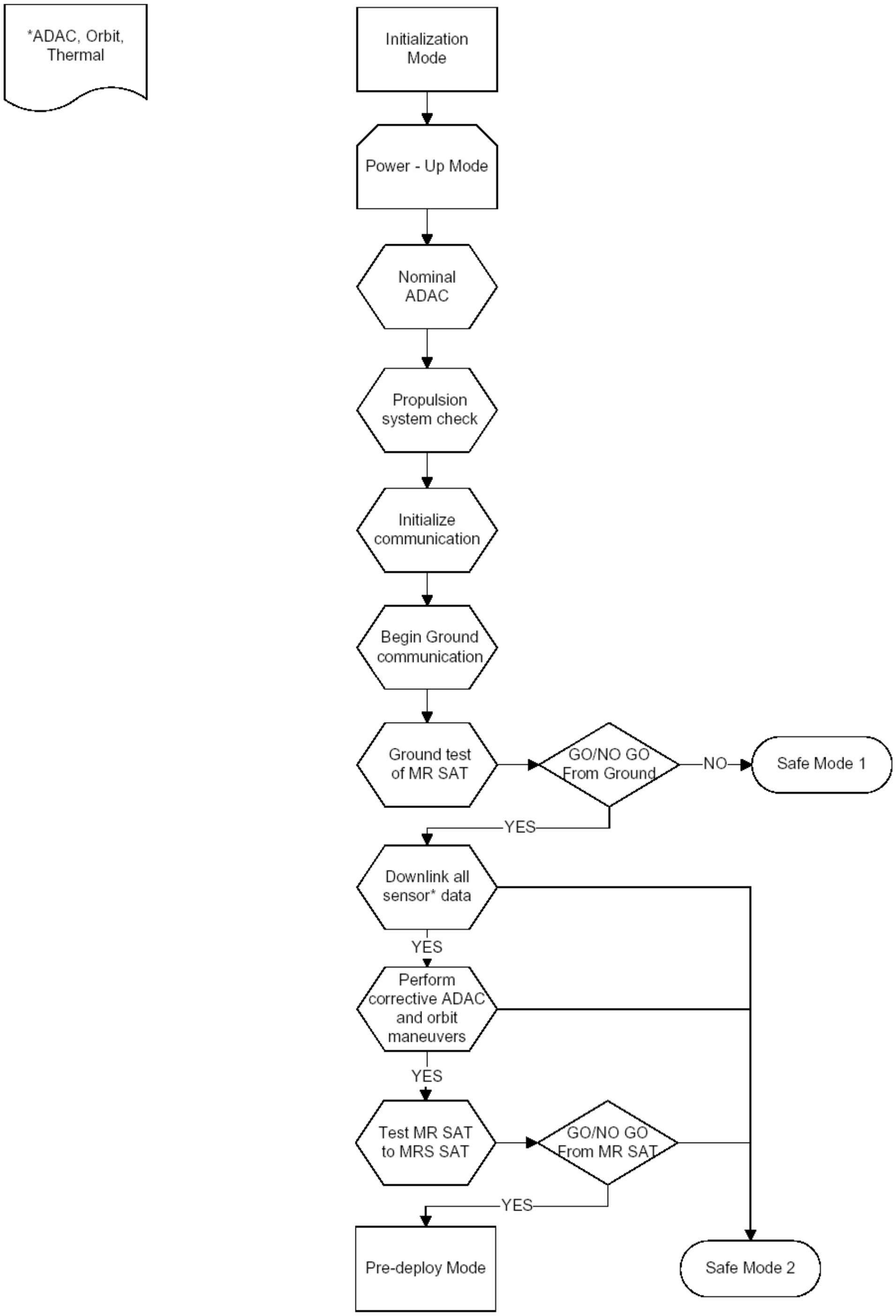


Figure C. 4 Initialization Mode

Detailed Steps

“Nominal ADAC”

- Check to see that satellite attitude is within mission requirements
- Transmit ADAC and Orbit data to ground

“Propulsion system check”

- Activate Propulsion board
- Check tank temperature and pressure
  - If above threshold -> Safe Mode 1
- Check line temperature and pressure
  - If above threshold -> Safe Mode 1
- Check if heater works based on power draw

“Initialize communication”

- Computer when powered up will turn on modem/transmitter/receiver

“Begin ground communication”

- MR SAT sends a sample packet of information to the ground station

“Ground test of MR SAT”

- Ground request basic signal from MR SAT

“GO/NO GO from Ground”

- Receive signal from MR SAT
    - Signal received – proceed
    - Signal not received – Safe Mode 2
- Test of the quality of data received.
    - Quality of signal good – proceed to next step
    - Quality of signal bad – Safe Mode 2

“Downlink all sensor data”

- Once the Ground Station has successfully made contact with the satellite, MR SAT will begin an automatic downlink of all telemetry and sensor data as prioritized by the flight software

“Perform corrective ADAC and orbit maneuvers”

- Perform maneuvers if necessary

“Test MR SAT to MRS SAT”

- Computer checks to make sure everything is functioning properly and then tells the modem to send the information to ground station

Power-Up Mode

Power-Up mode steps through the process of using the solar cells to sufficiently charge the batteries to turn on the onboard computer. Once the computer is on, it will perform a self-diagnostic check on all of its systems. Before the satellite continues into Detumble Mode the batteries will continue to charge until sufficient power is available to run the needed attitude components.

