Relative Navigation, Microdischarge Plasma Thruster, and Distributed Communications Experiments on the FASTRAC Mission

G. Holt, S. Stewart, J. Mauldin, T. Campbell, P. Eckhoff, H. Elmasri, B. Evans
M. Garg, J. Greenbaum, M. Linford, M. Poole,
E. G. Lightsey, L. L. Raja
The University of Texas at Austin
Department of Aerospace Engineering and Engineering Mechanics
1 University Station, C0600, Austin, TX 78712
Tel: (512)471-7593, www@www.ae.utexas.edu

T. Ebinuma
Surrey Space Centre, University of Surrey
Guildford, Surrey GU2 7XH, UK
Tel: +44 (0)1483 683882, t.ebinuma@sstl.co.uk

Abstract. Enabling technologies for nanosatellite formations will be demonstrated under the Formation Autonomy Spacecraft with Thrust, Relnav, Attitude, and Crosslink (FASTRAC) program. Two flight-ready nanosatellites will be designed, fabricated, integrated, and tested during the two year design period. Three specific new and innovative technologies which will be demonstrated during the mission are Relative Navigation, Plasma Microthrusters, and Distributed Communications.

A sensor set consisting of Global Positioning System (GPS) receiver, magnetometer, and MEMS Inertial Measurement Unit (IMU) will be used to determine position and coarse attitude. Using a radio crosslink, the two satellites will exchange state vector information and perform sub-meter level accuracy relative navigation.

Each satellite will also contain a Microdischarge Plasma Thruster (MPT) developed at UT-Austin. This innovative device is capable of generating low-thrust, high-efficiency propulsion at low power levels using microdischarge plasmas. The ability of the MPT to extend the life of the orbit will be determined by monitoring the orbit decay rates of the two vehicles as well as the MEMS IMU.

A distributed tracking network with multiple university partners will be utilized to track the low Earth orbit satellites. Amateur radio experimenters, high schools, universities, and other interested parties will be encouraged to record telemetry from the satellites and report their data to a project web site for processing. Although the main purpose of the mission is technology demonstration, science goals will also be pursued. These include post-processing sensor measurements to determine satellite drag, as well as Earth atmospheric and magnetospheric studies.

INTRODUCTION

SPACECRAFT formations will play an important role in the future utilization of space. The National Aeronautics and Space Adminstration (NASA) and the United States Air Force (USAF) have several missions planned to perform experiments with distributed space systems.[1] In these cases, multiple satellites work together in a coordinated manner to perform tasks that would be impossible or cost prohibitive using a single satellite. These missions will become progressively more challenging in terms of the number of satellites in the formation and the complexity of the tasks that must be performed. In order to prepare for these advanced mission concepts, new technologies must be developed and demonstrated that enable these tasks to be completed. Nanosatellites are well suited for missions that utilize spacecraft formations. There is always a premium on the mass and cost of an individual satellite, but these metrics are more significant when many satellites are required to perform the mission. There are obvious savings to be obtained by using nanosatellites (<20 kg and 45 cm linear dimensions per satellite) over conventionally larger satellites in these situations. Employing nanosatellite formations requires technologies and capabilities that are in relatively early stages of development. Many of the challenges associated with nanosatellites are related to the miniaturization and integration of suitable sensors and actuators that allow the vehicles to determine and control their position and orientation. Electrical interference and heat transfer are two of the integration challenges that must be addressed. These devices must be individually small and operate within centimeters of other devices. The supply of consumables, such as propellant, is also extremely limited. This requires the development of highly efficient microthrusters capable of delivering high specific impulses to minimize propellant mass. Navigation and control of the formation is also a challenge. Control of a large formation manually by ground operations is cumbersome and expensive. Formations will benefit from the ability to perform autonomous relative navigation via communications crosslinks so that on-orbit control may be performed. While control is performed on-orbit, the formation will also be monitored from the ground. New operations concepts, such as representing each satellite with a web site command interface, and using the internet to control ground station networks in remote locations, can simplify formation management. These techniques need to be demonstrated experimentally before they are incorporated into mainstream satellite design. Many of these nanosatellite formation concepts can be demonstrated with a two vehicle nanosatellite mission. The demonstration of these enabling technologies is the goal of the Formation Autonomy Spacecraft with Thrust, Relnav, Attitude, and Crosslink (FASTRAC) mission.

OBJECTIVES

The objective of this proposal is to design, fabricate, and test two flight-ready nanosatellites under the University Nanosat Program Broad Agency Announcement (AFOSR BAA 2003-2). The two satellites will be built within the mass, size, and cost constraints listed in the BAA for a single satellite. That is, each satellite will have mass <10 kilograms, and dimension less than 20×40×40 centimeters, so that when stacked on a launch vehicle, they fit within the total mass and volume budget of a single launch opportunity (total mass <20 kg and linear dimensions <45 cm). The entire project will be accomplished within the period of performance of 2 years and under a budget of less than $50k per year ($100k total cost). The satellites will be built and tested at the University of Texas at Austins Satellite Design Laboratory (SDL). UT-Austin will receive assistance in satellite and ground systems design from Santa Clara Universitys Robotic Systems Laboratory (RSL) in the form of a subcontracting arrangement. The technical objectives of the mission are to use the two satellites to demonstrate enabling technologies for nanosatellites and satellite formations. The two satellites will be deployed from a single launch vehicle with an initially small separation. Each satellite will contain a sensor set capable of determining its position and coarse attitude. The sensor set is defined as follows: Global Positioning System (GPS) receiver, magnetometer, and MEMS Inertial Measurement Unit (IMU). Using a radio crosslink, the two satellites will exchange state vector information and perform sub-meter level accuracy relative navigation. The relative navigation solutions will be reported to the ground station for monitoring, but the entire navigation system will reside on each vehicle. Autonomous on-orbit relative navigation will therefore be demonstrated. Each satellite will also contain a Microdischarge Plasma Thruster (MPT) developed at UT-Austin. This innovative device is capable of generating low-thrust, high-efficiency propulsion at low power levels using microdischarge plasmas. Although the MPT will reside on both vehicles for redundancy, the plan is to operate the MPT on only one vehicle when the satellites attitude is favorably aligned to reduce the rate of orbit decay. Using the second satellite as a control mass, it will be possible to demonstrate the use of the MPT to extend the life of the orbit by monitoring the orbit decay rates of the two vehicles. The MEMS IMU will be used as a sensor to detect the acceleration produced by the MPT and determine its on-orbit efficiency. Innovative ground tracking and satellite operations concepts will also be demonstrated. A distributed tracking network with multiple university partners will be utilized to track the low Earth orbit satellites. Each satellite will be represented as a TCP/IP node and have a user command interface that operates as an Internet web site. Amateur radio experimenters, high schools, universities, and other interested parties will be encouraged to record telemetry from the satellites and report their data to a project web site for processing. In this manner, global public participation is possible in the FASTRAC mission. Although the main purpose of the mission is technology demonstration, science goals will also be pursued. These include post-processing sensor measurements to determine satellite drag, as well as Earth atmospheric and magnetospheric studies.

RESEARCH EFFORT

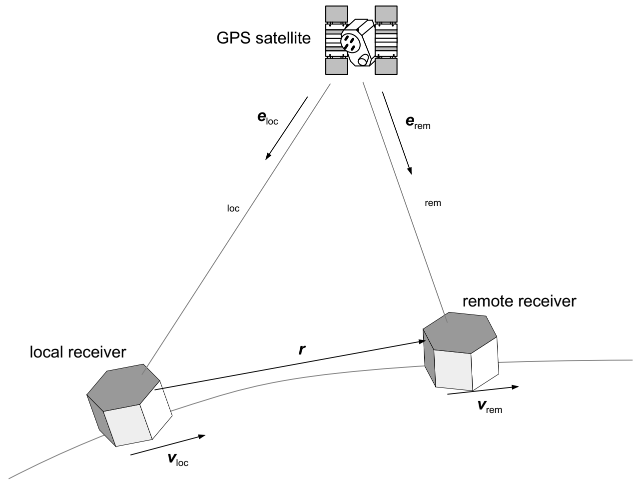
The FASTRAC mission is composed of several key mission elements. The mission elements are independent in the sense that the success or failure of one element is not directly related to the success or failure of the other elements. In this manner, the probability of overall mission success is maximized even if one element does not work as planned.

