SWALES
AEROSPACE

Final Report
Nanosat
Dispenser Ship Performance Feasibility

SAI-RPT-284

May 28 1999

Table of Contents

1.0 Reference Documents:

This document draws heavily on the documents listed below. To fully understand the results and conclusions given in this final report, it is strongly recommended that these documents be used as reference material.

Title	Organization/Author	Date
Nanosat Magnetospheric Constellation Mission	GSFC P Panetta	11/06/98
Nanosat Magnetospheric Constellation Mission Orbit Profiles SAI-RPT 265	Swales Aerospace R McGeehan	2/22/99
Magnetospheric Constellation Mission Document	GSFC A Lieberman	3/30/99
Nanosat Deployment Mechanism Conceptual Design SAI-TM-1449	Swales Aerospace J Young; D McBirney	5/13/99
Perigee Burn Performance Due to Thruster Misalignment	GSFC D Mangus	4/7/98
Memo: Nanosat Apogee Altitude Errors	From R Mc Geehan (Swales Aerospace to Peter Rossoni GSFC)	4/14/99

2.0 Introduction

2.1 Scope

This study was undertaken to validate the assumptions used in the "Nanaosat Magnetospheric Constellation Orbit Profiles" SAI-RPT 265. The objective of the SAI-RPT 265 was to maximize the number of the Nanosats that could be placed in elliptical orbits around the Earth, using a Delta 7925-9.5 and the Dispenser Ship described herein. All of the Nanosat were to have a perigee of 3 Earth Radii (ER), however, their apogees were to be separated by 2 ER. The lowest apogee was to be 12 ER and the highest 60 ER.
The assumptions made for the Dispenser Ship were:
The mass of the structure was 15% of the payload
The inert mass of the bi-prop was 30% of the mass of fuel plus oxidizer
The mass of the avionics would be equal to or less than 90 Kg.

2.2 Methodology for Performing the Task

The method for validating these assumptions was to:

1. Formulate a systems architecture for the Dispenser Ship
2. Make an estimate of the mass and power required by each of the following subsystems:
   ACS
   Propulsion
   C&DH
   Power

Structures and Mechanisms
Communications
Thermal
Harness

3. Allowing margins of 30% allocate the mass and power to each of the subsystem, ask the subsystem lead engineers to do a detailed design.
4. After receiving inputs from the leads the subsystems were documented
5. Finally the mass budgets were compared to the assumptions

2.3 Dispenser Ship Requirements:

Attitude Control System Requirements:

1. After release from the Delta 7925, lower the initial spin rate from approximately 70 RPM, to the required spin rate of at least 20 RPM
   Possible implementation
   Use Yo-Yo
   Use Reaction Control System

2. Control the spin axis to be perpendicular to the Sun during the non-deployment phase of the mission. Attitude control requirement ±10° to sun (normal to the spin axis) Nutation control ±1° TBD.

3. To raise the Dispenser Ship's perigee and change the orbit inclination, the spin vector of the Dispenser Ship must be properly aligned to the velocity vector at apogee. The mission time line assumes two apogee burns. Thrust vector attitude Accuracy (knowledge and control) ±1°.

4. Align the attached Nano-Sat thrust vector attitude to the orbital velocity vector in preparation for release and ΔV burn, by controlling the attitude of the Dispenser Ship. See SAI-RPT-265 for requirements..

5. The ACS system will consume less than 9.9Watts Orbital Average and its mass shall be less than 6Kg.

Command & Data Handling:

1. Perform T&C function for Dispenser Ship.

2. Housekeeping data rate 2 kb/s (TBD)

3. Store housekeeping data for Two orbits, each orbit is close to 2.25 days. (350E^6 bits)

4. Perform onboard processing by, issuing stored and real time commands, process ACS sensor data and calculate actuator commands, update S/C ephemeris, perform health and safety checks and process telemetry.

5. The C&DH system will interface with the communications system

6. The C&DH subsystem will consume less than 11 watts and its mass shall be less than 13Kg.

Communication Subsystem:

1. Receive and transmit X band data using the ground systems baselined for the Nano-Sats spacecraft.

2. Down link shall support the down loading two days of housekeeping data in a single pass.

3. The system shall consume less than 11.2 watts and have a mass of less than 12 Kg.

Power System:

1. The system voltage will be 28±7 VDC

2. During the sunlit portion, the power subsystem shall supply 100 watts orbital average power to the Dispenser Ship and sufficient energy to charge the battery.

3. The peak power is estimated as 200 watts (TBD).

4. During the occult, of as long as 40 minutes, the power subsystem will deliver 100 watts orbital average.

5. The power system's mass will be less than 2.3Kg (excluding the solar array) and consume no more than 2.5 watts orbital average.

Solar Array:

1. The solar array will be sized to accommodate the power requirements of the Dispenser Ship.

2. The array will be fixed and its mass shall be less than 4 Kg.

Propulsion System:

1. The specific impulse of the propulsion system shall be greater than 310 #sec/#.

2. The system shall supply the momentum needed to raise the apogee of the Dispenser Ship from 185 Km to 3 Er as well as provide for thrusters to control the attitude of the Dispenser Ship. It has been estimated 7,000 #sec of impulse will be required for attitude control and 143,220 #sec are needed for raising perigee and making the required orbital plane change. See SAI-RPT-265

3. The system shall consume no more than 2 watts peak orbital average and have a wet mass of less than 252 Kg.

Thermal System:

1. The components of the Dispenser Ship will be maintained in a temperature range 0 to 50 degrees C.

2. The maximum sun occultation time will be 40 minutes.

Structure:

1. The structure shall house (See "Nano-Sat Deployer" spread sheet):
   92 Nano-Sats
   Release Mechanisms
   Avionics
   Power subsystem and solar array
   ACS components
   Propulsion tanks and thrusters, valves and plumbing
   Harness, Heaters and Blankets

2. The mass of the primary and secondary structure's shall be less than 161Kg.

3. The structure will comply with the Delta launch vehicle environmental requirements.

Mechanisms:

1. The mechanisms shall release the Nano-Sats from the Dispenser Ship without transferring angular momentum from the Nano-sats to the Dispenser Ship.

2. There shall be no physical interference during the release.

3.The mechanism shall be capable of releasing a cluster of Nano-Sat at a time. The number in the cluster shall not to exceed 14.

4.During the release of each cluster of Nano-Sats, the time of release of any Nano-Sat shall differ from the time of release of any other Nano-Sat by no more than 0.1 seconds (TBD).

5.The NanoSat will be released in a manner which will not affect the position of the principle axis of the Dispenser Ship.

6.The total mass of all the Nano-Sat release mechanisms shall not exceed 16 Kg. and consume no more than 1 watt orbital average. The maximum power shall be less than 10 watts.(TBD).