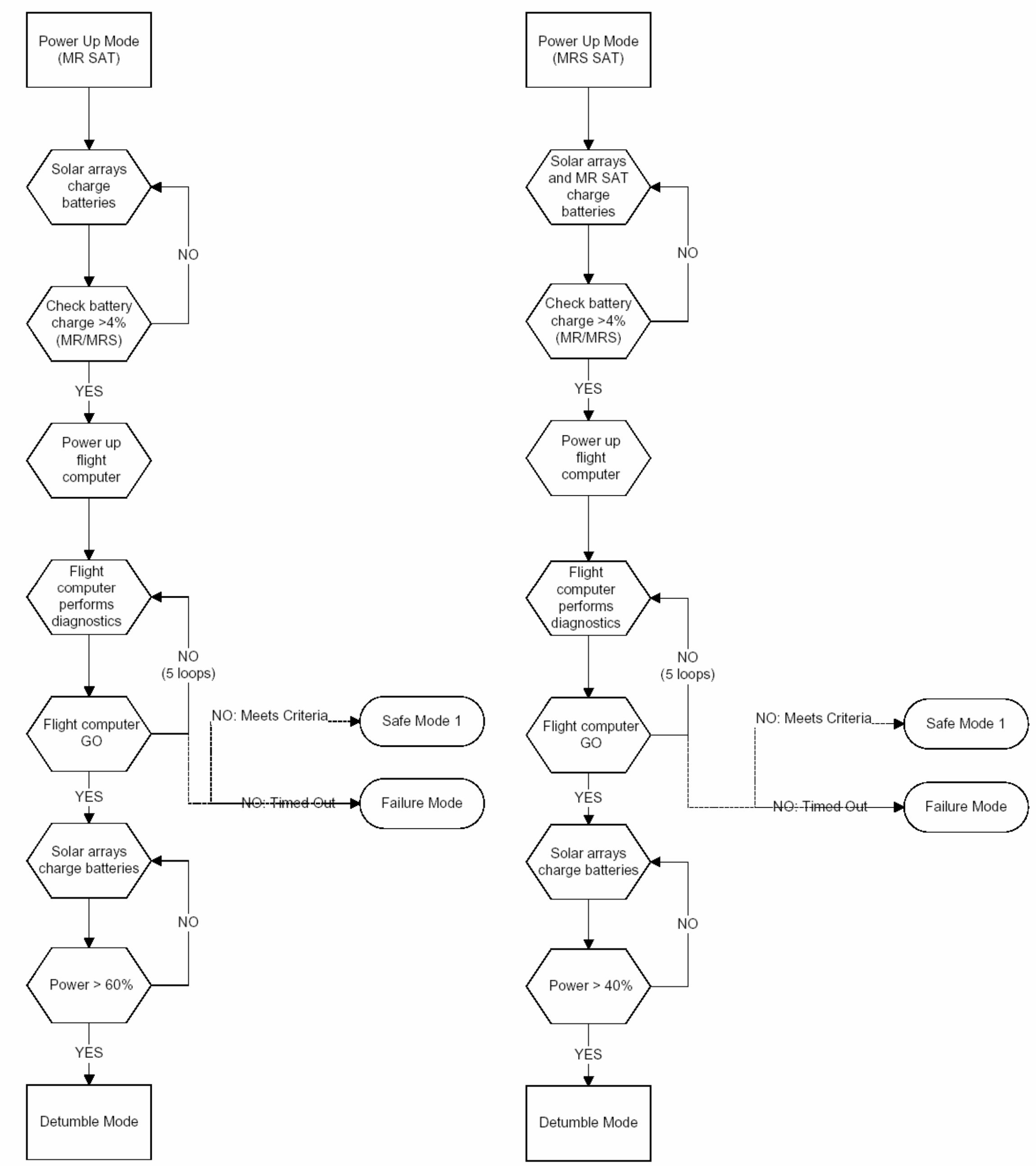


Figure C. 5 Power Up Mode

Detailed Steps (MR/MRS SAT)

“Solar arrays charge batteries”

- Happens as soon as inhibits are pulled

“Check battery charge is > 4%”

- Power board will use ADCs to check battery charge (internal to board)

“Power up flight computer”

- Should be done in the embedded software in Power board

“Flight computer performs diagnostic”

- Power on the 1-wire interface board
- Confirm that the data bus is operational
- Verify the contents of the memory
- Test reading to and writing from the Flash card

“Flight computer GO”

- Test passes = GO; Test fails = NO GO

“Solar arrays charge batteries”

- Always happening

“Power > 60% (MR); > 40% (MRS)”

- Power board will use ADCs to check battery charge (internal to board)

Detumble Mode

Detumble Mode activates all attitude measuring and control autonomously in order to stabilize the stacked satellite pair. Once the magnetometer telemetry indicates that the satellite is stable, it will proceed back to Initialization Mode to complete all necessary satellite activation.

Figure C. 6 Detumble Mode

Detailed Steps (MR SAT)

“Initialize MR SAT ADAC detumble software autonomously”

- Software will run in background for duration of mission

“Activate GPS unit”

- Onboard computer sends a command to the power board
- Onboard computer initializes communication with GPS unit
- Onboard computer sends the proper message to configure it to send position data

“Return ADAC data to OBC”

- On-board computer will have ADAC and orbit data at hand at all times

“Execute detumble software”

- Attitude and orbit control software modules begin attempting to detumble the satellite
- Step continues until conditions of software algorithms determine tumbling has stopped

“MR SAT stabilized”

- MR SAT ADAC software will autonomously correct tip-off error

Detailed Steps (MRS SAT)

"Activate ADAC/GPS system"

- Initialize ADAC and orbit software (Software will run in background for duration of mission)
- MRS SAT ADAC software will autonomously correct tip-off error
- On-board computer will have ADAC and orbit data at hand at all times

Pre-Deploy Mode

Pre-Deploy Mode is designed to ensure MRS SAT is prepared to leave MR SAT and functions as an independent satellite. This mode checks the power in MRS SAT's batteries, activates all necessary components on board, and checks the inter-satellite communication link. Once all necessary systems are checked the satellites proceed to Separation Mode.

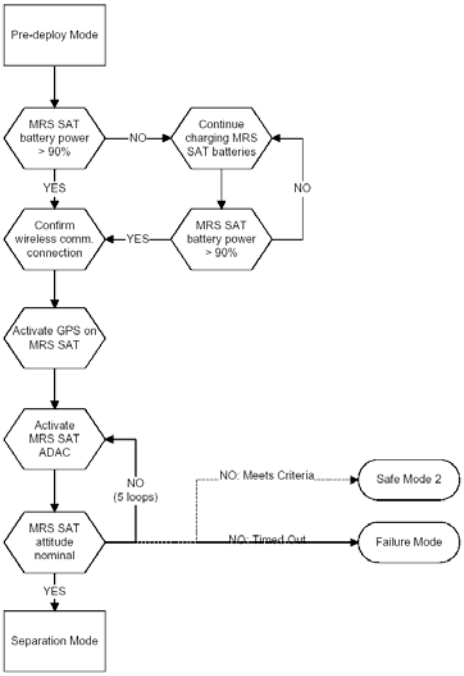


Figure C. 7 Pre-Deploy Mode

Detailed Steps

“MRS SAT battery power > 90%”

- Power board will use ADCs to check battery charge (internal to board)

“Continue charging MRS SAT batteries”

- Continues as long as inhibits are pulled

“Confirm wireless communication”

- Request health telemetry from MRS SAT
- If no response in 5 minutes try again
- After 5 tries go to Safe Mode 1

“Activate GPS on MRS SAT”

- Onboard computer sends a command to the power board to turn on the GPS unit
- Onboard computer will then initialize communications with the GPS unit
- Onboard computer send the proper message to configure it to send position data

“Activate MRS SAT ADAC”

- Begin monitoring MRS SAT attitude
- Take corrective action using algorithms in software

"MRS SAT attitude nominal"

- Check to see that satellite attitude is within mission requirements
- Transmit ADAC and Orbit data to ground

Separation Mode

The Separation Mode runs a diagnostic on all systems necessary for satellite separation. It then activates the separation mechanism and confirms the two satellites did separate. Once the satellites have separated, they will begin the autonomous Formation Flight Mode.

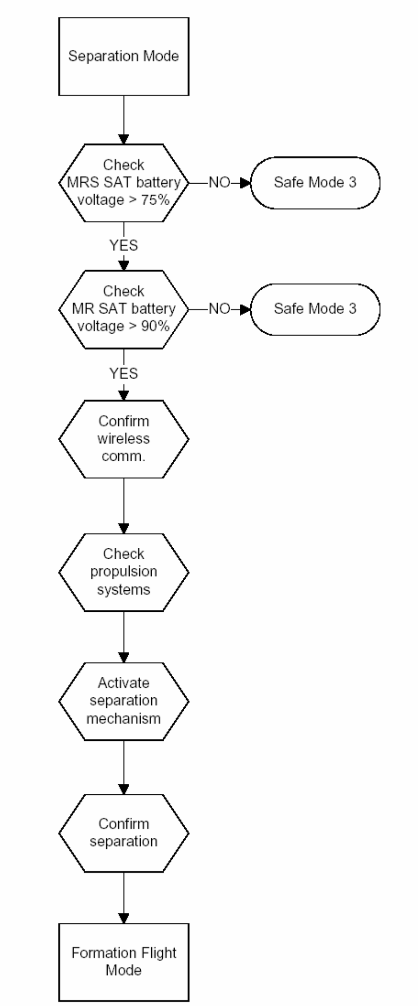


Figure C. 8 Separation Mode

Detailed Steps

“Check battery voltage on both MR & MRS SAT”

- Power board will use ADCs to check battery charge (internal to board)

“Confirm wireless comm.”