Mission Elements

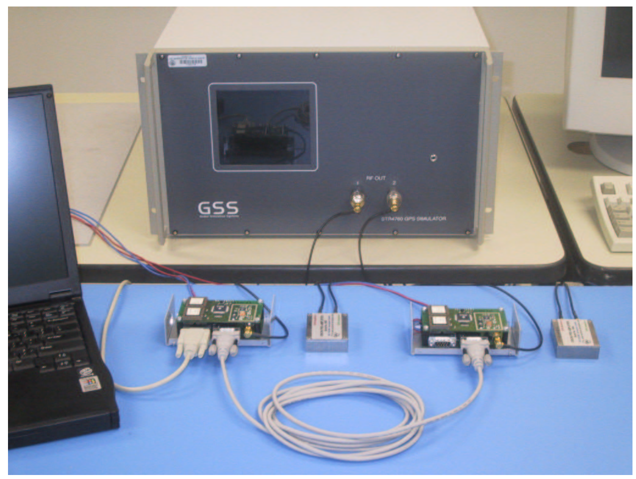
On-orbit Relative Navigation

In order to determine the relative position and velocity of two or more satellites in space, the state vector information must be collected and exchanged between the vehicles. For Earth orbiting satellites, this information is efficiently obtained using GPS receivers. Although position and velocity may be exchanged directly, it is usually more accurate to transmit raw observables directly (pseudorange, carrier phase, and Doppler shift measurements) and process these measurements collectively on each vehicle.[2]

A proposed relative navigation sensor, shown in Figure 1(a), is based on two 12-channel L1 single frequency GPS receivers. It employs two individual receivers exchanging raw pseudorange, carrier phase, and Doppler measurements via a radio link. Subsequent to computing its own position and velocity, each receiver processes the single-differenced pseudorange and carrier phase after obtaining the partners data set to obtain kinematic relative navigation solutions. The differential process allows for a high degree of common error cancellation over baselines of less than 10 km, which effectively eliminates the impact of broadcast ephemeris errors, ionospheric delay errors, and GPS satellite clock errors. In addition, a pronounced reduction of the measurement noise level is achieved through carrier smoothing techniques. Over longer baselines, the absolute and relative motion is modeled in a dynamical Kalman filter with a high-dimensional state vector.[3,4] A prototype implementation of this relative navigation system has recently been developed and demonstrated at UT-Austin. The GPS receivers used in this test are the same design that will fly on the FASTRAC mission and they are described separately in the satellite design section of this proposal. Extensive hardware-in-the-loop simulations were conducted to qualify the relative navigation system using a Spirent STR4760 GPS signal simulator capable of simulating L1 signals for 2 vehicles on up to 16 channels each, as shown in Figure 1(b). For the relative navigation application, the auxiliary data port was employed as a dedicated interface for the exchange of raw measurements between a pair of receivers remotely connected via two UHF radio modems. Hardware-in-the-loop tests conducted with the GPS signal simulator show that overall accuracies of better than 0.5 m and 5 mm/s for the relative position and velocity can be achieved when the separation distances are within 10 km.[5] In the FASTRAC mission, each satellite will carry a GPS receiver and transmit its raw measurements over a wide beamwidth antenna. To keep the satellite design relatively simple, the orientation of each satellite will not be actively controlled, but the wide beamwidth antenna will guarantee that some of the time one satellite will receive the other satellites measurement information when the satellites are within a range of several hundred kilometers (a detailed link budget has not yet been established). This minimum separation is guaranteed to occur at the beginning of mission life (at satellite deployment) and may reoccur at later times as the satellite positions continue to drift. During these times, relative navigation will be performed on the vehicle using the received measurements and stored for the next telemetry opportunity. Receipt of these relative solutions on the ground will demonstrate autonomous on-orbit relative navigation between the two vehicles. Although no control of the vehicles will be attempted using these measurements, the result will demonstrate that relative control could have been performed autonomously, if the satellite had been designed for that capability. The raw measurements will also be stored and telemetered to the ground so that relative solutions may be post-processed to determine the on-orbit relative solution accuracy. The GPS receiver solutions will also be used to enhance the return of the other experiments.



a) On-Orbit Relative Navigation



b) Hardware in the Loop Simulation

Fig. 1 FASTRAC GPS Relative Navigation

Microdischarge Plasma Thruster Experiment

In a significant recent development, a number of researchers have demonstrated the ability to generate and sustain a new class of plasmas in micron-sized geometries.[6] These are called microdischarges. Microdischarge plasmas are highly non-equilibrium plasmas that can be generated at reasonably low voltages and are stable in geometric dimensions of ∼10-100 m in length. An important aspect of microdischarge phenomena is the efficient thermal heating of the flowing gas stream to combustion-like temperatures of ∼1000 K. Importantly, the proposers are unaware of any other physical phenomena that can be used to heat a gas stream to combustion-like temperatures in micron length-scale geometries. The resultant thrust force, which is obtained from expansion of an inert gas such as helium or xenon, is in the range of 0.1 10 N. The simplicity of the microdischarge design, the compatibility of the microdischarge operation with that of micron-sized thruster devices (microthrusters), and the ability to batch fabricate these devices in large arrays, leads the proposers to believe that microdischarges are a critical enabling technology for nanosatellite station-keeping propulsion.

Figure 5(a) shows a schematic of a microthruster concept for nanosatellite station-keeping propulsion. The microthruster comprises two relatively distinct sections, one the microdischarge itself which is located ahead of an appropriately designed nozzle. The microdischarge can use the hollow-electrode configuration or the parallel-plate configuration to heat a gas stream to combustion-like temperature of $\sim$1000 K. The hot gases are then expanded through a De Laval-type converging-diverging nozzle to the high-vacuum conditions of outer space, thereby producing thrust. The gas heating in the discharge is accomplished at an upstream location from the nozzle where the pressure can be regulated to high enough values in order to sustain the microplasma. There is little heat transfer to the chamber as the gases are expanded. The actual microthruster propulsion device might comprise an array of individual microthrusters that are monolithically fabricated on a single substrate/panel. Furthermore, each microthruster could be addressed individually to control the overall propulsive performance of the system.

FASTRAC will fabricate and fly two experimental Xenon Microdischarge Plasma Thrusters (MPTs). Each satellite will contain one MPT, although in the nominal mission design only one of the satellites uses its MPT while the other satellite acts as a control mass. Having microthrusters on both satellites provides an important mission contingency, since the satellites can switch roles on-orbit if needed. The effectiveness of the MPT will be measured using two different methods. A MEMS IMU will provide a direct measurement of non-gravity vehicle accelerations. When the MPT is off, the IMU will sense the drag acceleration. When the MPT is on, the change in the sensed acceleration will provide a measurement of the MPT performance. The second measure of the MPTs effectiveness will be through observation of the different orbit decay rates of the satellites. Coarse attitude determination will be performed using the GPS receiver. The MPT will be commanded to fire when the vehicle is favorably aligned so as to extend the life of the vehicles orbit. Over time, this will cause the thrusting satellites orbit to decay at a slower rate than the non-thrusting satellites orbit. The observed difference in decay rates, as reported in the GPS position solutions, will provide a measurement of the MPTs effectiveness. This research leverages on-going activity in low pressure plasma research at UT-Austin. The UT-Austin Co-Investigator, Dr. Laxminarayan Raja, has received a National Science Foundation CAREER award for basic research in this subject area. The FASTRAC proposal builds on the current research to incorporate this work into a nanosatellite.

Distributed Communications System

The monitoring and management of a large satellite formation can be a formidable operations challenge. Low Earth Orbiting (LEO) satellites are typically visible over individual ground stations for only a few minutes per pass with perhaps 2 passes per day. In the case of formations, the entire formation will not generally be visible from a single ground station at the same time. In this case, it is advantageous to have multiple stations available for satellite tracking and communications. This will lead to more ground contacts overall and increase the number of satellites that can be tracked simultaneously. Multiple ground stations can lead to high operations cost and complexity, however, if each tracking site has to be locally scheduled and managed. Santa Clara University (SCU) has developed a tool to address these issues, known Remote Accessible Communications Environment (RACE). RACE is a general communications tool that can support operating several tracking stations simultaneously from a single location over an internet interface.[7] The graphical user interface is windows driven and appears as a web site. Data and commands are relayed over the internet to the bi-directional tracking stations and the results are displayed to the user in near real-time (subject to internet latency). Scheduling and mission planning are also possible so that multiple projects can use the same tracking network. Unattended operation of the remote stations is also possible. Application of the RACE system to formation tracking greatly lowers costs and simplifies operations while at the same time providing greater data return. RACE has already been demonstrated using amateur radio satellites on existing tracking stations in Pearl City, Hawaii, and Santa Clara, California.[7] As part of the FASTRAC proposal, the UT-Austin Satelite Design Lab tracking station will incorporated into the network. The hardware costs are minor since the UT-Austin station already has most of the required hardware. Other universities may also join the tracking network over time, further increasing the range of the system by the time that FASTRAC flies. In a related vehicle operations concept, the FASTRAC satellites will employ a TCP/IP communications standard so that each satellite may be effectively thought of as an internet node. A web site will be established with public and private sections for the monitoring of the formation status, display of real-time data, and archival of stored data. The secure portion of the web site will also be used to command the vehicle. For example, an authorized user could "log in" to the spacecraft during a real-time link and send commands or request data downloads from the spacecraft via a GUI. Command queues will allow unattended operation. These concepts will be explored further during the first year of the FASTRAC program and a demonstration system will be developed prior to inclusion in the satellite operating system.

Science

Although the primary mission elements of FASTRAC are focused on technology demonstration, science will also be performed based on the return of data from the satellites. For example, the reported positions of the satellites and the IMU measurements will be used to make studies of the drag forces that are acting on the vehicles. Atmospheric properties can be estimated as a function of altitude by studying the orbital decay rates of the satellites. The satellite crosslink will be used as an instrument to determine the inter-vehicle communication range as a function of altitude. Since the position of each vehicle is known, the Earths magnetosphere will be measured and mapped. In a public outreach activity, schools and radio hobbyists in other parts of the world will be invited to track the satellites using amateur radio equipment. Any information that is recorded by the public and provided to the project web site will be used to improve the science return of the mission. In this manner, the public may monitor and participate in the FASTRAC mission. Prior to launch of the FASTRAC satellites, at least two American high schools will be specifically recruited and mentored by students at UT-Austin to guarantee a minimum level of public involvement in the project.

SATELLITE DESIGN

The two FASTRAC satellites are identically designed for simplicity and redundancy, even though they will perform slightly different roles on-orbit. If needed, the roles of the satellites can be switched on-orbit to account for unplanned events. The major components of the satellite design are described below in more detail.