3.0 Mission Description

3.1 Orbital Maneuvers of the Dispenser Ship

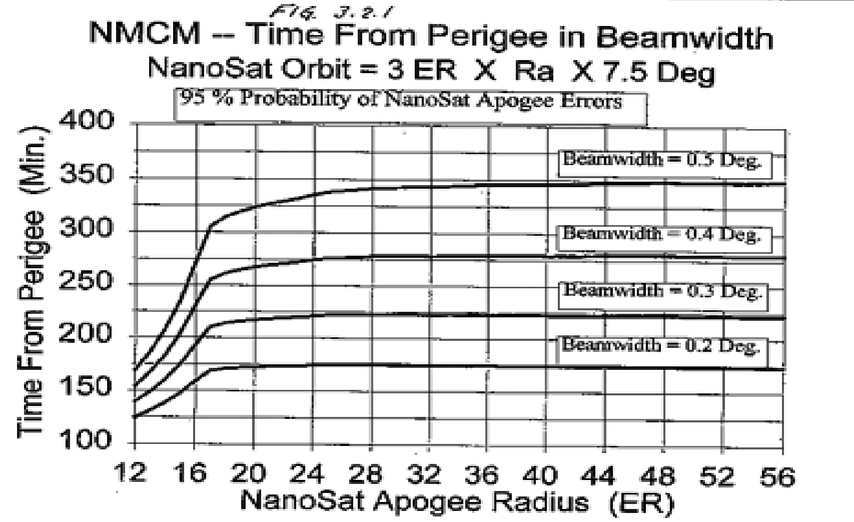
Six methods for placing the Nanosats in orbit were studied in the SAI-RPT-265.For a description of each of the 6 strategies see page 8 of the SAI-RPT-265. Of the strategies studied only II and IV were nonviable. The three most favorable strategies were, I, VI, and VII. Strategy VI was dismissed since it required the Nanosat engines, currently baselined as solid motors, to have a restart capability. Strategy I was selected since it was the least complicated and minimized the Nanosat propellant mass requirements.

For strategy I, the Delta places the Dispenser Ship (D.S.) in an elliptical orbit whose parameters are perigee 185 Km, apogee 20 ER with inclination of 28.7°. The D.S. performs an apogee burn and raises the perigee to 1000 Km and makes a small change in the inclination. A second apogee burn raises the perigee to 3 ER and removes 21.2° of inclination. The parking orbit of the D.S. is 3ER perigee, 20 ER apogee, 7.5° inclination with the line of apses lies in the ecliptic. From the parking orbit the several Nanosats are released with their spin axes aligned to the D.S perigee velocity vector. The Nanosat kick motors are ignited at perigee. Some Nanosats will raise their apogees and others will fire in retrograde direction to lower their perigees.

3.2 Nanosat Orbital Maneuvers and Mission Operations

Four Nanosat release mechanisms have been proposed. The kinematics of release have been simulated and it was found that all four will provide for a non-interference separation of the Nanosat from the D.S. They all have a common operational interface i.e. the requirement for a discrete electrical command which will cause the force holding the Nanosat to the D.S. to cease to exist in a short period of time, approximately 1 msec. The command will be given simultaneously to up to 14 Nanosats. When released the rotating Nanosat will “fly” tangentially away from the D.S. The angular rate will be approximately the same as that of the D.S. The command receivers of the separated units will be turned on, however, only one will have its transmitter on. After the Nanosat’s (the one with the active Xmitter) kick motor has fired, the ground station, using the nominal burn trajectory for a reference orbit, will point its antenna at the Nanosat. The doppler shift of the transmitted signal will be used to determine the Nanosat orbital velocity and by analysis the ground station will be able to determine the Nanaosat's orbit. Errors introduced by non-ideal attitude control of the Nanosats, Delta V errors caused by uncertainties in solid fuel performance and Delta insertion errors will modify the Nanosat orbit from the nominal. A study performed by R McGeehan has determined that with a 95% probability, using a _° beam width, all of the released Nanosats can be found with open loop pointing. See Figure 3.2.1 attached for the allowable time vs apogee altitude.. From the figure it can be seen that, to guaranty to a 95% probability of finding a Nanosat using open loop tracking, the maximum allotted time, between the firing of the kick motor and the antenna pointing, is dependent upon the new apogee of the Nanosat. For those going to a higher apogee the elapsed time can be as long as 325 minutes, for those going to 12 ER the elapsed time is 175 minutes (appx. 3 hrs). When the Nanosats are dispensed, they will be selected such that no two satellites will be transferred into an orbit with same apogee. This requirement will assure 1) the ground station has adequate time to track the Nanosats and 2) the true anomaly of satellites in the same orbit will be different. If 10 Nanosats are dispensed at 2 ER separation no more than 4 will be in an orbit whose apogee is less than 20 ER. Thus the ground station will be able to get the 30 minutes of tracking per Nanosat needed to get "good" data for each of the 4 "lower" apogee Nanosats before they leave the _° search field. The Ground station can then turn it attention to the remaining 6 Nanosats destined for the higher apogees. Approximately 200 (325-120) minutes (33minutes per satellite) are available to track the remaining 6.

FIG. 3.2.1



4.0 Dispenser Ship Architecture

4.1 Block Diagram

Figure 4.1.1 is a diagram of the D.S. architecture. Each of the of the subsystems will be described in detail in the sections that follow.

The heart of the system is the Command and Data Handling System. The X band receiver, located in the Communications Subsystem receives the ground commands. They are decoded and stored in the C&DH as relative or absolute time commands. The ACS sensors send attitude signals to the C&DH, where they are processed to determine the actuator commands (5 thrusters) that are needed to maintain attitude control or to maneuver the D.S. to a new attitude. The C&DH issues release commands to the Nanosats via the Arm and Fire relays. The C&DH also send commands to the main thruster during each of the two orbit change maneuvers. Finally, the C&DH processes and formats, housekeeping, status, and health and safety telemetry for transmission to the ground.

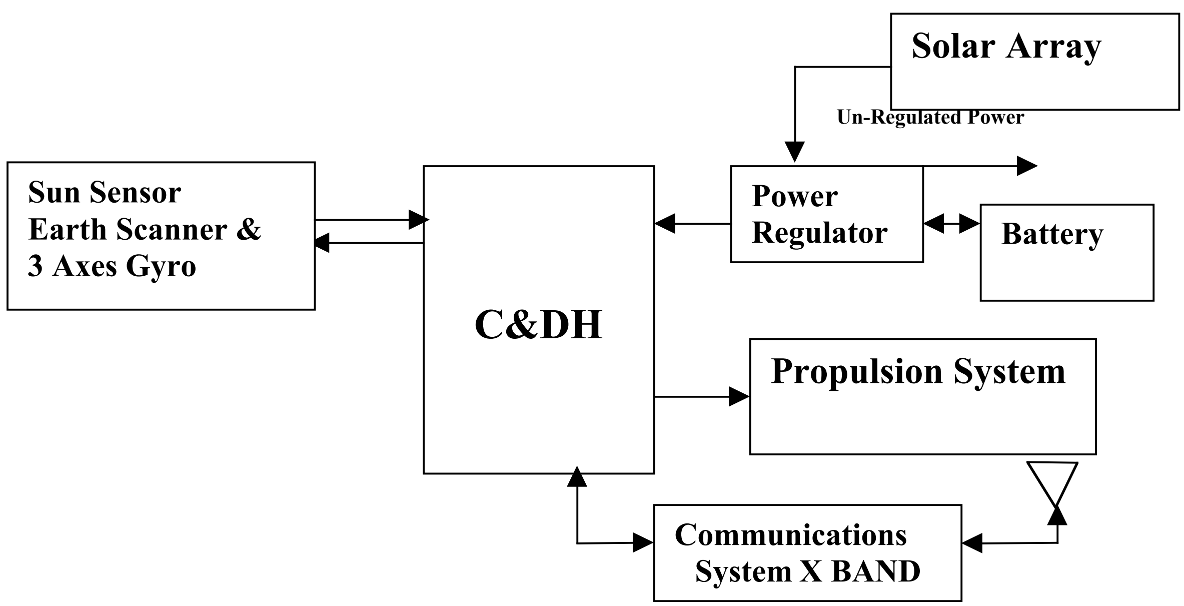


Figure 4.1.1

4.3 Mass and Power Spreadsheet

Table 4.3-1 is a mass and power spreadsheet used by systems engineering to make a first cut allocation for the mass and power to the subsystems. The entry at the bottom of the spreadsheet shows a little over 2% margin on the lift capacity of the Delta. The allocation to each of the subsystems was less than the mass and power rack-up shown in the spreadsheet. In that manner systems engineering was able to hold a 20% margin. Although the overall architecture was maintained, the final hardware configuration of the subsystems differs from those shown in the figure below. The spreadsheet is included for reference only. The actual estimates of the final subsystems are compared to their allocations and are shown in each section.