- The computer on MR SAT will confirm that the Bluetooth is still working before separating. The computer will tell the modem to send the information to ground station, as well as the confirmation of separation.

“Check propulsion systems”

- Activate Propulsion board
- Check tank temperature and pressure
    - If above threshold -> Safe Mode 1
- Check line temperature and pressure
    - If above threshold -> Safe Mode 1
- If tank temperature is below acceptable ranges?
    - Check for sufficient power to turn on heaters
    - Turn on heaters
    - Are heaters working based on power draw

“Activate separation mechanism”

- Pending more information from Starsys

“Confirm separation”

- Receive GPS coordinates from MRS SAT
- Confirm MRS SAT is separated from MR SAT

Formation Flight Mode

The Formation Flight Mode will continue for a minimum of one orbit. This mode maintains the 50 meter distance between the two satellites by using the propulsion system. Throughout the Formation Flight Mode MRS SAT will transmit data to MR SAT which will then use this information to perform the propulsive maneuvers autonomously. MR SAT will also downlink both satellites’ telemetry data to the ground station. Once all propellant has been expended the two satellites will begin to drift apart beginning the Range Test Mode.

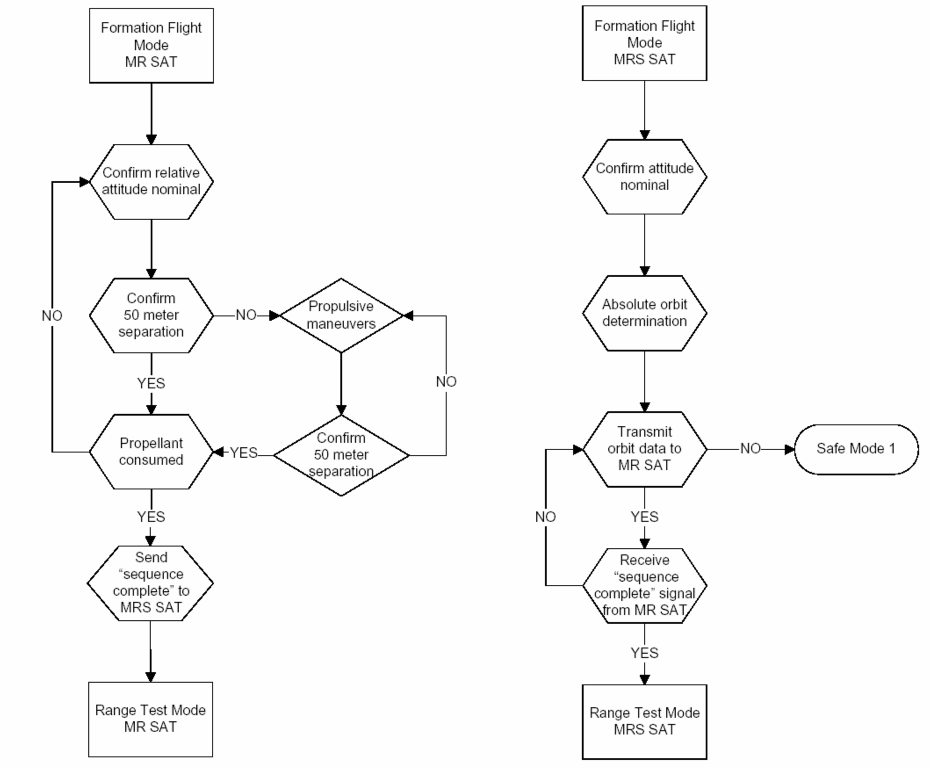


Figure C. 9 Formation Flight Mode

Detailed Steps (MR SAT)

“Confirm relative attitude nominal”

- ADAC software continually checks for nominal attitude

“Confirm 50 meter separation”

- Orbit software confirms and maintains 50 meter separation

“Propulsive maneuvers”

- Turn heaters on
- Check temperature and pressure acceptable
- Open valves for maneuver

“Confirm 50 meter separation”

- Orbit software confirms and maintains 50 meter separation

“Propellant consumed”

- Is propellant consumed?
    - Yes – shut down propulsion system
    - No – continue maneuvers

“Send ‘sequence complete’ to MRS SAT”

- Once MR SAT’s propellant is consumed a signal will be sent via modem/transmitter to the ground station and MRS SAT to complete the mode and proceed to Range Test Mode

Detailed Steps (MRS SAT)

“Confirm attitude nominal”

- ADAC software continually checks for nominal attitude

“Absolute orbit determination”

- Orbit software determines the position and velocity of MRS SAT

“Transmit orbit data to MR SAT”

- MRS SAT sends absolute orbital position to MR SAT every 3 seconds

“Receive ‘sequence complete’ signal from MR SAT”

- MRS SAT will receive a signal via the Bluetooth intersatellite communications link notifying her to move into Range Test Mode
- The switch from Formation Flight Mode into Range Test Mode will be handled automatically by the task manager software module on the MRS SAT onboard computer

Range Test Mode

Range Test Mode will test the range of the wireless communication as the two satellites drift apart. Once the propellant is spent the two satellites will move slowly away from one another allowing the wireless communication to continue to transmit as long as power and distance allow. At the completion of this mode MRS SAT will no longer be accessible from MR SAT or the UMR ground station.

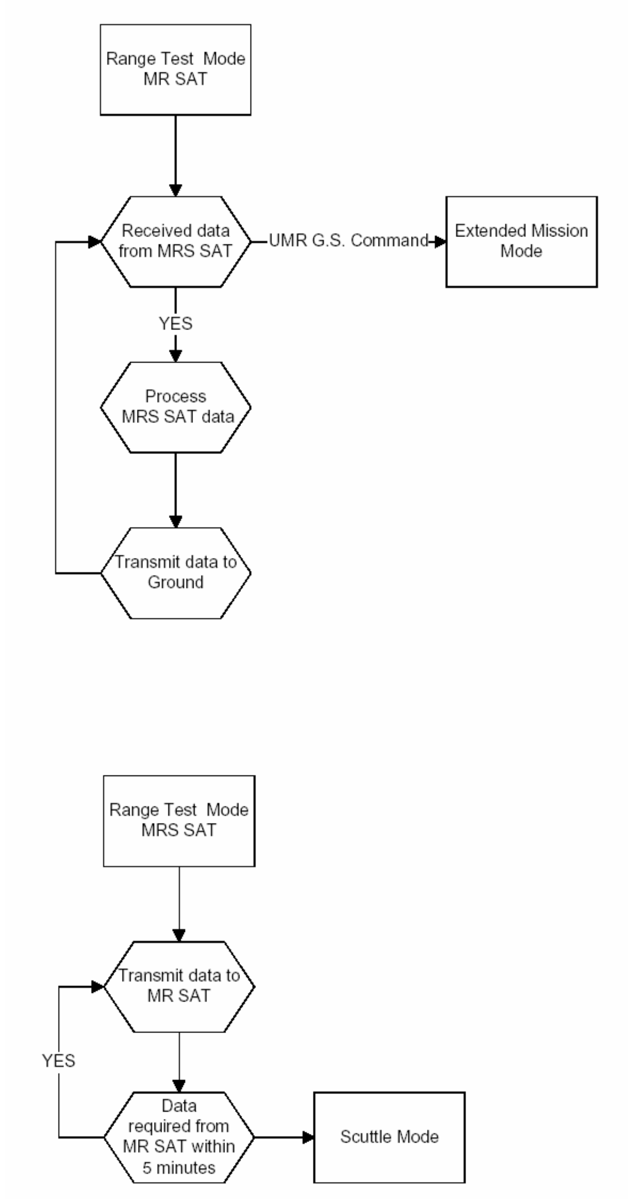


Figure C. 10 Range Test Mode

Detailed Steps (MR SAT)

“Receive data from MRS SAT”

- The computer on MR SAT receives data from MRS SAT and processes it. The computer then tells the modem to transmit the information to the ground station.