Mass Budget

The Preliminary Mass Budget is shown in Table 1. This is the third draft of the mass budget, and will continue to change as we do further analysis and design. Currently, our budget is above the allowable margin; however, many of the estimates are considered conservative and once closely analyzed will be fitted to the constraint of 12 kg per satellite (Which totals 24 kg, leaving 1kg for the UNP-supplied Lightband.)

Sensors

GPS Receiver

The GPS receiver used for FASTRAC has already had its algorithms modified and tested for space use by students at UT-Austin. Ten of these receiver boards were recently fabricated at UT-Austin, and one of them will be used on each FASTRAC satellite. The other boards will be available as spares if replacements are needed prior to integration. The availability of these receivers which will be donated, their suitability for installation on a nanosatellite, and the fact that their design has been previously modified for space and demonstrated in simulation and on-orbit, is a key advantage to this proposal. The GPS receiver board is based on the GPS Orion receiver, which is a reference design of a terrestrial GPS receiver built around the Zarlink (formally Mitel) GP2000 chipset.[8] The original receiver provides C/A code tracking on 12 channels at the L1 frequency. The receiver main board is roughly 5 cm $\times$ 10 cm in size and requires a power of 2 W for normal operation. An additional 1 W of power is needed for 2 antennas and preamplifiers. To support user specific software adaptations for the GPS Orion receiver, the GPS Architect Development Kit was made available by Mitel Semiconductor.[9] Numerous software modifications and enhancements have already been made to the original firmware of the Orion receiver and tested on the GSSI STR 4760 simulator at UT-Austin.[10] These modifications substantially improve the on-orbit performance of the receiver and its suitability for use in a relative navigation application.[11] Raw measurement accuracies obtained in signal simulator tests are better than 1 m for C/A code pseudorange, 1 mm for L1 carrier phase, and 10 cm/s for L1 Doppler measurements in the absence of environmental error sources such as multipath.[12] While the GP2000 chipset has not specifically been designed for space applications, Surrey Satellite Technology has demonstrated a sufficient radiation tolerance to allow its use in many low Earth orbit missions.[13] The Orion receiver design itself was successfully flown on the PCsat radio amateur satellite.[14] Two patch hemispherical GPS antennas will be placed on opposite sides of the satellite to allow for reception of GPS signals regardless of vehicle attitude, which will not be controlled. The signals from the two antennas will be combined so that the GPS receiver will a signal that is visible on either antenna. Although there is not a requirement for continuous GPS position fixing, it is believed that the receiver will see the minimum 4 GPS satellites necessary to obtain a solution most of the time. The exact antenna design has not yet been chosen, but standard designs (e.g. from Micropulse) should be suitable. These designs have a footprint of about 5 cm $\times$ 5 cm on the surface of the vehicle.

Table 1 FASTRAC Mass Budget

Component	mass (kg)	volume (cm^3)	length (cm)	width (cm)	height (cm)
Structure	2.00	32000.00	20.00	40.00	40.00
Solar Cells	0.50	surface	N/A	N/A	N/A
Batteries	1.50	500.00	5.00	10.00	10.00
Voltage Regulators	0.09	250.00	5.00	5.00	10.00
CPU/C&DH	0.80	500.00	5.00	10.00	10.00
Transceiver	2.56	4014.83	17.78	17.78	12.70
RF Antennas (2)	0.50	320.00	10.00	4.00	8.00
GPS	0.30	320.00	8.00	10.00	4.00
GPS Antennas (2)	0.50	50.00	5.00	5.00	2.00
MEMS IMU	0.90	840.00	12.00	7.00	10.00
ACS (magnets)	0.20	200.00	10.00	4.00	5.00
Magnetometer	0.30	200.00	4.00	5.00	10.00
Microthruster	2.00	1.00	1.00	1.00	1.00
Tank for thruster	0.01	12.50	2.50	2.50	2.00
Wiring	0.20	0.06	0.50	0.50	0.25
Lightband (ours)	1.00	surface			
TOTAL	**13.36**	**7208.39**			
ALLOWABLE	**12.00**	**32000.00**			
Margin	**-1.36**	**24791.61**			
% Margin	**-11.29%**	**77.47%**			

Magnetometer

A simple magnetometer will be selected as an additional sensor. This will provide a separate directional measurement which may be combined with GPS measurements to coarsely determine the attitude vehicle. The magnetometer will also be used as a science instrument to make magnetic field measurements. Although a specific device has not yet been selected, government and industry partners will be sought to donate the hardware. If necessary, a simple magnetometer may be built or purchased at low cost and risk. Although desirable as a source of extra measurements, the magnetometer is not required for mission success.

Inertial Measurement Unit

A MEMS IMU demonstration is also planned for FASTRAC if possible. The MEMS IMU will either be donated or purchased. A preliminary market survey has identified a unit from Systron Donner Inertial Division, the BEI Motionpak, as a possible candidate. This IMU can resolve measurements of linear acceleration as small as +/- 10 g and has mass less than 0.9 kg. The sensors are hermetically sealed and are therefore not affected by vacuum. The main drawback of the Motionpak is its cost, which is estimated at $14,000 per unit. A more substantial market survey, along with solicitation of donated or discounted equipment, will be attempted during the first year of the program. If available, the IMU will be used to provide drag acceleration measurements and to evaluate the performance of the MPT. Since the MPTs effectiveness may also be assessed by observing the change in orbit decay, the IMU is not strictly required for mission success. A go or no-go decision will be made for the IMU at the end of the first year of the program.

Command and Data Handling/Telemetry (C&DH)

Radio Design

The radio design is composed of individual Kantronics and Hamtronics components. This design was chosen over an integrated wireless modem because the individual electrical components are simpler than an integrated modem and the overall design is cheaper. The design includes: a UHF downlink (435-438 MHz), a VHF uplink (144-146 MHz), a VHF APRS Automatic Position Reporting System beacon, and a 900 MHz crosslink for intersatellite communication (902-928 MHz). There is also a UHF receiver acting as a secondary uplink. Figure 2 shows the radio system schematic with its associated components. The primary uplink will operate at 1200 baud in order to minimize communication errors, while the telemetry downlink operates at 19,200 baud. It remains to be determined if the UHF frequency allocation will provide the necessary bandwidth for this high of a data rate. If it is determined that the bandwidth requirement cannot be satisfied, the downlink will be restricted to 9600 baud.

Data Budget

Currently, the estimated telemetry sample is 1000 bytes, as shown in Table 2 . The data sample contains processed and raw GPS data, battery/solar panel status, magnetometer measurements, command echoes, check sums, and encryption.

Data Rate and Sampling Modes

Each satellite will be sampling data and storing it in onboard memory. When the satellite is within view of an authorized ground station, it will downlink its

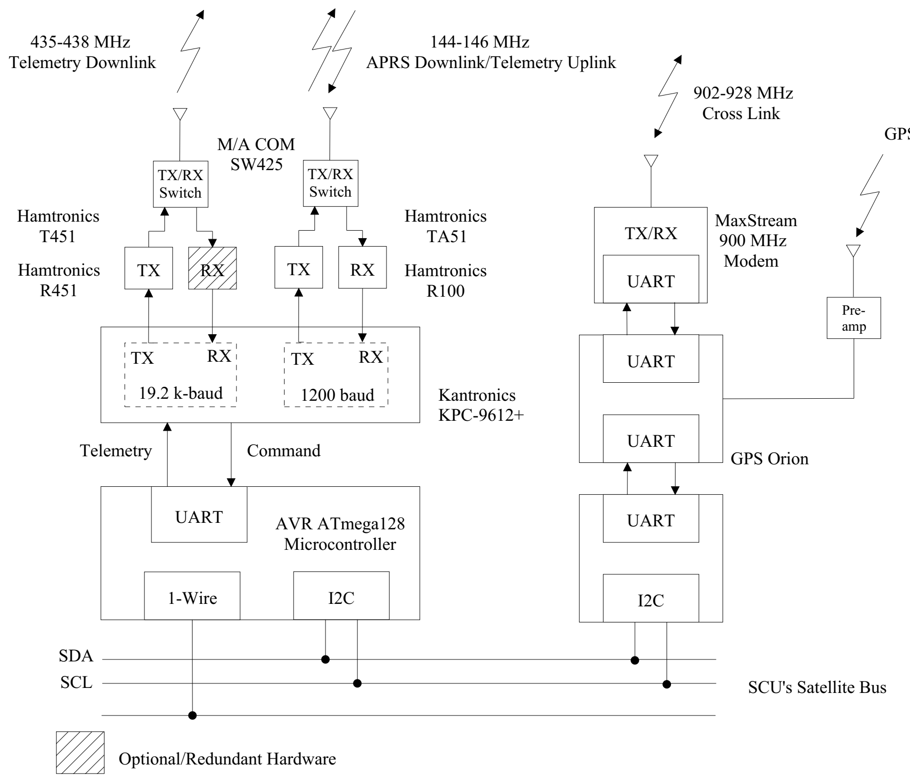


Fig. 2 FASTRAC Communications System

Table 2 FASTRAC Data Budget

GPS Measurements	600 bytes
Housekeeping Measurements	100 bytes
Magnetometer Measurements	50 bytes
Battery/Solar Panel Status	50 bytes
Command Echoes/Check Sums	50 bytes
Encryption	50 bytes
Telemetry Re-Sends (10%)	100 bytes
Total	1000 bytes

stored data upon proper request. It is planned to have two data sampling modes: high and low. The low rate mode of 1 sample per minute is the normal operating mode. During the initial separation of the satellites however, it is preferred to have more frequent data. The high rate mode will sample at 30 samples per minute, and is intended for use over short intervals. Several ground passes may be required to downlink the data sampled at this rate. The low and high rate modes will require 60 and 1800 Kbytes of data storage per hour of sampling. It has been determined that the average ground pass will last only 6 minutes. At the data rate of 19.2 kbps, this allows access to 0.864 Mbytes of data per ground pass. For this reason, there will be 15 Mbytes of onboard memory storage to allow for ∼10 hours of continuous high rate sampling during the initial separation.