Table 4.3.2 is a comparison, by subsystem of the allocation and the spreadsheet mass and power.

Table 4.3-2

Subsystem	Mass Kg Spreadsheet/ Allocation	Power Watts Spreadsheet/ Allocation
ACS	7.45/6.0	12.6/9.9
C&DH	21/13	11/2
Communications	15/12	11.2/11.2
Power	9.4/6.3	32/26
Propulsion	64.7/50	2/2
S/C Harness	14/14	0
Thermal	6/4.5	5/4.4
Structure	194/161	0
Total	331.5/266.8	73.8/55.5

These margins will be held by systems engineering, on a case by case basis, until it has been shown that there is a good reason to modify them. As a case in point, the C&DH mass and power allocations were reduced when it deemed risk free to use the light weighted, low power C&DH system needed by the Nanosat. A cost saving was also achieved by eliminating the cost that would be incurred in the design and development of a new C&DH for the D.S.

TABLE 4.3-1

SPACECRAFT SUBSYSTEMS	Source	Part Num	Qty	MASS ea (kg)	MASS tot (kg)	POWER ea (W)	DUTY Cycle	POWER tot (W)	Eclipse Duty Cy.	Eclipse Power	DIMENSIONS (mm) X	Y	Z	Comments
ACS														
Coarse Sun Sensor	Adcole	41760	3	0.25	0.75	0.5	1	1.5	1	1.5	27 DIA		12	
Fine Sun Sensor	Adcole		1	1.4	1.4		1		1		97	104	25	
Fine Sun Sensor Elec.	Adcole		1	1	1	0.6	1	0.6	1	0.6	198	114	51	<.1 deg
Earth	Ithaco		1	1.3	1.3	0.5	1	0.5	1	0.5	137	137	131	.1 deg
Laser Ring Gyros	Litton		1	3	3	10	1	10	1	10				
			Sys Total		7.45			12.6		12.6				
INTEGRATED AVIONICS														
Nanosat C&DH	GSFC		1	1	1	1	1	1	1	1				Rad6000, 128MB, 3MB
Actuator Arm & Fire Board	GSFC		1	20	20	10	1	10						Dig/Analog/1553
											11	8	8	
			Sys Total		21			11		1				
COMMUNICATIONS														
X-band Shaped Hemi Antenna			2	0.3	0.6		1		1					
X-band Receiver			2	3.86	7.72	4	1	8	1	8	6	7	8	4W/34W
Diplexer, U. Stable Osc.			2	1.1	2.2		1		1					
X-band Transmitter			2	2.27	4.54	3.2	0.5	3.2	0.5	3.2	9.6	15.3	1.42	8225 Mhz; QPSK; I & Q Channels 27dB gain; 105Mbits/sec
			Sys Total		15.06			11.2		11.2				
POWER														(6.84 kg/m^2 used for array calc.)
Solar Array W/Panels, Fittings			1		3.60		1		1					0.527 m^2
Hardware			30	0.01	0.3		1		1					
Battery			1	1.00	1.00		1		1					12 AHR (mass estimated)
Power Sys Electronics			2						1					8051 Microprocessor
Battery/Switching Module	Litton		2	0.5	1	7	1	14	1	14				
Solar Array/Module	Litton		2	0.5	1	9	1	18	1	18				
Chassis	Litton		2	1.25	2.5				1		8	8	5	
			Sys Total		9.40			32		32				
PROPULSION														
Tank fuel	PSI	80353-1	2	3.86	7.72		1		1		19 in Dia			7150 in3 total vol need 5000
Tank Oxidizer	PSI	80297-1	1	19	19						27.9 "Dia			8648 in3 vol need 8053
Tank pressurant	PSI	80386-101	1	6.36	6.36						15.5 " Dia			700 psi P initial, 100psi P final
Valves	Moog		5	0.6	3		1		1					
Thrusters	Primex		3	0.34	1.02		1		1					
Support Structure			1	2	2		1		1					
Lines & Filters			1	3.6	3.6		1		1					
Misc. (Fittings, Pressurant)			1	22	22	2	1	2	1	2				20 Kg pressurant
			Sys Total		64.7			2		2				
S/C HARNESS														
Power Harness	Swales		1	7	7		1		1					
Data Harness	Swales		1	5	5		1		1					
1553 Coax, Couplers	Swales		1	2	2		1		1					
			Sys Total		14									
THERMA L														
Blankets	Swales		1	5	5									
Heaters	Swales		1	0.5	0.5	5	1	5	1	5				
Surface Coatings	Swales		1	0.5	0.5									
			Sys Total		6			5		5				
STRUCTURE														
Primary	Swales		1	144	144									
Secondary	Swales		1	27	27									
Mechanisms	Swales		1	20	20	20	0.001	0.02						
Balance	Swales		1	3	3									
			Sys Total		194			0.02						
			Bus Total		331.61	Kg		73.82		63.80				

PAYLOAD	Source	Component	Qty	Mass	Mass	Power	Duty	Power	Ecl. Duty	Ecl.Pwr	Power			Dimensions (mm)
Acronym	Instrument				(ea) Kg	(tot) Kg	(ea) W	Cycle	(tot) W	Cycle	(Total) W	Veloc ity	Solar/ AntiS	Nadir
Nanosats	Nanosats			92	10	920								
				Totals		920								