Data referred to in each step.

- ADAC and orbit software on each spacecraft determines and maintains nominal attitude while tracking spacecraft position and velocity

“Process MRS SAT data”

- Run algorithms on the onboard computer

“Transmit data to Ground”

- MR SAT has automatic downlink of all telemetry data with the Ground Station

Detailed Steps (MRS SAT)

“Transmit data to MR SAT”

- Bluetooth remains operational and MRS SAT constantly sends data to MR SAT about position

Data referred to in each step.

- ADAC and orbit software on each spacecraft determines and maintains nominal attitude while tracking spacecraft position and velocity

“Data required from MR SAT within 5 minutes”

- Start timer when data is sent
- If timer reaches 5 minutes enter Scuttle Mode

Extended Mission Mode

The Extended Mission Mode only applies to the MR SAT spacecraft. This mode consists of monitoring and transmitting all orbital, attitude, and thermal measurements to the UMR ground station.

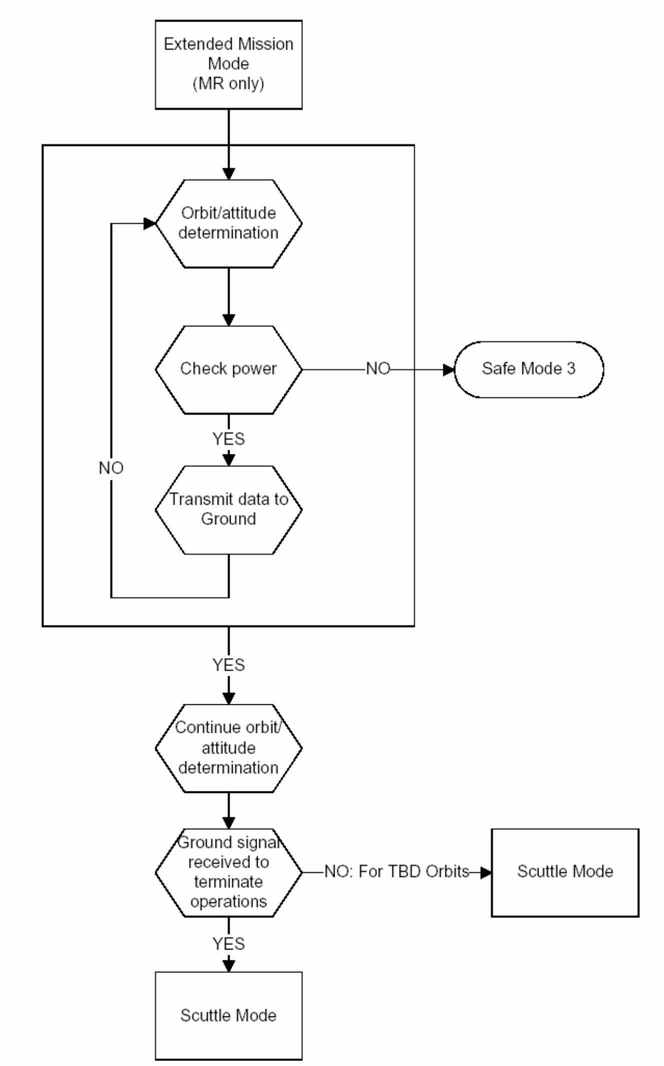


Figure C. 11 Extended Mission Mode

Detailed Steps

"Check power"

- Power board will use ADCs to check battery charge (internal to board)

"Transmit data to ground"

- MR SAT will transmit all data stored in the computer from the ADAC, Orbit, and other systems

"Ground signal received to terminate operations"

- Ground station sends signal to MR SAT to end operations and enter Scuttle Mode

Safe Mode

The satellites will have several Safe Modes as a contingency in case an anomaly occurs on either satellite. Entering a Safe Mode will shut down all but the necessary components such as the Computer, Power, and Communication systems to provide the UMR Operations team time to trouble shoot the problem.

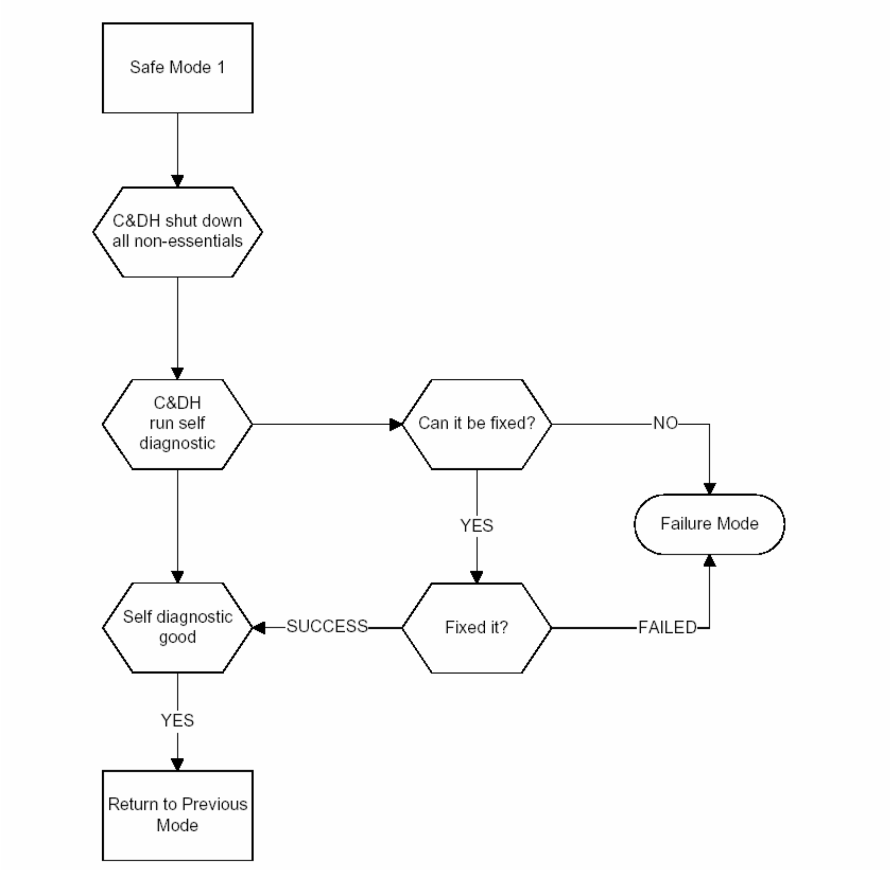


Figure C. 12 Safe Mode 1

Detailed Steps (Safe Mode 1)

“C&DH shut down all non-essentials”

- Onboard computer requests the power board to turn off all subsystems not necessary for current operations

“C&DH run self diagnostic”

- Onboard computer runs a series of tasks to verify hardware status
- Checks that all outputs are valid

“Can it be fixed?”

- Hardware/software reset where possible

“Fixed it?”