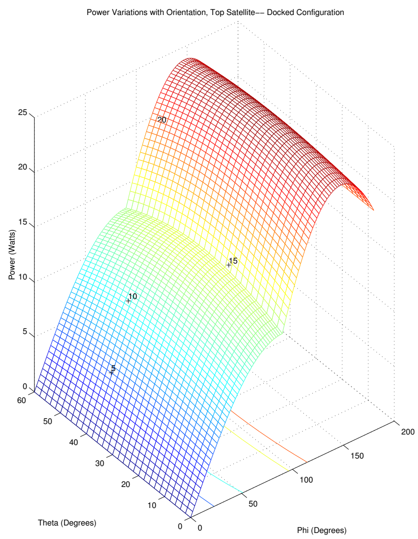
Command and Data Handling

There will be two separate buses used for data and power distribution respectively. The power bus will provide 5 and 12 volts to each subsystem. An I^2C protocol will be used for intersystem communication over a distributed data bus architecture. This will be used to control the operational mode of the satellite (automatically and manually) as well as monitor the temperature and power consumption of each subsystem.

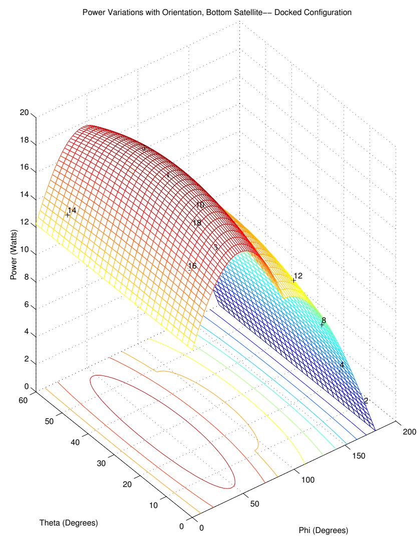
Power

The objective of the power subsystem is to supply sufficient power to subsystems to support successful completion of the mission. The power is supplied to the electrical system, which distributes the power to all other subsystems and provides all switching requirements. The power system must meet average requirements as well as all peak requirements, as well as supply a continuous, regulated power supply regardless of illumination state.

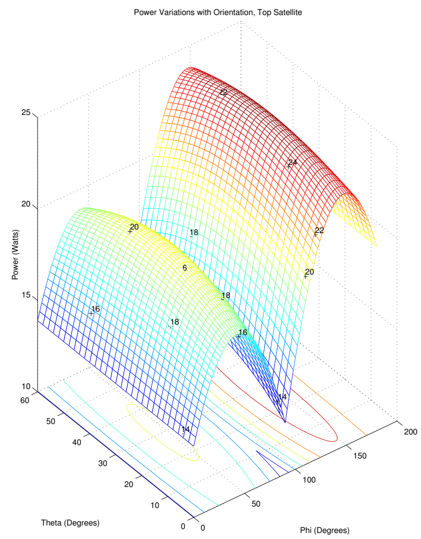
All power production will be from the spacecraft solar panels. A 5V and 12V regulated output will be supplied to the electrical subsystem. In addition, there will be sufficient power storage to enable uninterrupted operation during eclipses. The power subsystem will consist of solar arrays, batteries, voltage regulators, battery chargers, and extra circuitry.



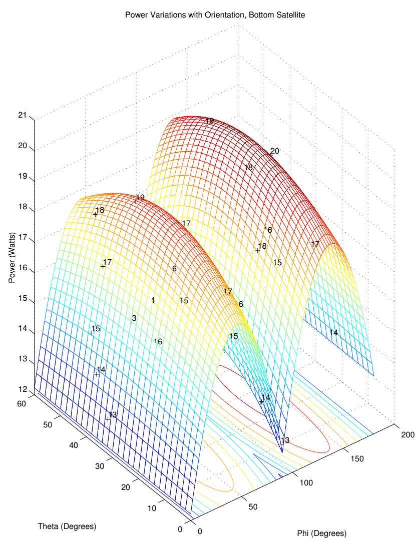
a) Top Satellite- Docked



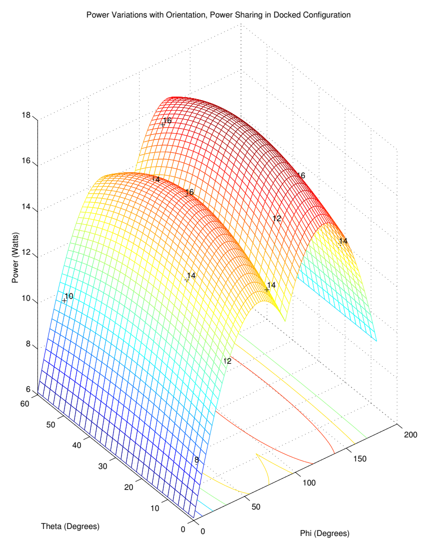
b) Bottom Satellite- Docked



c) Top Satellite- Undocked



d) Bottom Satellite- Undocked



e) Stacked Power Sharing

Fig. 3 Average Orbit Power by Satellite Orientation

Solar Array

A Power-Available analysis is an important part of solar array selection and design. For FASTRAC, a hexagonal satellite of diameter 46 cm and height 22 cm is assumed. Also, 90% cell coverage is assumed on the sides. On the bottom of the satellites, there are Keep-Out areas for the separation system and the NSS. The remaining cell coverage in these areas is 90% and 80%, respectively. Assuming a solar constant of 1353 W/m^2, this gives the Average Illuminated Power levels shown in Figure 3. Obviously, the satellite will not spend its entire time illuminated, but will spend a portion of each orbit eclipsed by the sun. Preliminary analysis of eclipse times based on the FASTRAC orbit shows an Average Eclipse Schedule of 36.2% and Maximum Eclipse Percentage of 40%. Since the satellite spends significant times near maximum eclipse, that value will be used for the normal power budget. Multiplying the illuminated power by the percentage of time illuminated yielded the eclipse results in Table 3. Note that this is the power output from the solar array, not the actual power delivered to the satellite's electrical distribution system, and any power loss in the diodes in the array was not calculated. It is also important to compare this to the estimated Power Required Budget shown in Table 4. The values show that the satellite can operate normally during a majority

Table 3 Average Illuminated Power

		Top Satellite	Bottom Satellite	Average
Undocked	No Eclipse (W)	32.64	29.37	N/A
	Avg Eclipse (W)	20.83	16.74	N/A
	Max Eclipse (W)	19.59	17.62	N/A
Docked	No Eclipse (W)	26.85	23.58	25.22
	Avg Eclipse (W)	17.13	15.04	16.09
	Max Eclipse (W)	16.11	14.15	15.13

Table 4 Power Required Budget

		Power (W)		On Orbit	Power (W)
Component	Input Voltage	Peak	Continuous	Time	Orbit avg.
CPU/C&DH	10.00	2.00	2.00	100%	2.00
Transceiver	1.50	10.77	5.89	100%	6.00
GPS	5.00	3.00	2.50	100%	2.50
MEMS IMU	25.00	3.00	3.00	100%	3.00
Magnetometer	34.00	1.00	1.00	100%	1.00
Microthruster	250.00	6.00	6.00	50%	2.00
Total	325.50	25.77	20.39		16.50

of its mission life. It is of interest to know how the power generated varies with orientation of each satellite. The orientation plots are found in Figure 3, and all power values are the orbit average values for each individual orientation. If the satellite had a particular inertial orientation for an entire orbit, this would be the average power. The plot represents this power for all orientations. Phi represents "latitude" with 0 being the "South Pole" and Theta, which is periodic in 60 degrees, represents "longitude." The bottom satellite always generates at least 12W of power when illuminated in any orientation. This worst case orientation occurs when the Nanosat Separation System (NSS) is pointed towards the Sun. In the docked configurations, both satellites have orientations in which they are eclipsed by the other and generate almost no power. Fortunately, the Lightband Separation System has the electrical connections necessary to share power between satellites. The average power produced by both satellites combined can be shared. the power each satellite receives is the average power shown in Table 3. Figure 3 shows the power each satellite will receive as a function of the orientation of the stack. Some power sharing system will be necessary, but even with the power sharing, an orientation exists in which each satellite receives only 6W of power, and this orientation must be avoided.

To select the solar array voltage, the input to the voltage regulator and battery charger must be considered. Generally a lower voltage is preferred since the solar cell strings can be made shorter, reducing the risk associated with loss of a solar cell string due to debris or other failure. For a voltage regulator requiring a nominal 12V[15] and a battery charger requiring a nominal 14.5 V,[16] a string of seven cells with diodes on the end will provides the needed voltage to the power subsystem.