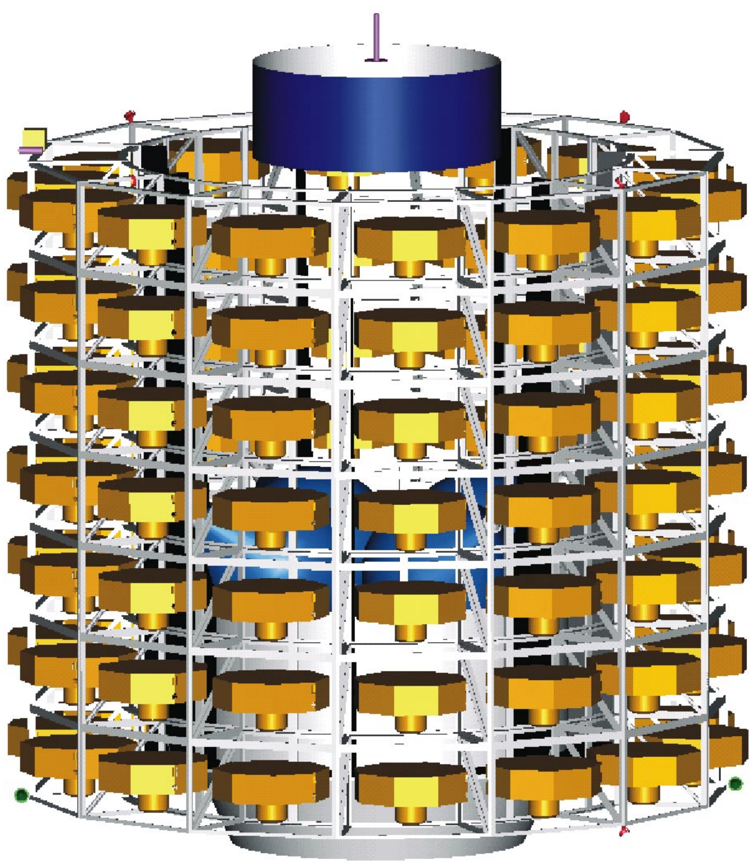
Spacecraft Totals:	1251.61	Kg	73.82	W	63.80 W
Margin:	1.79%				
DeltaV:	202	(includes two 180 deg flips)			
Delivered:	1476				

5.0 Mechanical Configuration:

Figure 5.1.1 shows the mechanical configuration of the Nanosat Dispenser Ship. The blue ring at the top is the 130 watt solar array. Above the array is the X band omni antenna. Located on the top ring are 3 coarse sun , Earth Sensors and a Fine Sunsor..

Figure 5.1.1

NanoSat Dispenser Spacecraft Configuration



The 92 Nanosats are located in individual bays. There are 14 bays per tier and 7 tiers, a total of 98 bays. Since the lift mass of the Delta only permits a payload of 92 Nanosats 6 bays will be empty. Located in area around the base of the DS are, the main thruster, 3 more Coarse Sun Senors an 4 small thrusters. The propulsion tanks, power regulators and the avionics are housed in the interior of the DS. Section 6.5 will give the details of the structure, dimensions of the DS, location of the components, mass of the structure and a description of the bay construction.

BOL inertia ratio (MOI around a principle axis to the MOI around the spin axis) is 1.17. The EOL inertia ratio is 1.07. Because of this favorable inertia ratio maintaining the spin about the thrust axis of the main thruster will not require active control.

6.0 Subsystems:

6.1 ACS Subsystem Description:

The block diagram of the ACS is shown in figure 6.1.1. The Earth sensor and fine sun sensor are used for attitude references and to measure the spin rate. The Ring Laser gyro is used as attitude reference to precess the spin axis to a desired attitude and for sensing and controlling the nutation of the D.S. The normal mission attitude of the spin axis is perpendicular to the ecliptic except during the portion of the orbit when the Nanosats are to be released. Prior to release the D.S will be commanded to precess the spin axis to be parallel to the velocity vector at perigee. Close to the perigee (exact time is TBD) the Nanosats will be release and the scenario describe in section 3 will commence. Precession will be accomplished by the actuation of the bi-propellent thrusters.

Six coarse sun sensors have been provided. From their outputs the position of the sun with respect to the D.S will always be known, excluding the time when the sun is occulted. This information from the CSS will be use during the initial stabilization phase after the D.S has been released from the Delta. To precess the spin axis of the D.S. from the release attitude to the normal operational attitude (perpendicular to the ecliptic) using the 5# attitude the thrusters.

Figure 6.1.2 shows the location of the sensors and actuators on the D.S.

Diagram Figure 6.1.1

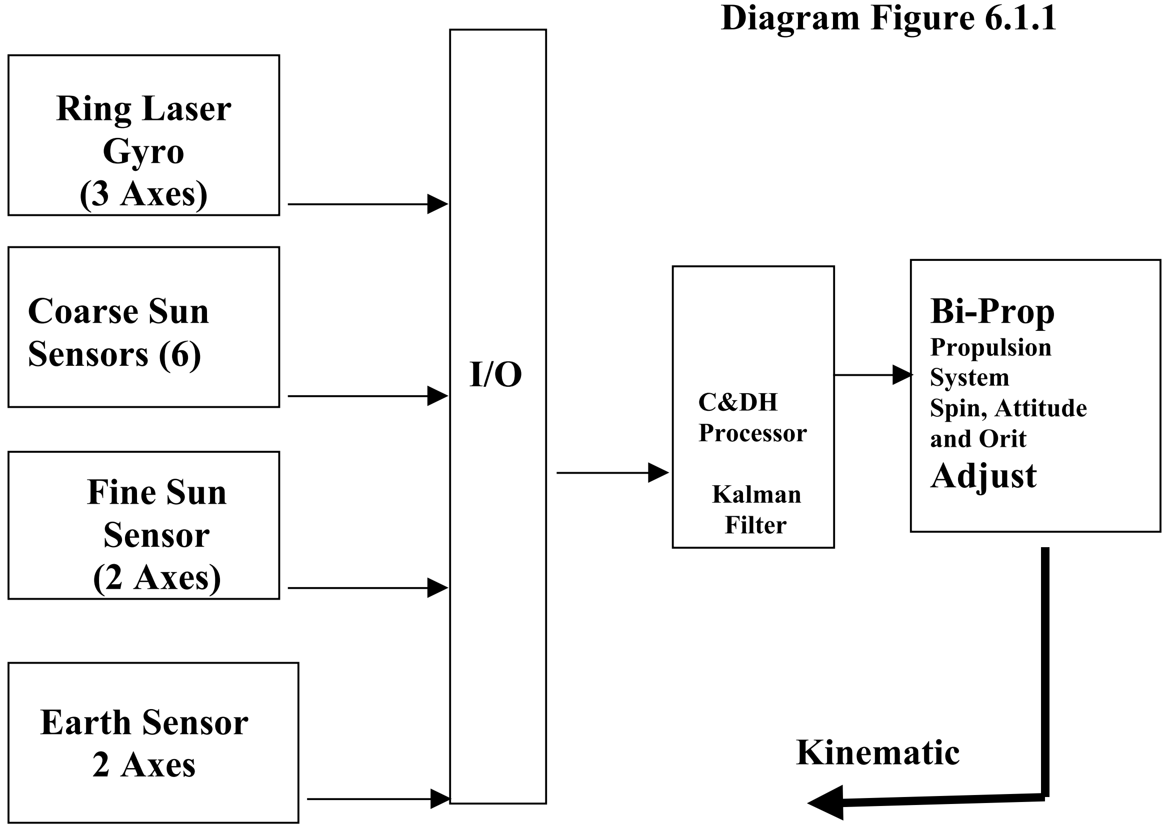
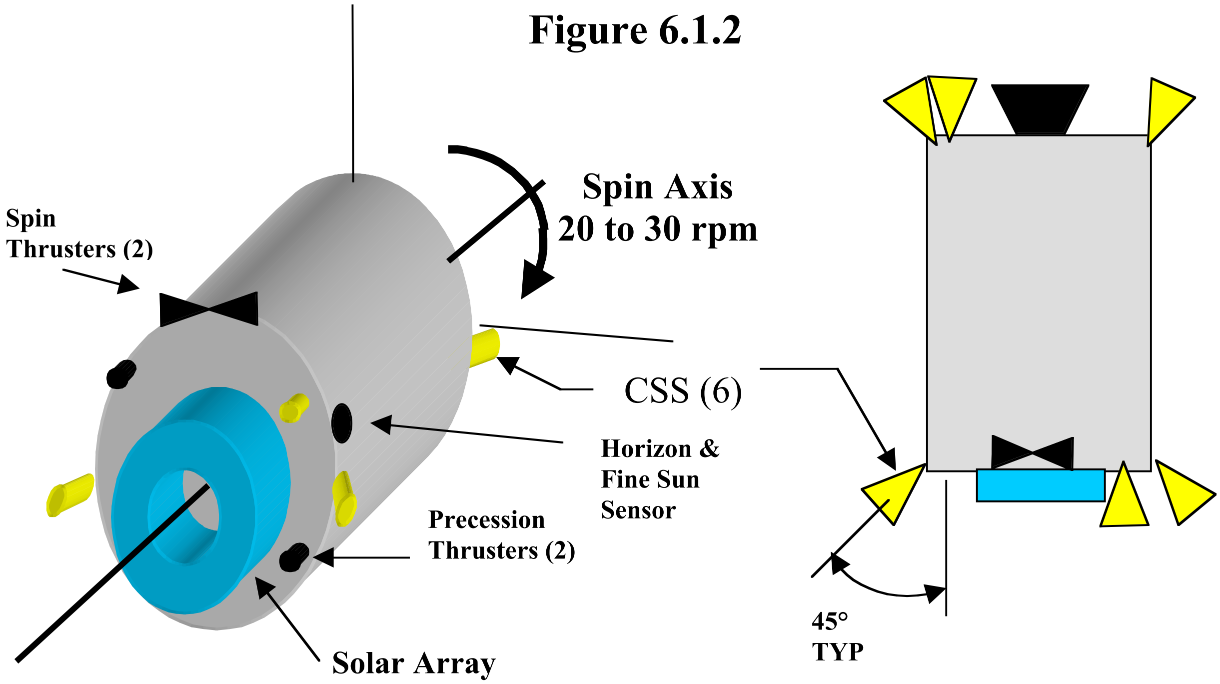