- Rerun self diagnostic

“Self diagnostic good”

- Return to mode which placed satellite in Safe Mode

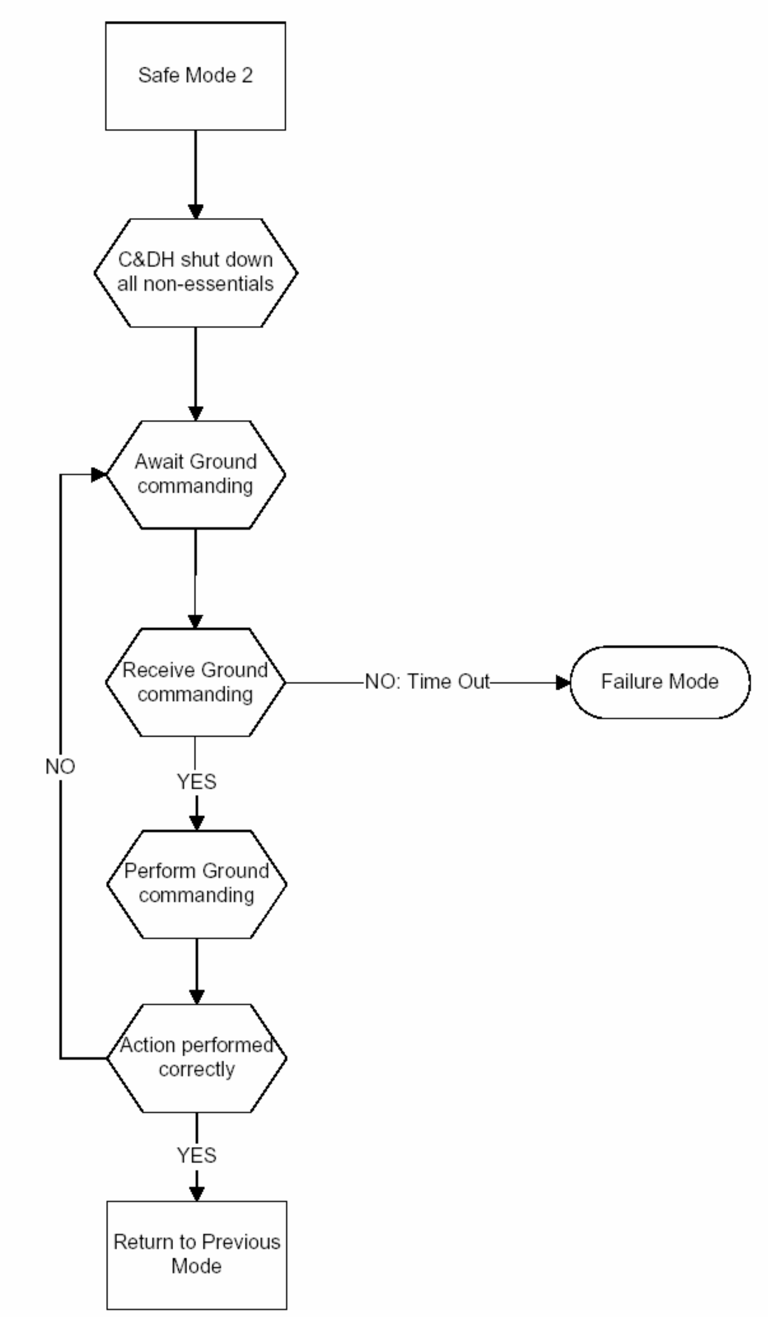


Figure C. 13 Safe Mode 2

Detailed Steps (Safe Mode 2)

“C&DH shut down all non-essentials”

- Onboard computer requests the power board to turn off all subsystems not necessary for current operations

“Await Ground commanding”

- Check communication hardware
- If hardware failed, go to Safe Mode 1
- If hardware good, wait for signal from Ground Station
- “Receive Ground commanding”
- Receive and act on software commands received from Ground Station

“Action performed correctly”

- Verify command executed
- Verify expected reaction occurred

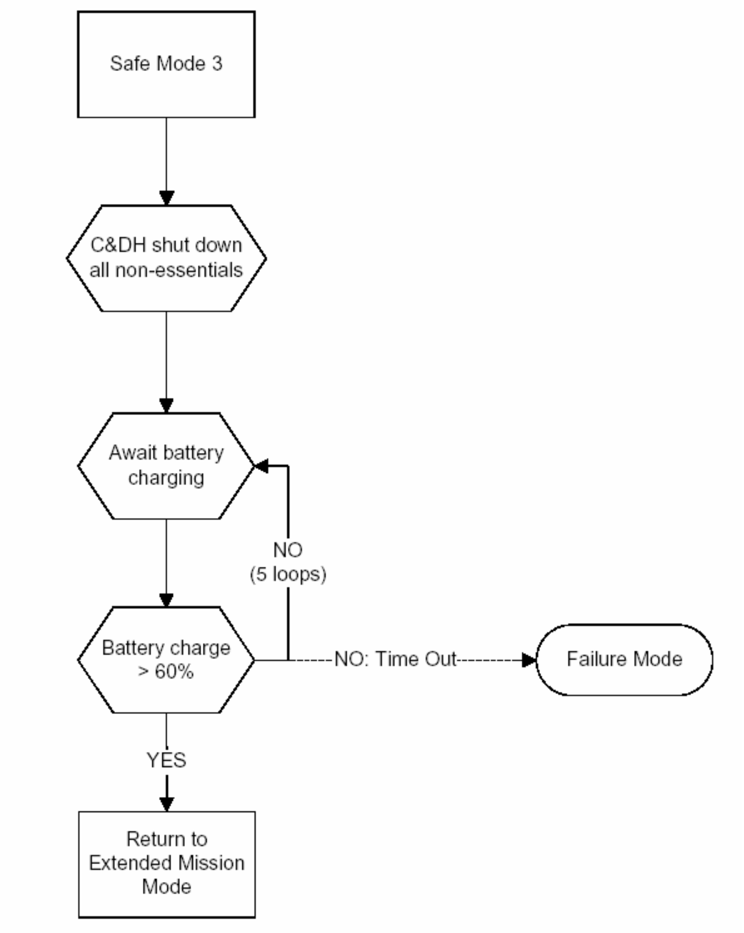


Figure C. 14 Safe Mode 3

Detailed Steps (Safe Mode 3)

"C&DH shut down all non-essentials"

- Onboard computer requests the power board to turn off all subsystems not necessary for current operations

"Await battery charging"