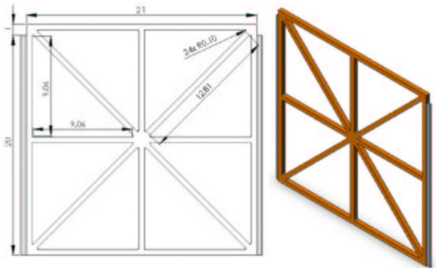
Batteries

The FASTRAC mission will use NiCd batteries for power storage. These are an excellent choice as NiCd batteries meet all the requirements of space operation, have been extensively space-qualified, and meet NASA safety requirements. NiCd batteries also have an extensive database of past performance in space, allowing more accurate estimates for sizing and lifetime. NiCd batteries have an energy density of ~25Wh/kg. Over six months of operation, the FASTRAC satellites will orbit the Earth almost 3,000 times, and the batteries experience one charge/discharge cycle per orbit. To have a 3,000 cycle lifetime, extensive experience with NiCd batteries in space states that the depth of discharge must be less than 45%.[17] The <35% depth of discharge allows a cycle life of almost 10,000 orbits, or about 20 months. This 10% margin is to allow for adjustments to depth of discharge, if the thruster runs extensively during one orbit, using power that would have charged batteries, or excessively drains batteries.

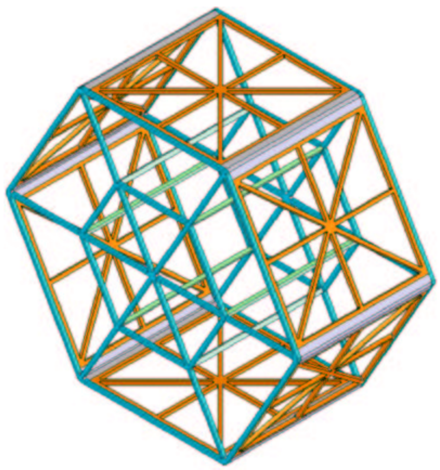
Structure

The structure subsystem houses all the major subsystems. It is designed to withstand the harsh space environment (i.e. temperature fluctuations) and the difficult launch phase (vibration and high gravity loads). Material selection is an important factor that must be considered when designing a structure for a particular satellite. The specific material must provide a stable environment for the structure and the components inside. Material selection was based on the following criterion: density, stiffness, cost, availability, workability, thermal, vacuum, fracture, fatigue, and magnetic properties. For example, temperature fluctuates dramatically in space (-160^{o}C - 180^{o}C). One side of the structure may be hot and the other side may be cold. Cold environment increases the yield strength, tensile strength and Young's Modulus of the material. The material must have low thermal expansion coefficients to avoid scenarios that affect the stability of the structure. Since the use of composite structure is discouraged low expansion coefficiency can still be achieved by selecting the appropriate material. Aluminum Alloys are non-magnetic, easy to work, have high stiffness to density ratio, high corrosion-resistance and high thermal conductivity. Therefore, the structure team chooses Aluminum 6061-T6 for the structure. The structure is a simple hexagonal isogrid with each side having a dimension of $22 \times 23 \times 0.5$ cm, as shown in Figure 4. All the panels will be attached with NASA approved fasteners and brackets. The internal subsystems would attach to vertical and horizontal bars that connect the top and bottom panels of the structure. A .067 cm aluminum skin would cover the entire structure to provide additional stiffness and to provide a place for the solar cells to attach. Currently, the mass of the entire structure is about 1.8 kg.

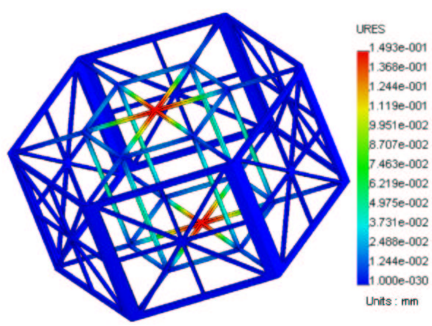
The structure was modeled using SolidWorks and initial Finite Element Analysis (FEA) was performed using COSMOSWorks. The structure withstood the 11G $\times$ 11G $\times$ 11G inertial loads; it had a minimal FOS 12 and a maximum xyz deflection of 0.149mm. Incorporation of pressure and thermal forces in the analysis is currently ongoing. A dummy satellite is currently being fabricated. The panels will be cut using a water-jet facility and the bars will be machined. Stress, vibration, and thermal tests will be conducted on the structure. All tests are scheduled to be com-



a) Side 23 by 22 cm Side Panel



b) Structure Assembly



c) Finite Element Analysis: Total Displacement

Fig. 4 FASTRAC Structure

pleted by September 2003. These tests will utilize facilities at the University of Texas at Austin such as shaker tables, tensile testers, and temperature chambers. The design will be improved after the initial phase of testing and another dummy structure will be fabricated. The testing process is repeated until the design of the structure is finalized.

Thermal Control

The thermal sub-system must help decide the location of components to guarantee that the satellites stay within thermal operational limits. Three stages guide the work in this sub-system. The first stage involves defining the critical temperatures and component properties. Concurrently, a model to determine the most efficient locations will be created in SINDA.

Table 5 Critical Temperature Levels

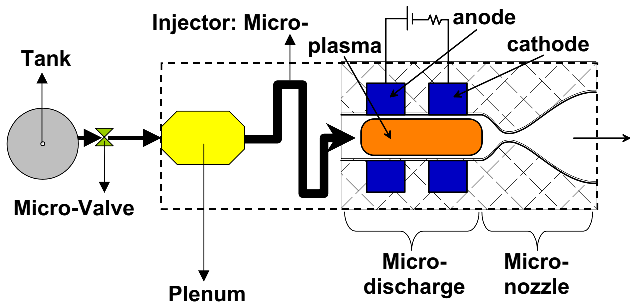
Critical Temperature	Description
Operation	the temperature range at which the unit will function successfully
Non-Operation	the range which the unit can endure while turned off and when returned to the operation temperature will function successfuly
Survival	the temperature(s) at which the unit will suffer permanent damage.
Safety	the temperature(s) at which the unit could cause damage to the orbiter or injure crewmembers

Finally, testing of the satellite will ensure the temperatures remain inside the critical regions.

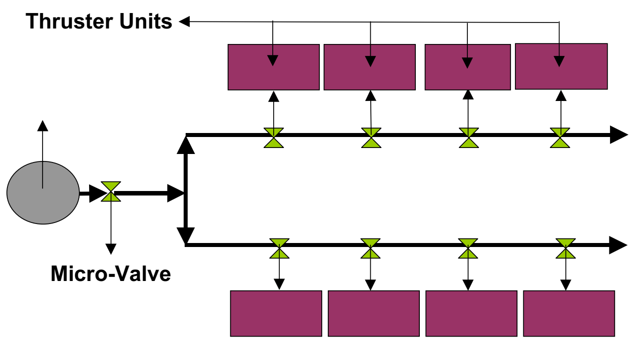
There are 4 critical temperatures which must be defined for each component as shown in Table 5. These temperatures along with the thermal properties of the components are being compiled by the other subsystems and will determine the design criterion. The anticipated range inside the satellite is around 0^{O}C-50^{O}C. The thermal properties include the emmisivity of the surfaces of the components and the thermal capacitance. These properties combined with the heat generation and physical geometry will determine the model in SINDA. The modeling process in SINDA is complex and requires a lot of education for our team. SINDA uses the conductor-capacitor network representation of thermal systems. The procedure is generally as follows: The geometry of the structure is first created in the sub-program SINDA/ATM (Advanced Thermal Modeler). Nodes are added that correspond to the different components and a mesh is made of the structure. Nodes represent either heat flux or thermal capacitance. The model is then passed to the SINDA program where transient and steady state analysis takes place. The SINDA program calls NEVADA to compute the radiation view factors and then performs the analysis needed. Once this model is run, the placement of various devices will be revised to better allow heat exchange out to space. Since the only mode of cooling is radiation to space thermal material will be used to help create channels of expulsion as well as insulation. FASTRAC has no active thermal control and relies exclusively on passive heat transfer. Multi-Layer Insulation (MLI) will be procured and used on the majority of the satellite's interior. Various optimizations will be run in the model to help re-design the locations of the sensitive components. Once a model yields results that satisfy our design criterion the satellite will be tested in a thermal vacuum. This test will be designed to measure the temperature at critical locations. Other information including thermal stresses will be measured and incorporated into the test. Final design will be determined once the tests are completed.

Propulsion

The propulsion subsystem will employ a Microdischarge Plasma Thruster (MPT). The primary purpose of the MPT will be to provide station keeping propul-



a) Individual Thruster Unit



b) Multiple Thruster Units

Fig. 5 Microdischarge Plasma Thruster

sion for UT nanosatellites. The thrust produced by this kind of propulsion system is expected to be in the range of 0.1-10μN. Several individual thruster units can be used in tandem to provide the required thrust for the nanosatellites. While a preliminary design is available, details of the thruster configuration and operational parameters are yet to be determined. The basic layout of the propulsion system is shown in Figure 5(a) and is comprised of individual thruster unit (enclosed in dashed box) connected to a pressure tank. The unit is comprised of a plenum, an injector, a discharge chamber, and a two-dimensional converging-diverging micro-nozzle. Figure 5(b) shows the configuration of the subsystem using multiple thrusters.