Figure 6.1.2



Location of Sensors and Actuators

Care will be exercised to assure that the FOV of the sensors are not occulted and that uncertainties in the sensor outputs will not be caused by reflections from near by bodies on the D.S. To the first order, in the mechanical design, the impingement of the thruster plume on the D.S has been avoided. Due to mass constraints and geometrical factors, there are 98 bays and only 92 Nanosats. The Fine Sun Sensor and the Horizon Scanner are located in the D.S in an unoccupied bay.

The mass and orbital average power of the ACS are as follows:

Mass and Power of the ACS Subsystem

component	Mass Kg	Power Watts
6 Coarse Sun Sensors	1.5	3
Fine Sun Sensor	1.4	N/A
Fine Sun Sensor Electronics	1	0.6
Earth Sensor	.2	.2
Laser Gyro	3	10
Total	7.1 Kg	13.8
Allotted	6.0	9.9
Spread Sheet	7.45	12.6

6.2 Integrated Avionics:

The requirements placed on the Command and Data Handling (avionics module) subsystem for the dispenser ship are as follows:

Item	**Requirement**
Power	2 Watts
Weight	12 kg
Operating Temperature	0 – 50 Degrees C
Radiation	40 kRad Si (Total Dose)
Data Rate From Telemetry	2 kbits/s
Data Storage	2 Gbits
Uplink/Downlink Protocol	CCSDS
Uplink Rate	1 kbits/s
Downlink Rate	100 kbits/s

. The Avionics module is based on a central processor. The subsystem also consists of a solid state recorder to store data that will be transmitted to the ground stations for distribution to the end user. The Avionics module includes interfaces to the Attitude Control System (ACS), the power subsystem, the communications subsystems as well as the release actuators.

A block diagram of the dispenser ship architecture is shown in Figure 6.2.1. The avionics module takes the form of a stack of Multi Chip Module (MCM) that will serve as the packaging technology for use by the Avionics module. For commonality with the Nano-Sat C&DH the MCM module was selected for the dispenser ship. The Avionics module is responsible for sending commands, gathering telemetry data, processing the data, storing the data using Consultative Committee for Space Data Systems (CCSDS) packets, time tagging the data, and transmitting the stored data to the ground. The Avionics module will be a processor-based system which will process commands, packetize the data, perform the timekeeping functions, perform ACS computations and control power. Data will be taken from the bus by the processor where the data will be manipulated into the required format. The avionics module will contain 2.0 Gbits of RAM. The avionics module will interface to the ACS subsystems Earth/Sun Sensor (analog data), Attitude Thruster (pulse command), Orbit Thruster (single pulse), the latch valves and the pyro actuated valves. The housekeeping functions include reading the thermistors, pressure transducers, reading the voltage and current monitors, and gathering other analog telemetry. These functions will be handled using a 12 bit A/D converter. The Uplink/Downlink interface is connected directly to the transmitter and receiver. This interface sends CCSDS packet telemetry to the ground antennae, and receives CCSDS packet commands from the ground antennae and processes them.