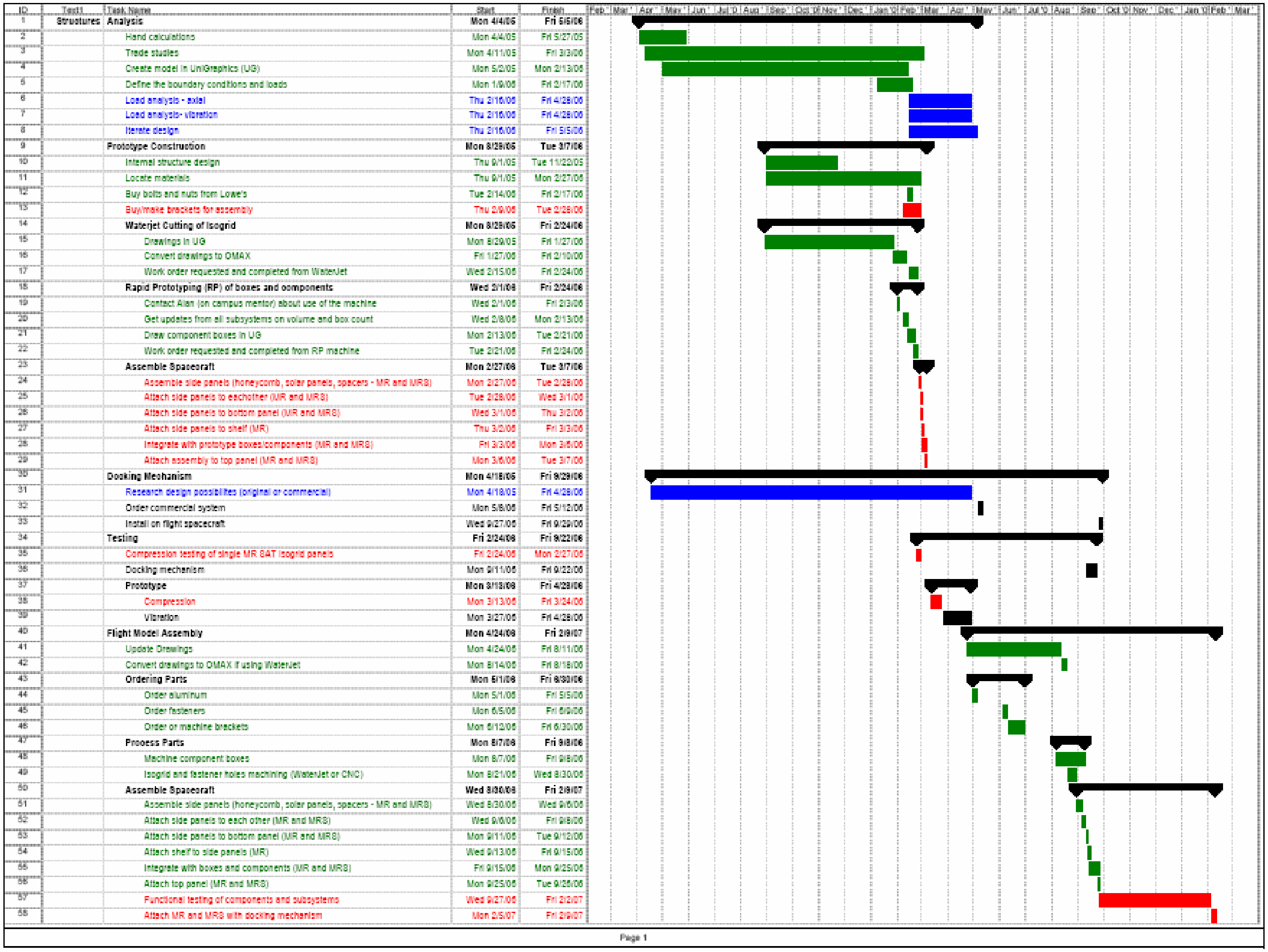
- Always happening

"Battery charge > 60%"

- Power board will use ADCs to check battery charge (internal to board)