Structure

The estimated weight of the propellant subsystem is 2 kg, mostly due to the propellant tank and electrical components. The size of the individual thruster unit will be about 1 cm^3. The components of the propulsion subsystem will have the following function and approximate specifications. The gas tank will be used for storing the propellant and will be made of space rated aluminum alloy. The pressure inside the tank will be about 2 to 5 atm and about 1 atm inside the plenum, the injector, and the discharge chamber. The plenum will act as a reservoir for the individual thruster unit. The micro-channel, 1500 μm long, with a rectangular cross-section, 29 x 50 μm, and 90^{O} bends, will act as an injector that will supply the discharge chamber with propellant regulated for both the pressure and the mass flow rate. The injector will provide the regulated propellant flow to the discharge chamber by decoupling the pressure fluctuations, by preventing the back flow, and by reducing the propellant pressure through viscous losses. The discharge chamber will be 1000 x 200 x 200 μm. Lastly, the two-dimensional converging-diverging nozzle will have a throat area of 9000 μm^2, an exit area of 72000 μm^2, and a length of 500 μm. The nozzle will exhaust in a vacuum at a Mach number of 4.5.

Advantages and Disadvantages

The microdischarge plasma thruster offers many advantages. Once designed, MPT is expected be a simple system with high thrust density and high efficiency. In addition, a variety of propellants can be used. There are, however, some disadvantages. A pressure tank is required and a high voltage impulse of about 1000 V is initially required to initiate the microdischarge.

Propellant

Early studies suggest the following properties of the microdischarge plasma were found through tests using Helium gas. The voltage, current and pressure at which a continuous discharge was created were of the order of 200 V, 30 mA, and 0.75 atm, respectively. In order to produce a stable discharge, the electrodes were separated by a distance ranging between 10 and 100 m apart. Xenon, Helium, or a mixture of both gases are currently being considered as prospective propellant for the nanosatellites. These gases were chosen due to the fact that they are non-hazardous, non-contaminating, they offer high thrust density and the possibility of higher specific impulse on the order of 700 s. The primary gas will be Xenon, which has a molecular weight of 131.3 kg/kmol and a density of 5.84 kg/m3. As a propellant, it offers more mass for a given pressure. The propellant flow rate will be about 15 g/s in order to produce the required thrust of 10 N.

Power Supply

The design of the power supply will be a challenge mainly because of the high voltage needed to initiate the discharge. Initial plans include the use of ultra-miniature DC to High Voltage DC converters connected to capacitors and controlled by microcontrollers when the nanosatallites are in favorable attitude. Provisions will be made in order to isolate the power supply with the rest of the power supply, for example, by reset-able fuse.

Design and Test Plan

The tentative design plan until will be posted soon on the FASTRAC website. The design plan includes the initial science experiments with Helium, Xenon, and their mixture. Optimization of the thrust by minimizing current, voltage, and propellant mass flow rate requirement will be the main goal in the design of the thruster. Next, the electrical system and the microvalves will be designed and tested for space rating and leakage, respectively. Later, a MEMS device will be designed, fabricated, and then tested again for performance and structural integrity. The detailed test plan is currently in the making and will also be posted on the web page along with the design plan. Finally, the propulsion system will be assembled in the FASTRAC satellite, and launch will take place on March 1, 2006.

Cost Analysis

The total estimated cost of the MPT is $15,000. The money will be spent over a period of two years. Of the $15,000, about $6000 is for the initial science experiments (most of which is already under way) and the rest will be spent in the final design, fabrication, tests, and assembly of the MPT in the near future.

Separation System

The separation system for the FASTRAC nanosatellites will involve the use of two Planetary Systems Corporation (PSC) Lightband clamp-release separation mechanisms. The first will be used following the complex launch mode necessary for all University nanosatellites. This sequence is described in detail in the proceedings of the University Nanosatellite-3 Program kickoff meeting held on 2 February 2003. Generally, the nanosatellites are launched from the Space Shuttle Canister-for-All-Payload-Ejections (CAPE) while it is contained within the Internal Cargo Unit (ICU). Shortly thereafter, the ICU opens and releases the nanosatellites while they are in their stacked configuration using an AFRL-supplied round 15-inch PSC Lightband release mechanism. Following a two-week checkout period during which the two nanosatellites will remain attached, a second Lightband mechanism will be used to separate the two spacecraft and initiate the primary mission phase. Planetary Systems Corporation has generously committed to providing the FASTRAC team with a 15-inch hexagonal Lightband separation mechanism as shown in Figure 6 to separate the two nanosatellites for this phase of the mission. PSC will provide the necessary training in the operation of the system and will certify necessary persons from the FASTRAC team to work on the mechanism.

PSC Lightband separation mechanisms are non-pyrotechnic and low shock systems that are easily re-settable for testing. They consist of two rings connected by a leaf-groove interface held together by a Vectran retaining line. To initiate separation, the retaining line is heated to failure when 30W electrical power is applied for four seconds by two small heaters mounted on the ring that also holds four separation springs. It is important to note that separation will still occur if one heater fails to activate. Without tension in the retaining line, the leaf-groove interface disengages and the four springs impart the required delta-v to the nanosatellites. Several inhibits will be

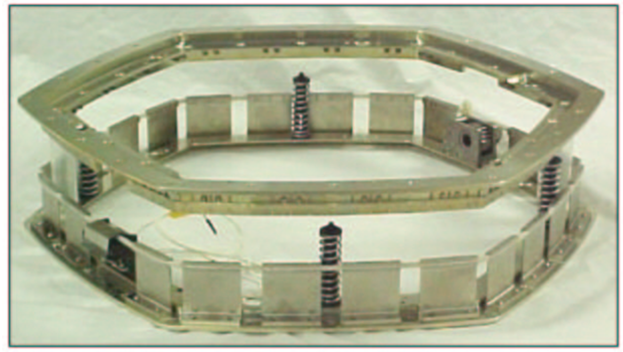


Fig. 6 Hexagonal PSC Lightband Separation System

incorporated into the design of the separation system to guarantee that premature separation cannot occur.

An aggressive series of performance tests on the separation sequence are being developed by the FASTRAC separation subsystem team and will be carried out in the spring of 2004. Many tests will be done in the UT Austin Satellite Design Laboratory, however, the separation team will be submitting a proposal in October 2004 to the NASA Johnson Space Center requesting approval to test the Lightband system on the KC-135 Microgravity research aircraft in March 2004. These tests will be done to examine the separation velocity and tip-off rates of the nanosatellites in deployment. This performance must be well understood to ensure that the nanosatellites will remain in the required range for crosslink and to provide accurate a priori knowledge for relative navigation.

Software

Operational modes will be developed for every possible phase of the mission. These different modes will be designed to ensure the safest, fail-proof operation of the satellites. The modes designed for the satellites are the following:

- Launch Mode
- Automatic Satellite Self-Verification Mode
- Stacked Mode
- Separation Mode
- Thrust Firing Mode
- Normal mode
- Variable Power Crosslink Mode
- Safe Mode

During almost all modes of operation, the communication subsystem will be powered in order to maintain communication with the ground in case of a satellite malfunction. Once the satellites have been attached to the launch vehicle, the satellites will hibernate in

Launch Mode. NASA requirements prevent the satellites from using any power during the launch of the satellites. Because of this requirement no subsystems will be powered up until the connection between the lower satellite and the launch vehicle has been severed. After the connection has been severed, the satellites will initiate the Automatic Satellite Self-Verification Mode. The purpose of this mode is for the satellites to verify startup and begin checking each subsystem to verify that no damage was incurred during launch. During this mode, the satellites will initiate communication with the ground and satellite power will be delivered by the solar cells. After the satellites have verified proper startup and experiment initiation from the ground, the Stacked Mode begins. The ADCS will begin attitude determination for both satellites and the relative navigation experiment will begin. After several orbital periods, the satellites will initiate the Separation Mode. The lightband connecting the two satellites will begin to sever causing the two satellites to disconnect and begin tumbling independent of each other. A Thrust Firing Operational Mode will be used to manage the large power consumption required by the propulsion system. All nonessential subsystems will be turned off to conserve power. After separation, the thrusting satellite will alternate between Normal Mode and Thrusting Mode. During the Normal Mode, the relative navigation experiment will be operating along with the ADCS. Data and telemetry will be transmitted to the ground during this mode. Another operational mode that will be employed during the initial phase of the mission is the Variable Power Crosslink Mode. If necessary, all nonessential systems will be shut down except for the relative navigation system. The available power going to the crosslink will be increased or decreased as a function of the distance between the two satellites. This mode is important because the relative amount of time that the two satellites are within range of the crosslinks is small compared with the life of the mission. A worst case Safe Mode will be developed in case of a malfunction within the satellites. All nonessential systems will be shut down and the power subsystem will be charging the batteries. A ground station command or an automatic timer will reset and restart the satellite back to Normal operation.

Currently, the flight software is in the early stages of development. However, a development plan has been defined. One or two individuals will be designated to develop coding for the subsystems based on that subsystem's requirements. After the individual subsystem programs have been compiled and tested, they will be integrated into a prototype data bus. As errors are found and the programs become updated, revision control software will be utilized to create a history of the software development. A National Instruments emulator will be utilized to simulate microcontrollers within the laboratory. In addition, all intersystem communication tests will be conducted in the SDL.

Attitude Determination

The GPS receiver signal to noise ratio measurements will be used for coarse pointing information. This technique, which has been developed and demonstrated at UT-Austin, can be used to determine the antennas direction to within approximately 15 degrees.[18] FASTRACs only on-board attitude determination requirement is to know when the MPT is favorably aligned for thrusting to extend the orbit lifetime. 15 degrees of direction knowledge is considered sufficient for this requirement. In post-processing, the magnetometer and GPS receiver measurements may be combined to determine three-axis attitude to within a few degrees.[19] It is anticipated that this technique will be employed to enhance science data return and improve situational awareness.