Nanosat Architectural Diagram

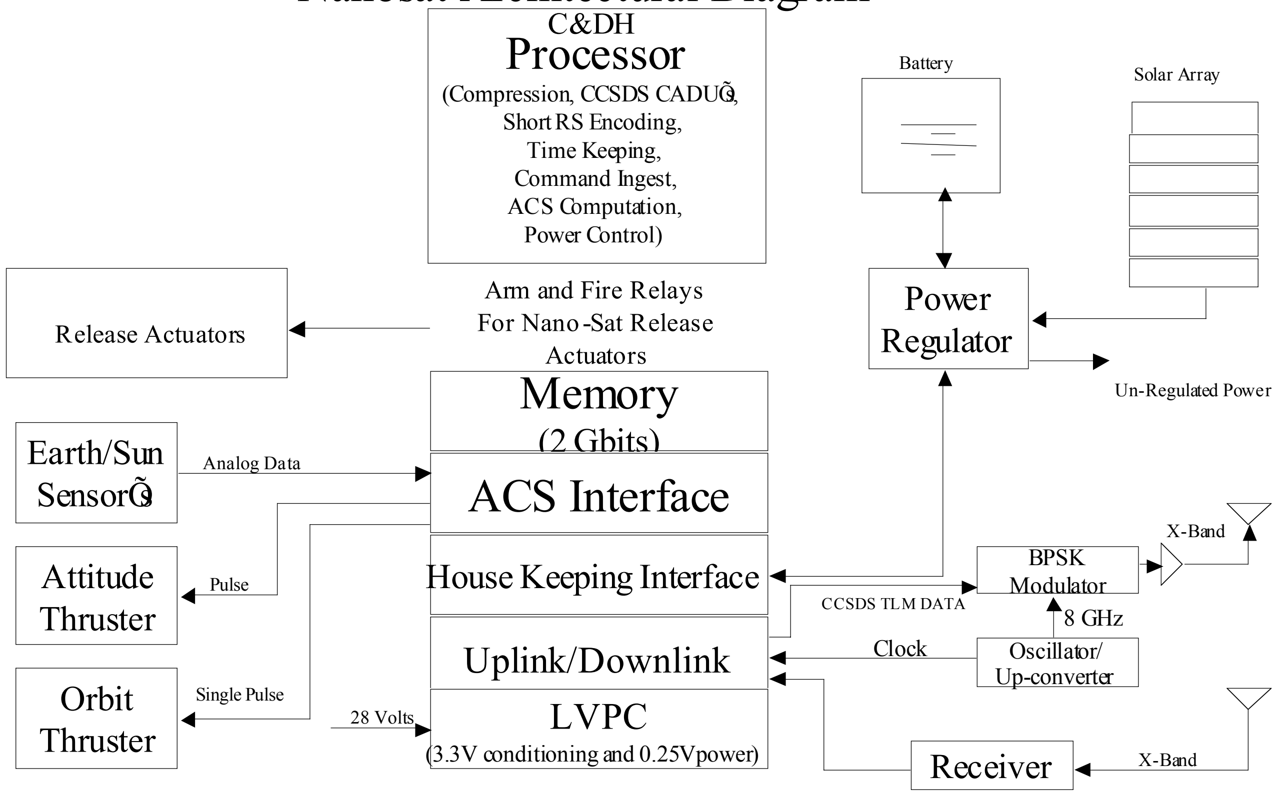


Figure 6.2.1

The stacked MCM will be composed of six functional interfaces, each of which will perform separate functions required by the avionics module. These functions are the processor, the memory, the actuator interface, the ACS interface, the housekeeping interface, and the communications interface. The development of these interfaces will require the extensive use of Field Programmable Gate Arrays (FPGAs). These FPGAs will be developed in a low power technology.

The following is a description of the different slices of the avionics module:

Processor – The processor is responsible for all of the digital processing capability. The processor will also include the non-volatile memory to store the processor code and the memory required to execute the code. There will be two external interfaces to the processor. The first will be the standard backplane interface. The other will be a programmable communications interface, such as an 8251, for system level programming and debugging of the software.

In addition, the processor also includes the following hardware capabilities:

Spacecraft time keeping, which maintains mission elapsed time in seconds and sub-seconds;
Watchdog timer circuits, which provide an automatic/autonomous reset capability;

External timers, which provides a timed interrupt capability;
External wait-state generators, which provide for setup and hold times to different memory and I/O.

The processor will perform the following software functions:

Commands
Perform CCSDS telecommand operations (receive and process commands that were sent to the spacecraft);
Distribute commands to other MCM slices;
Perform stored command operations.
Telemetry
Perform CCSDS packet operations (packetize telemetry);
Collect telemetry
Data Storage
Provide 1 orbit worth of spacecraft data storage;
Provide for simultaneous telemetry storage and playback operations.
General
Support ACS Processing;
Perform Health and Safety, processing;
Provide spacecraft-to-ground time correlation.

Actuator Interface – This interface is between the release actuators and the processor via the standard backplane interface. The actuator I/F will send the fire commands to the actuators, gather status data from the actuators, and format the data for transfer to the processor. The interface contains the prearm, arm and fire relays.

Memory Interface– The memory will contain 2 Gbits of data in the form of static or dynamic RAM. If dynamic RAM is chosen it will contain the refresh circuitry. The memory will receive data from the processor slice and store the data for later playback. The data will be protected by Error Detection And Correction (EDAC) encoding of the data. At the proper time the playback will begin and the data will be sent to the Uplink/Downlink card for formatting and transmission to the ground.

ACS Interface – This interface is between ACS sensors and ACS actuators and avionics module. The sensors include an Earth sensor and a sun sensor. The actuators consist of 5 thrusters, 4 for attitude control and 1 for delta V control. The processor gathers the sensor data from the ACS I/F and commands the ACS to fire the thrusters at the appropriate time.

Housekeeping Interface – The housekeeping interface is responsible for two primary functions. First, it performs all of the avionics modules housekeeping telemetry collection. This data includes the thermistor (temperature), pressure, voltage, actuator status, and current telemetry. Second, the housekeeping interface performs the discrete commanding associated with the spacecraft, not including the ACS. This includes heater control and any switching required by the power system. The housekeeping slice interfaces to the processor, which collects the telemetry and acts on it if required. The telemetry is also packetized and sent to the memory for later transmission to the ground station. The processor sends commands to the housekeeping interface and the housekeeping interface in turn sends the appropriate discrete command.

Uplink/Downlink Interface – The Uplink/Downlink I/F performs two functions. First, it receives CCSDS commands from the ground via its interface to the receiver. These commands are hardware decoded, which include verification of proper format and proper spacecraft identification. After the command is deemed valid, either a discrete command will be generated such as a reset to the processor, or the commands will be collected and acted upon by the processor.

Second, it receives data from the memory and formats the data into the proper CCSDS protocol, adding spacecraft time, encoding and other CCSDS overhead to the data. Then the data is sent to the transmitter for transmission to the ground station. The interface to both the transmitter and the receiver are custom interfaces, requiring clock and data lines.

Low Voltage Power Converter (LVPC) – The LVPC slice will convert the spacecraft bus voltage (28 volts) to the operating voltage of the devices in the MCM stack (~0.2 volts).

6.3 Communications:

The communication system for the D.S consists of a transmitter, receiver and a omni antenna. It operates in the X band. The up link/ down link frequencies are 7209.125 and 8470.XXX MHz (requested). The link analysis shows positive margin with an 11 meter ground station antenna and an omni antenna on the D.S. The G/T ratio for the ground segment must be 35.4 dB/°K in the X band. The EIRP from the D.S is 1.76 db_w (1.5 watts in to antenna). To be compliant with the system requirement, using one way doppler for tracking, the oscillator must be stable to 5E^-8 per day. The down link transmission rate can be as high as 100 Kb/sec. and the command rate is baselined as 1 Kb/sec.

The communications system interfaces with the C&HD via the up link and down link interface shown in Figure 6.2.1. The function of the interface is described in section 6.2.

Mass and Power for the Communications System

Item	Mass Kg	Power Watts
Transmitter	2.27	3.2
Receiver	3.86	4
Oscillator/Diplexer	1.1	Negligable
Antennas	.6	N/A
Total	7.83	7.2
Allocated	12	11.2

6.4 Power Subsystem:

The baseline requirements for the power subsystem are:

- The D.S. shall deliver no power to the Nanosats either while in orbit or on the ground (the requirement was imposed to eliminate the need for a connector between the Nanosat and the D.S. As a result he requirements on the flyaway mechanisms and ships wiring are eased)
- The subsystem will deliver at 28 V DC to theD.S.
- 100 watts orbital average is required (Although the spreadsheet shows approximately 78 watts are needed the 100 W requirement was impose because it gave ample margin with little effect on the D.S. design)
- The launch of the D.S will be timed to prevent eclipses longer than 40 minutes (this requirement decreased the battery capacity needed to operate thru the eclipse and eased the the thermal design of the un-powered Nanosats)
- The mission lifetime shall be less than 3 months

Referring to figure 6.4.1 the power subsystem consists of three main elements, the solar array which converts solar energy to electrical power, the regulators which, as the name implies, reduces the variation of the voltage on the power bus and the Lithium Hydride battery. The output to the bus will be 28±7v DC. The solar array is sized to deliver 130 watts off the array at BOL.
With a 40 minutes eclipse time the array can deliver 100 watts orbital average power. The spreadsheet requirement, as shown in Table 4.3-1 is slightly under 78 watts, leaving a healthy margin.