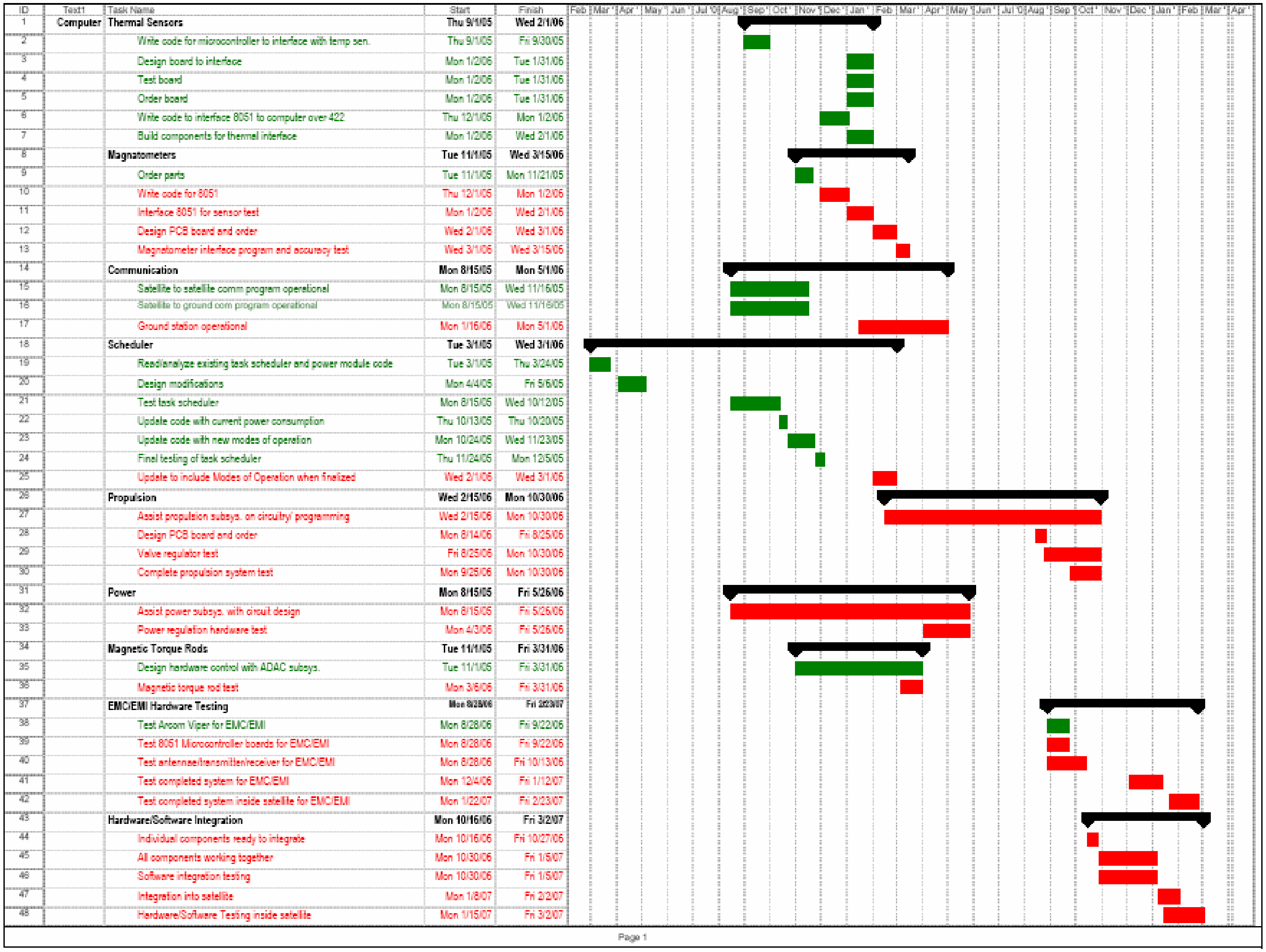
APPENDIX D

GANTT CHARTS



ID	Text1	Task Name	Start	Finish
1	**Structures**	**Analysis**	**Mon 4/4/05**	**Fri 5/5/06**
2		Hand calculations	Mon 4/4/05	Fri 5/27/05
3		Trade studies	Mon 4/11/05	Fri 3/3/06
4		Create model in UniGraphics (UG)	Mon 5/2/05	Mon 2/13/06
5		Define the boundary conditions and loads	Mon 1/9/06	Fri 2/17/06
6		Load analysis - axial	Thu 2/16/06	Fri 4/28/06
7		Load analysis- vibration	Thu 2/16/06	Fri 4/28/06
8		Iterate design	Thu 2/16/06	Fri 5/5/06
9		**Prototype Construction**	**Mon 8/29/05**	**Tue 3/7/06**
10		Internal structure design	Thu 9/1/05	Tue 11/22/05
11		Locate materials	Thu 9/1/05	Mon 2/27/06
12		Buy bolts and nuts from Lowe's	Tue 2/14/06	Fri 2/17/06
13		Buy/make brackets for assembly	Thu 2/9/06	Tue 2/28/06
14		**Waterjet Cutting of Isogrid**	**Mon 8/29/05**	**Fri 2/24/06**
15		Drawings in UG	Mon 8/29/05	Fri 1/27/06
16		Convert drawings to OMAX	Fri 1/27/06	Fri 2/10/06
17		Work order requested and completed from WaterJet	Wed 2/15/06	Fri 2/24/06
18		**Rapid Prototyping (RP) of boxes and components**	**Wed 2/1/06**	**Fri 2/24/06**
19		Contact Alan (on campus mentor) about use of the machine	Wed 2/1/06	Fri 2/3/06
20		Get updates from all subsystems on volume and box count	Wed 2/8/06	Mon 2/13/06
21		Draw component boxes in UG	Mon 2/13/06	Tue 2/21/06
22		Work order requested and completed from RP machine	Tue 2/21/06	Fri 2/24/06
23		**Assemble Spacecraft**	**Mon 2/27/06**	**Tue 3/7/06**
24		Assemble side panels (honeycomb, solar panels, spacers - MR and MRS)	Mon 2/27/06	Tue 2/28/06
25		Attach side panels to eachother (MR and MRS)	Tue 2/28/06	Wed 3/1/06
26		Attach side panels to bottom panel (MR and MRS)	Wed 3/1/06	Thu 3/2/06
27		Attach side panels to shelf (MR)	Thu 3/2/06	Fri 3/3/06
28		Integrate with prototype boxes/components (MR and MRS)	Fri 3/3/06	Mon 3/6/06
29		Attach assembly to top panel (MR and MRS)	Mon 3/6/06	Tue 3/7/06
30		**Docking Mechanism**	**Mon 4/18/05**	**Fri 9/29/06**
31		Research design possibilites (original or commercial)	Mon 4/18/05	Fri 4/28/06
32		Order commercial system	Mon 5/8/06	Fri 5/12/06
33		Install on flight spacecraft	Wed 9/27/06	Fri 9/29/06
34		**Testing**	**Fri 2/24/06**	**Fri 9/22/06**
35		Compression testing of single MR SAT isogrid panels	Fri 2/24/06	Mon 2/27/06
36		Docking mechanism	Mon 9/11/06	Fri 9/22/06
37		**Prototype**	**Mon 3/13/06**	**Fri 4/28/06**
38		Compression	Mon 3/13/06	Fri 3/24/06
39		Vibration	Mon 3/27/06	Fri 4/28/06
40		**Flight Model Assembly**	**Mon 4/24/06**	**Fri 2/9/07**
41		Update Drawings	Mon 4/24/06	Fri 8/11/06
42		Convert drawings to OMAX if using WaterJet	Mon 8/14/06	Fri 8/18/06
43		**Ordering Parts**	**Mon 5/1/06**	**Fri 6/30/06**
44		Order aluminum	Mon 5/1/06	Fri 5/5/06
45		Order fasteners	Mon 6/5/06	Fri 6/9/06
46		Order or machine brackets	Mon 6/12/06	Fri 6/30/06
47		**Process Parts**	**Mon 8/7/06**	**Fri 9/8/06**
48		Machine component boxes	Mon 8/7/06	Fri 9/8/06
49		Isogrid and fastener holes machining (WaterJet or CNC)	Mon 8/21/06	Wed 8/30/06
50		**Assemble Spacecraft**	**Wed 8/30/06**	**Fri 2/9/07**
51		Assemble side panels (honeycomb, solar panels, spacers - MR and MRS)	Wed 8/30/06	Wed 9/6/06
52		Attach side panels to each other (MR and MRS)	Wed 9/6/06	Fri 9/8/06
53		Attach side panels to bottom panel (MR and MRS)	Mon 9/11/06	Tue 9/12/06
54		Attach shelf to side panels (MR)	Wed 9/13/06	Fri 9/15/06
55		Integrate with boxes and components (MR and MRS)	Fri 9/15/06	Mon 9/25/06
56		Attach top panel (MR and MRS)	Mon 9/25/06	Tue 9/26/06
57		Functional testing of components and subsystems	Wed 9/27/06	Fri 2/2/07
58		Attach MR and MRS with docking mechanism	Mon 2/5/07	Fri 2/9/07

Figure D. 1 Structure Subsystem Gantt Chart



ID	Text1	Task Name	Start	Finish
1	**Computer**	**Thermal Sensors**	**Thu 9/1/05**	**Wed 2/1/06**
2		Write code for microcontroller to interface with temp sen.	Thu 9/1/05	Fri 9/30/05
3		Design board to interface	Mon 1/2/06	Tue 1/31/06
4		Test board	Mon 1/2/06	Tue 1/31/06
5		Order board	Mon 1/2/06	Tue 1/31/06
6		Write code to interface 8051 to computer over 422	Thu 12/1/05	Mon 1/2/06
7		Build components for thermal interface	Mon 1/2/06	Wed 2/1/06
8		**Magnatometers**	**Tue 11/1/05**	**Wed 3/15/06**
9		Order parts	Tue 11/1/05	Mon 11/21/05
10		Write code for 8051	Thu 12/1/05	Mon 1/2/06
11		Interface 8051 for sensor test	Mon 1/2/06	Wed 2/1/06
12		Design PCB board and order	Wed 2/1/06	Wed 3/1/06
13		Magnatometer interface program and accuracy test	Wed 3/1/06	Wed 3/15/06
14		**Communication**	**Mon 8/15/05**	**Mon 5/1/06**
15		Satellite to satellite comm program operational	Mon 8/15/05	Wed 11/16/05
16		Satellite to ground com program operational	Mon 8/15/05	Wed 11/16/05
17		Ground station operational	Mon 1/16/06	Mon 5/1/06
18		**Scheduler**	**Tue 3/1/05**	**Wed 3/1/06**
19		Read/analyze existing task scheduler and power module code	Tue 3/1/05	Thu 3/24/05
20		Design modifications	Mon 4/4/05	Fri 5/6/05
21		Test task scheduler	Mon 8/15/05	Wed 10/12/05
22		Update code with current power consumption	Thu 10/13/05	Thu 10/20/05
23		Update code with new modes of operation	Mon 10/24/05	Wed 11/23/05
24		Final testing of task scheduler	Thu 11/24/05	Mon 12/5/05
25		Update to include Modes of Operation when finalized	Wed 2/1/06	Wed 3/1/06
26		**Propulsion**	**Wed 2/15/06**	**Mon 10/30/06**
27		Assist propulsion subsys. on circuitry/ programming	Wed 2/15/06	Mon 10/30/06
28		Design PCB board and order	Mon 8/14/06	Fri 8/25/06
29		Valve regulator test	Fri 8/25/06	Mon 10/30/06
30		Complete propulsion system test	Mon 9/25/06	Mon 10/30/06
31		**Power**	**Mon 8/15/05**	**Fri 5/26/06**
32		Assist power subsys. with circuit design	Mon 8/15/05	Fri 5/26/06
33		Power regulation hardware test	Mon 4/3/06	Fri 5/26/06
34		**Magnetic Torque Rods**	**Tue 11/1/05**	**Fri 3/31/06**
35		Design hardware control with ADAC subsys.	Tue 11/1/05	Fri 3/31/06
36		Magnetic torque rod test	Mon 3/6/06	Fri 3/31/06
37		**EMC/EMI Hardware Testing**	**Mon 8/28/06**	**Fri 2/23/07**
38		Test Arcom Viper for EMC/EMI	Mon 8/28/06	Fri 9/22/06
39		Test 8051 Microcontroller boards for EMC/EMI	Mon 8/28/06	Fri 9/22/06
40		Test antennae/transmitter/receiver for EMC/EMI	Mon 8/28/06	Fri 10/13/06
41		Test completed system for EMC/EMI	Mon 12/4/06	Fri 1/12/07
42		Test completed system inside satellite for EMC/EMI	Mon 1/22/07	Fri 2/23/07
43		**Hardware/Software Integration**	**Mon 10/16/06**	**Fri 3/2/07**
44		Individual components ready to integrate	Mon 10/16/06	Fri 10/27/06
45		All components working together	Mon 10/30/06	Fri 1/5/07
46		Software integration testing	Mon 10/30/06	Fri 1/5/07
47		Integration into satellite	Mon 1/8/07	Fri 2/2/07
48		Hardware/Software Testing inside satellite	Mon 1/15/07	Fri 3/2/07