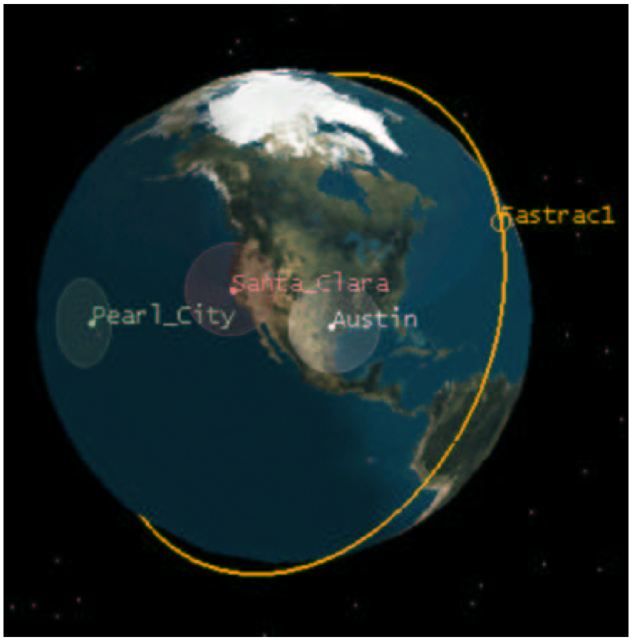
MISSION SUPPORT

Orbit Analysis

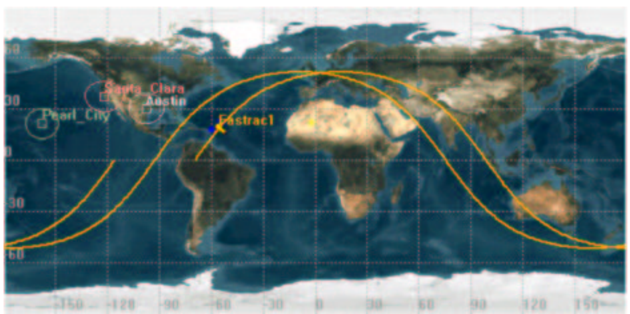
In order to provide accurate space environment conditions for the FASTRAC design team, satellite orbit analysis, and access visualization, a simulation of the mission was built using Satellite Tool Kit (STK). STK is a commercial, off the shelf, product created by Analytical Graphics. Sample orbit plots are shown in Figure 7.

The FASTRAC orbit was modeled using both a two-body and high precision orbit propagator. An arbitrary circular orbit of 350 km altitude, inclined 51.6, was chosen for the simulation because of it's similarity to a typical Space Shuttle orbit. STK's high precision orbit propagator uses lunar and Earth oblateness effects as well as atmosphere, gravity, and solar flux models to accurately depict orbit decay. The two-body model does not incorporate any drag effects, allowing the satellite to remain in orbit indefinitely. The two-body model was used to observe trends, such as eclipse times, for a given orbit over an arbitrary length of time. The high precision model was used to analyze environmental effects on the spacecraft during the mission life, and even the mission lifetime itself.

The mission lifetime was determined using the high precision model and STK lifetime determination tools. The lifetime was determined to be approximately 100 days; variations depend on the solar flux and atmospheric density conditions. This lifetime value was determined using no thrust contributions from the vehicle. The mission lifetime is projected to increase with the use of the micodischarge plasma thruster. Future work in this area includes generating an orbit model that includes the thrust contribution of the vehicle. This new model should show the expected benefit of the thruster through improved mission lifetime results.



a) FASTRAC 3-Dimensional Orbit Track



b) FASTRAC Groundtrack

Fig. 7 FASTRAC Orbit

The high precision model was also used in analyzing the drag on the vehicle. This analysis is ongoing, and includes the use of atmospheric and solar pressure drag in determining a total drag value over the lifetime of the orbit. The drag magnitude is used in determining the size of thrust that is needed to produce noticeable improvement in mission lifetime. The drag analysis will be completed using minimum, maximum, and mean solar flux variations, and a Harris-Priester atmosphere model.

Both the high precision and two-body orbit models were used to determine groundstation access opportunities. Access to the satellite was determined for the University of Texas (UT) groundstation, as well as the entire UT-Santa Clara University network. These results will be used to schedule groundstation usage for data retrieval.

Ground Station

The ground station is being configured to serve both the specific task of supporting the FASTRAC mission and more generally to allow communication with a wide range of amateur radio and research satellites. Design and construction of the ground station is currently under way atop W.R.Woolrich Laboratories located at The University of Texas Austin campus.

The equipment used directly to support the FASTRAC mission will include V-band (144-146 MHz) and U-band (435-438 MHz) transmit and receive hardware for the primary command and data handling functions and additionally 902-928 MHz receive-only hardware for reception and analysis of the crosslink signal. Antenna positioning hardware and software along with Doppler correction software will also be needed.

The V-band equipment will consist of a 12.25dB gain, circularly polarized Yagi antenna connected directly to a low noise-figure pre-amp mounted at the antenna. The signal will then be fed to an Icom IC910H transceiver connected to a Kantronics KPC-9612 packet communicator. Appropriate transmit/receive switches and filters will be used to protect the system from damage. The Icom radio will be computer controlled to facilitate Doppler correction. The U-band equipment is similar to the V-band equipment. A 16.8dB circularly polarized Yagi antenna will be used in conjunction with the appropriate pre-amp and associated hardware.

Both antennas will be mounted on a fiberglass crossboom connected to a Yaesu G-5500 computer controlled antenna positioner. Position track files will be generated and sent to the positioner using STK software.

The 902-928 MHz receive-only hardware will consist of a 47-element loop Yagi antenna with gain of 20dB. An antenna mounted pre-amp and down-converter will transfer the signal to a receiver where the crosslink can be monitored. An available 3-meter parabolic dish antenna may be employed for this task if the gain proves to be sufficient. An appropriate antenna positioner will be required.

Currently it is planned to make the ground station compatible with the Remote Accessible Communications Environment (RACE) ground station network pioneered by Santa Clara University. This will allow the ground station to be operated remotely via the Internet. Scheduling and control will be achieved using Labview software created by Santa Clara University. Being a member of the RACE network will permit additional access to the FASTRAC satellites by using the ground stations in Santa Clara California and in Pearl City Hawaii. Prior to the launch of FASTRAC the ground station will be thoroughly tested by communicating with a multitude of satellites. Experience will be gained and signal strengths will be analyzed and compared to similar ground stations. This process will be used to bound the station's capabilities allowing for an accurate link budget to be calculated.

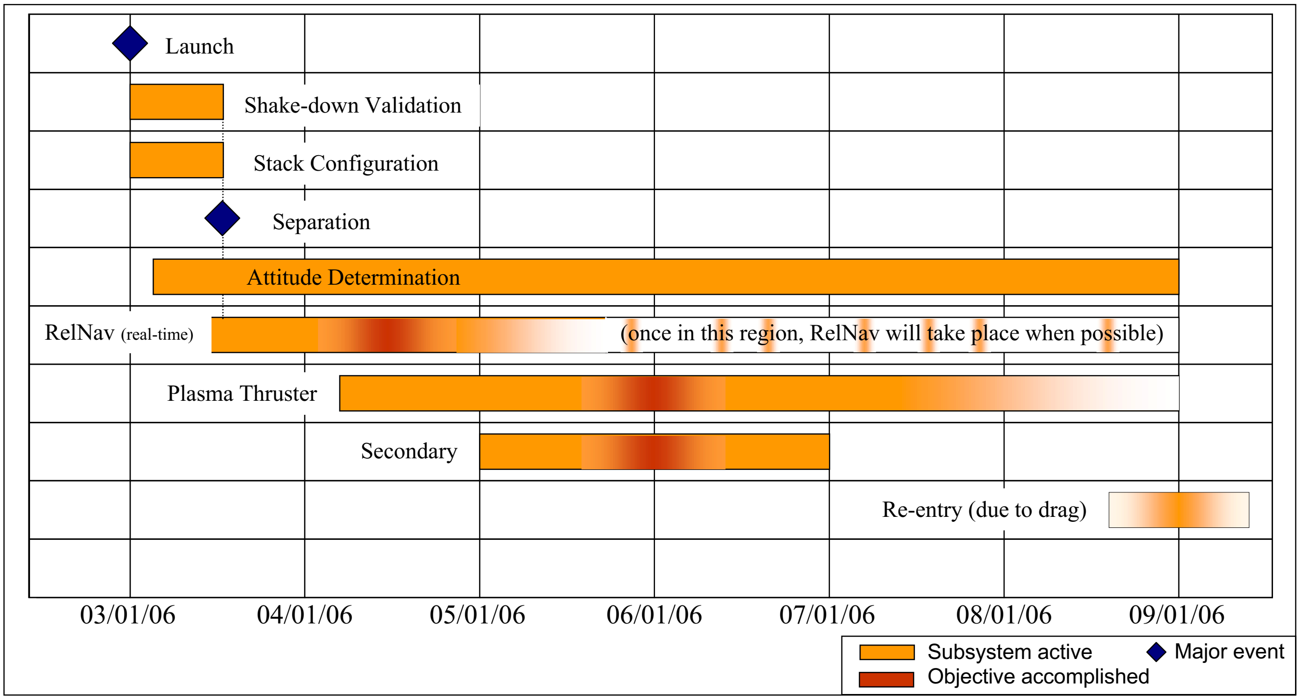


Fig. 8 FASTRAC Mission Timeline

Safety

Standard mechanical and electrical safety procedures will be observed when working with satellite hardware. On-orbit, the main safety considerations are the NiCd batteries and the Xenon pressure vessels. The NiCd batteries being considered have been previously approved for Space Shuttle flights. It is anticipated that the Xenon pressure vessel can be approved with appropriate NASA certifications. The tank volume is small (10 cm^3) and the pressure level is relatively low (5 atmospheres). The project team will contact safety engineers at NASA to ensure that all proper certifications are obtained.