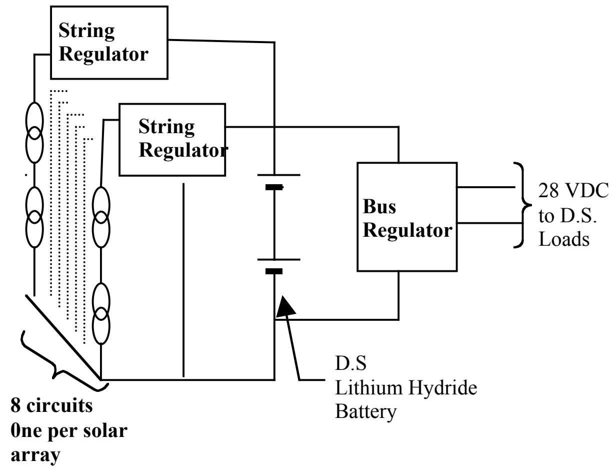


Figure 6.4.1

Mass and Power of the Power Subsystem

Item	Mass Kg	Power Watts
Solar Array	3.6	N/A
Battery	1	N/A (recharge loss factored in by increasing the array size)
Regulators	1	32
Total	4.6	32
Allocation	6.3	26

The power system was selected for its simplicity and reliability. By not supplying power to the Nanosats the need for breakaway connectors was eliminate, the amount wiring was reduced and the power requirements was also reduced. Operating at 28V is conventional which eliminates the interface problem with the Propulsion and ACS system components and permits the use of smaller gauge wire as compared to a 3 volt system.

Figure 6.4.2 is an alternate power system configuration that could be used if the power system requirements were change to require the use of the Nanosat array power to power the D.S.

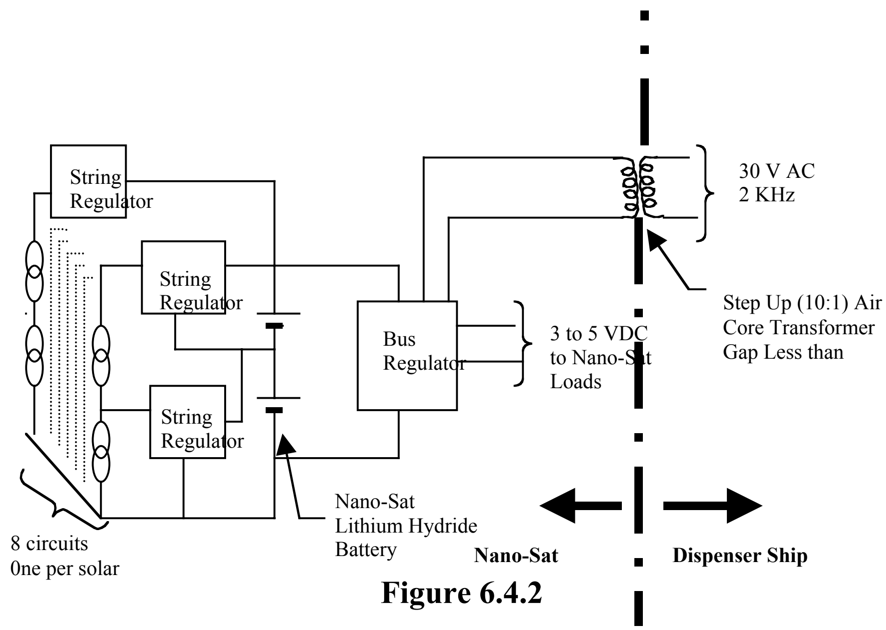


Figure 6.4.2

In this version of the power system the output from each of the Nanosat arrays would be converted to AC and bucked from the 3 to 5 V Nanosat voltage to 30V AC @ 2 KHz. Transmission of the power across the interface is via a transformer. In this manner power is transferred without physical contact. Rectification and regulation of the AC power would be done in the D.S. A variation of this configuration would to incorporate a LED/photodiode combination along with the transformer. With this enhancement, telemetry data could be sent across the interface, between the Nanosat and the D.S., during I&T or while the Nanosat is attached to the D.S in orbit.

The advantages of the system are:

- Eliminates need for separate solar array on the D.S.
- Can obtain TM data from the Nanosats while on the pad (assumes Nanosat batteries are charged while on L/V)

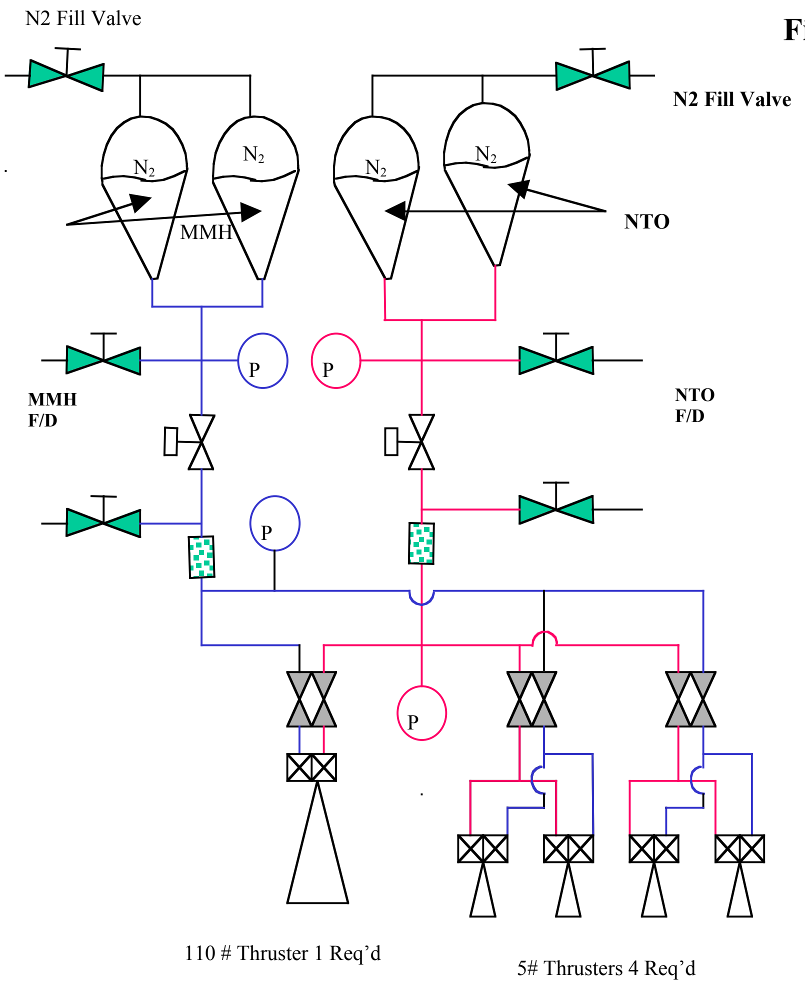
The disadvantages are:

- Requires more wiring
- As Nanosats are released, the power available to the D.S decreases thereby requiring a larger battery in the D.S.
- The Nanosat power system is more complex
- There is a mass penalty to the Nanosats

6.5 Propulsion:

Figure 6.5.1 is a diagram of the D.S. propulsion system. It is required to have 202 Kg of bi-propellant with an I_{sp} of at least 315 $\#_f$ sec/$\#_m$. The inert mass of the system shall not exceed 60 Kg. It must operate properly while the D.S. is spinning at 30rpm. The system will be used for adding Delta V, precessing the spin axis, controlling the spin rate and maintaining attitude control. A 110# thruster will be used for Delta V maneuvers and the 5# thrusters will be used for the other functions.