Figure D. 2 C&DH Subsystem Gantt Chart

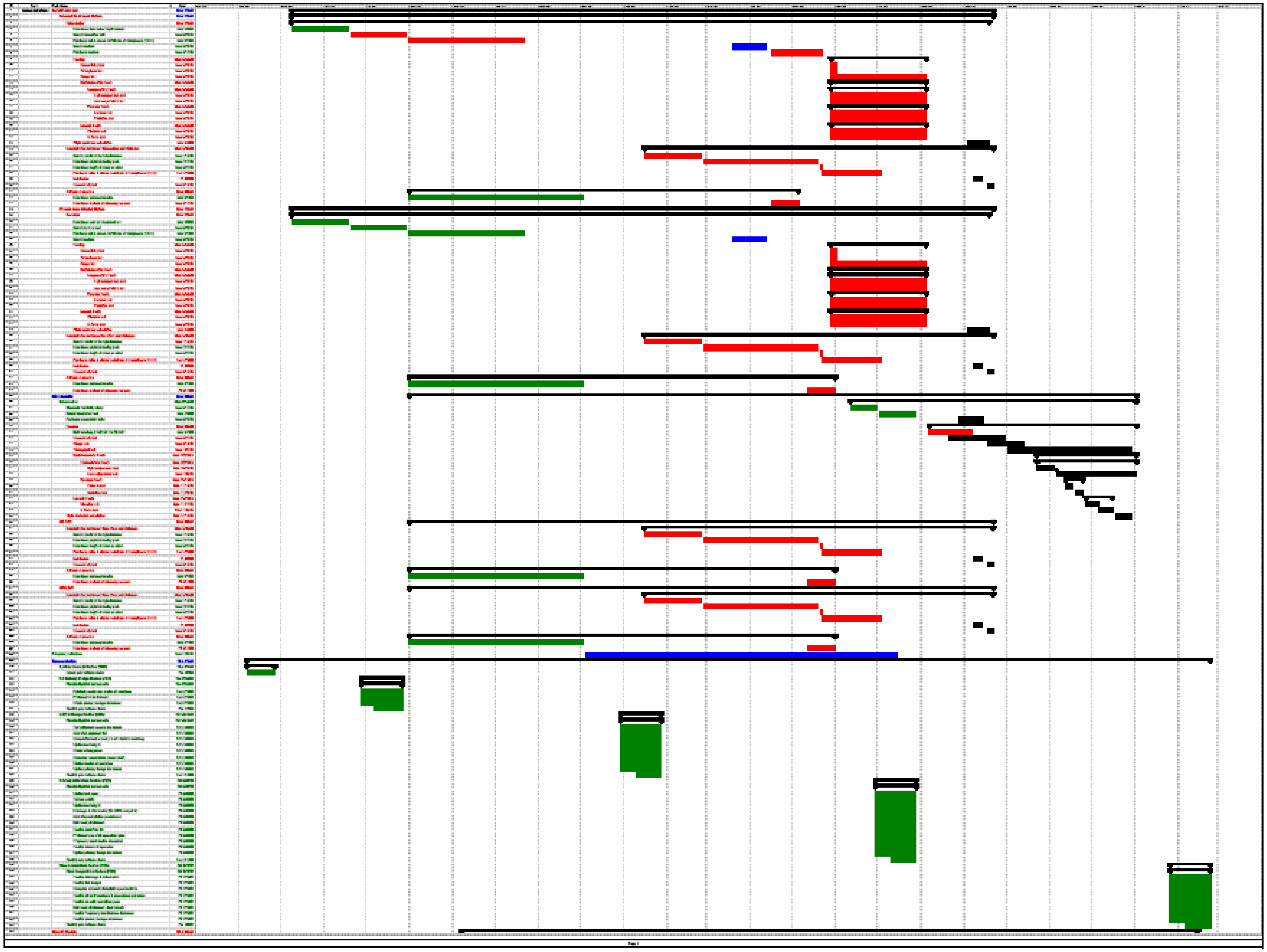


Figure D. 3 Communication Subsystem Gantt Chart

BIBLIOGRAPHY

(1) University of Missouri–Rolla Satellite Team, “00-003 Executive Summary,” Rev E, March 2007.

(2) Air Force Research Laboratory, “University Nanosat Program,” February 2006. http://www.vs.afrl.af.mil/UNP/index.html

(3) AFRL/VS, University Nanosat-4 Program, “Nanosat-4 User’s Guide,” (Limited Release) UN4-0001 – Rev A, University Nanosat Program Office, Kirtland AFB, NM, June 2006.

(4) AFRL/VS, University Nanosat-4 Program, “Nanosat-4 Configuration/Document Management & Quality Assurance Plan,” (Limited Release) UN4-0002 – Rev -, University Nanosat Program Office, Kirtland AFB, NM, September 2005.

(5) University of Missouri–Rolla Satellite Team, “06-002 Power Budget,” Rev B, March 2007.

(6) University of Missouri–Rolla Satellite Team, “05-001 Computing Budget,” Rev C, March 2007.

(7) University of Missouri–Rolla Satellite Team, “01-001 MR SAT Mass Budget,” Rev H, March 2007.

(8) University of Missouri–Rolla Satellite Team, “01-003 MR SAT Volume Budget,” Rev H, March 2007.

(9) AFRL/VS, University Nanosat-4 Program, “UNP Program Management Tips 2005,” (Limited Release), Meeting presentation hosted by Mr. Brian Engberg, April 4, 2005.

(10) Ziegler, Lori, “Design and Implementation of Assembly and Integration Procedures for a University Microsatellite,” Master’s Thesis, University of Missouri-Rolla, in progress to be completed December 2007.

(11) University of Missouri–Rolla Satellite Team, “FCR UMR Requirements Verification Matrix,” Rev D, March 2007.

(12) University of Missouri–Rolla Satellite Team, “00-005 On-Orbit Operations Plan,” Rev B, March 2007.

(13) University of Missouri–Rolla Satellite Team, “00-002 Program Schedule and Team Budgets,” Rev C, March 2007.

(14) Answers.com, “Technology Readiness Levels,” April 10, 2007. http://www.answers.com/topic/technology-readiness-level

VITA

Abbie Marie Stewart was born on October 5, 1982 in Bowling Green, KY. She graduated from Coronado High School in May of 2001. Abbie went on to earn her Bachelor’s Degree in Aerospace Engineering from the University of Missouri–Rolla in May of 2005. Upon completion of this degree she began pursuit of a Master’s degree in Aerospace Engineering from UMR which was completed in May of 2007. During her Master’s program, Abbie interned with the Air Force Research Laboratory working primarily on the Nanosat program and small satellite testing. While attending UMR, she was a member of AIAA, treasurer of Sigma Gamma Tau and Christian Campus Fellowship, a team member of Miners in Space UMR’s microgravity research team, a member of Omicron Delta Kappa, a second soprano in Madrigal Singers, an avid member of the UMR musical theater community and the UMR SAT Chief Engineer.