SCHEDULE AND BUDGET

FASTRAC is a two year (24 month) program to design, fabricate, integrate, and test two flight-ready nanosatellites. The second year is listed as an option, but it is needed to finish the program. The first six months of the first year will consist of a detailed satellite design, review, and preliminary parts selection. UT-Austin will employ its consulting arrangement with SCU to receive advice on successful nanosatellite design practices and suggested parts selection. After a design review, the second six months will be used to finish parts selection, close action items, and purchase components for the first nanosatellite. The cost for FASTRAC-1 (satellite number 1) is therefore encumbered in the first year. All final go/no-go decisions for sensors and subsystems (for example, the MEMS IMU) will be made by the end of the first year. The first six months of year two will consist of integration and testing of FASTRAC-1 and purchase of components for FASTRAC-2. The costs for FASTRAC-2 are therefore encumbered in the second year. The second six months of year two will be used to integrate and test FASTRAC-2 and resolve any known problems with FASTRAC-1. A flight readiness review will be held at the conclusion of the second year with members of the University Nanosat Program from AFRL and/or NASA invited to participate. FASTRAC program expenses are broken down by year in the following categories: (1) management oversight and overhead, (2) travel, and (3) fabrication and testing. The majority of expenses occur in the fabrication and testing category by design. In all cases, donated and/or discounted hardware will be sought whenever possible. The C&DH subsystem is delivered by SCU as part of their subcontract to UT-Austin, and the GPS subsystem is donated by UT-Austin. These subsystems are not included in the fabrication cost. Costs may be shifted between categories as appropriate. If it is not possible to obtain a suitable sensor with the funds available, it will be eliminated from the budget and the funds will be reprogrammed into other categories as appropriate. The fabrication costs include testing and incidental expenses. When possible, existing equipment will be used rather than purchasing test equipment specifically for this program. The existing labs contain most of the necessary equipment for testing and other equipment can be borrowed if needed.

MISSION TIMELINE

For the FASTRAC Mission, a timeline of the mission is important in visualizing the duration of the mission, and mapping out the lifetime of each subsystem onboard, as well as understanding a reasonable range of time for each of the mission objectives to be accomplished. Attached below is the mission timeline for FASTRAC once the mission has been certified and prepared for launch. The launch date is known as being March of 2006, and has been chosen on the timeline arbitrarily as March 1, 2006. Our team was advised based on previous Nanosat missions to successfully achieve our mission goals within a time span of three months after launch. After analysis, our team concluded a lifetime of six months based on drag calculations. Therefore, we will accomplish our goals in the three months as recommended, but anticipate additional time afterward to further collect and analyze data. Since one of our mission objectives is to prolong the lifespan of the satellite, an aspect of determining success will be in defying the three month supposed limitation.

As can been seen in the timeline below, the RelNav will be turned on throughout the duration of the mission. However, since the satellites will drift apart relatively early after separation, RelNav will only be applicable when the satellites come back in range (based on Crosslink range of 45 km). In addition, the Micro-Plasma Thruster will be fired until no more fuel is available.

FACILITIES

FASTRAC draws upon the resources of a major research university (UT-Austin) and a university with experience in small satellite and mechatronics fabrication (SCU). Each of these organizations contributes state of the art facilities and expertise to the program.

UT-Austin Satellite Design Lab

The design, fabrication, and testing of the FASTRAC satellites will take place in the Satellite Design Lab (SDL) at UT-Austin. The UT SDL was created in 2001 to provide hands-on fabrication and test experience for undergraduates and graduates in aerospace engineering. The lab emphasizes cross-disciplinary projects with a high diversity in subject matter (aero, electrical, mechanical, etc.) and student seniority (graduate, high seniority undergraduate, and low seniority undergraduate). The lab received an industry grant and successfully designed, built, and launched a sounding rocket payload in 2002. The UT SDL contains 2 marble tables for satellite integration and 4 electronics bench areas for component fabrication and testing. All tables and floor tiles are electrically grounded, and electrostatic discharge (ESD) procedures are followed when working with flight hardware. A satellite tracking station, including a 3 m S-band dish antenna, is currently being installed.

UT-Austin GPS Lab

UT-Austin has a world-class GPS lab for testing spaceborne GPS receivers. The lab contains a GPS Formation Flying Testbed, which allows multiple vehicles to be simulated with real-time GPS hardware-in-the-loop closed-loop formation testing.[3] Additional resources include more than 20 GPS receivers, including 10 recently fabricated flight-ready GPS Orion receiver boards. At least two of these boards will be donated to the FASTRAC project. The availability of the GPS lab will ensure a low-risk delivery of the GPS receiver to the FASTRAC project.

UT-Austin Plasma Research Lab

UT-Austin has a Plasma Research Lab located in the same building as the Satellite Design Lab. The Plasma Research Lab was set up under a recent NSF CAREER award by Dr. L. L. Raja to perform basic research on low pressure plasmas. The lab already contains equipment to test microdischarge plasma propulsion nozzles, including a small vacuum chamber. It is anticipated that the final combustion chamber and nozzle design will be contracted out to a local mechanical fabrication facility and this cost has been incorporated into the MPT budget.

Santa Clara University Robotic Systems Lab

SCUs RSL conducts an aggressive, integrative research and education program in intelligent robotic systems. Initiated in 1998, the centerpiece of this program is a set of yearly undergraduate design projects in which teams of senior students completely design, fabricate, test, operate, and manage high-quality robotic systems for performing a variety of scientific investigations. Past and ongoing projects include spacecraft, underwater vehicles, terrestrial rovers, airships, telescopes, and industrial robots. For FASTRAC, the RSL will be subcontracted to deliver the CPU/C&DH subsystem. FASTRAC benefits from the experience that the RSL has obtained in developing a similar distributed communications system for the Emerald project. The RSL will also provide the resources of the Satellite Tracking Network with ground stations in Hawaii and California as well as Austin, Texas. Additionally, the RSL has agreed to provide valuable experience gained in previous University Nanosat projects to UT-Austin. The RSL will offer consulting advice on design, hardware, parts selection, integration, and testing. This will enable the UT-Austin team to benefit from the lessons learned by the RSL in previous efforts.

PARTICIPATION

Student Participation

The education of new engineers is one of the most important goals of the University Nanosat program. Student participation provides the manpower that enables the FASTRAC mission to be completed under the proposed budget in two years. At UT-Austin, two senior project and hardware design courses were used in 2002 by the Satellite Design Lab to guide a team of 8 undergraduates to successfully design, build, and launch a sounding rocket payload. A similar mechanism will be employed for FASTRAC, with students being asked up front to commit to a two year work plan. Design team members will be solicited based on academic performance, expertise, and seniority diversity, ranging from sophomores to (potentially) graduate students. A selection process will be used where students may apply for FASTRAC by submitting applications with resumes and references. The students will not be paid but will instead receive design course credit for their time. This approach enables the majority of the budget to be used for satellite fabrication and testing costs. Based on the comments of current students, there should be many outstanding students who will volunteer their time for the opportunity to work on a real flight program.

Outreach

FASTRAC provides opportunities to increase public awareness and participation in space flight research, and to encourage individuals to pursue careers in science and engineering. The Texas Space Grant Consortium will be asked to help promote awareness of the FASTRAC program. The FASTRAC satellite signal is designed so that anyone with access to amateur radio equipment will be able to receive the signal and relay the data they record to the project web site. Because of the internet-enabled communications system, a satellite web page will be available for the public to use to display live or the most recent data coming from the satellites. In addition to the general promotion of the FASTRAC program through press releases and a project web site, at least two high schools will be selected to participate in the program. These schools will receive mentoring from university students to assist them in receiving signals from the satellites and to encourage their participation in amateur radio.

Throughout the next two years, the members of the FASTRAC team will be engaging in several forms of outreach activities. The primary avenue of outreach will be through presentations that the team will give to primary, middle, and high school students from the Austin Independent School District. The Aerospace Engineering Department has participated in many successful presentations to various audiences in the past several years including heavy participation in the annual EXPLORE UT event that consistently hosts thousands of visitors from several counties surrounding Austin. Our team has also developed a relationship with the UT Austin College of Engineering Women in Engineering Program (WEP) that organizes outreach programs meant to introduce engineering and the sciences to visiting students from all over Texas. In addition to WEP, FASTRAC will also be organizing several tours and presentations with the Texas Space Grant Consortium that will be focused on middle and high school students. Finally, FASTRAC is also involved with the Student Engineers Educating Kids (SEEK) program in the College of Engineering that organizes tour groups and mentoring between engineering teams and students from local middle schools. This program is very comprehensive and is a wonderful way to educate children in the sciences.

In addition to presentations and tours, the FASTRAC team will be featured in several publications around the University and Austin-area communities. The team will be featured in departmental and college-wide newsletters as well as the University newspaper, the Daily Texan, reaching over fifty thousand students, faculty, and staff. Lastly, the team will maintain an interactive and detailed team website that will track the team's progress, post pictures, and video files, and include data from the spacecraft after launch.

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