Figure 6.5.1



LEGEND

Symbol	Function	Quan.	Mass
	Fill & Drain	6	0.6
	Latch Valve	3	1.5
	Pyro Actuated Valve	2	.24
P	Pressure Transducer	4	.88
	Filter	2	0.8
	Conosphere Tank 18" Equator dia.	4	15
	5# Thruster	4	2.68
	110# Thruster	1	3.2
———	Plumbing (CRES)		9

System Dry Mass 34.47 Kg
Total System Mass 251.6 Kg

The pyro valves are opened after the D.S has been placed in orbit by the Delta V. This action, arms the system. The thrusters will not fire until the latch valves are commanded open. The main engine latch valve will be kept closed and opened when a Delta V maneuver is immanent. The other latch valves will be left open and closed only if a thruster malfunctions.

The estimated mass of the inert elements is shown in the inset of Figure 6.5.1. The total is 34.47 Kg, which is below the allotted 50 Kg and below the spreadsheet mass of 64.7Kg. The thrusters are fired infrequently and therefore the orbital average power is negligible.

6.6 Structures:

The D.S structure is shown in figure 6.6.1. It consists of the Inner Structure, 7 Berthing Rings. Figure 6.6.2 shows the Internal Structure of the D.S. The inverted cone at the base of internal support transition cylinder interfaces with the L/V's payload adapter fitting. Attached to cylinder are 7 vertical gussets. The gussets support the 7 Nanosat Berthing Rings, shown in Figure 6.6.3. A detail view of each bay in the Berthing ring is shown in Figure 6.6.4.

Figure 6.6.1 Dispenser Ship Structure

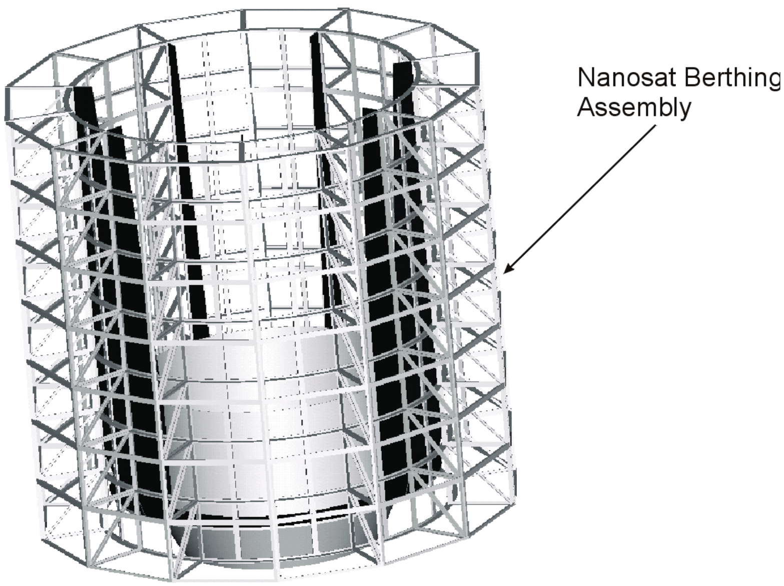
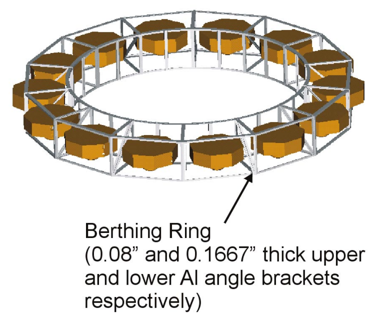


Figure 6.6.3



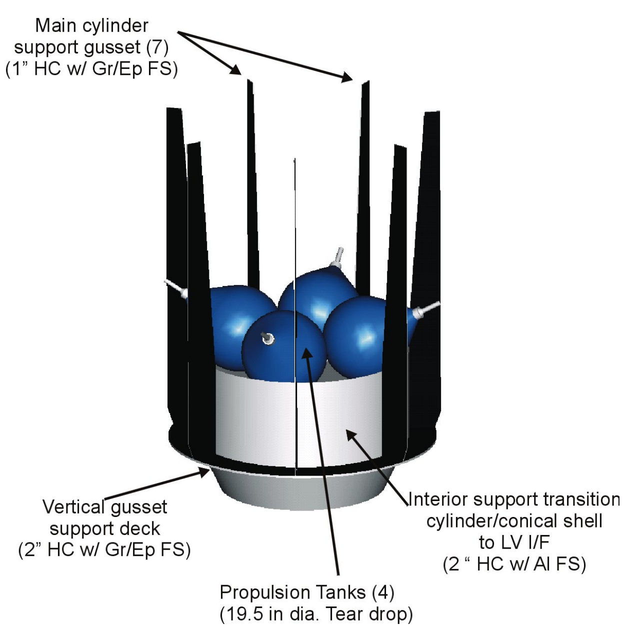
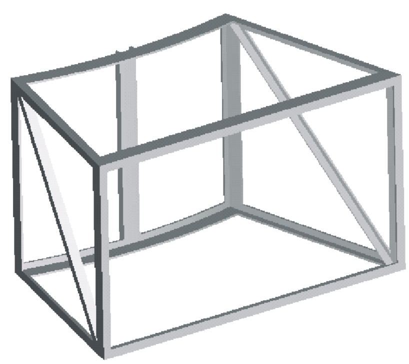


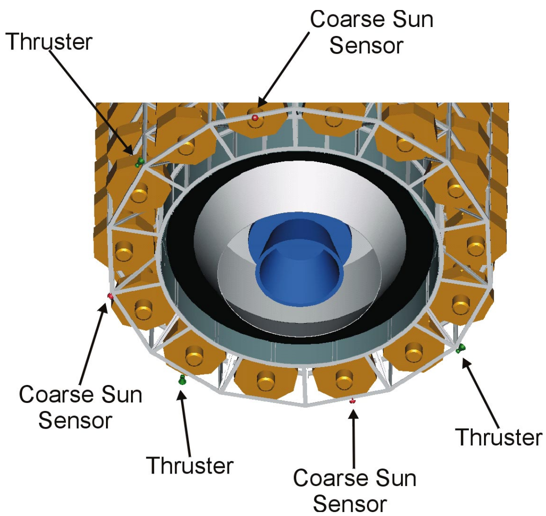
Figure 6.6.2 Inner Structure



NanoSat Bay
Figure 6.6.4

The propulsion system's 4 tanks and the 110# thruster are carried by the inner structure. Figure 6.6.5 is an aft view of the D.S. The 4 thrusters are located on the lower berthing ring. Two of the thrusters are for spin control, a third is used for precession control and the fourth is a backup for the precession control thruster. Also shown in the figure are the three coarse sun sensors. Figure 6.6.6 shows the location of the ACS sensors located on the top berthing ring, the solar array and the omni antenna. Not shown is the thermal heat shield for the main thruster and other thermal devices needed for thermal control of the D.S.

The fields of regard of the ACS sensors are not shown, they are shown in Section 6.1, ACS.



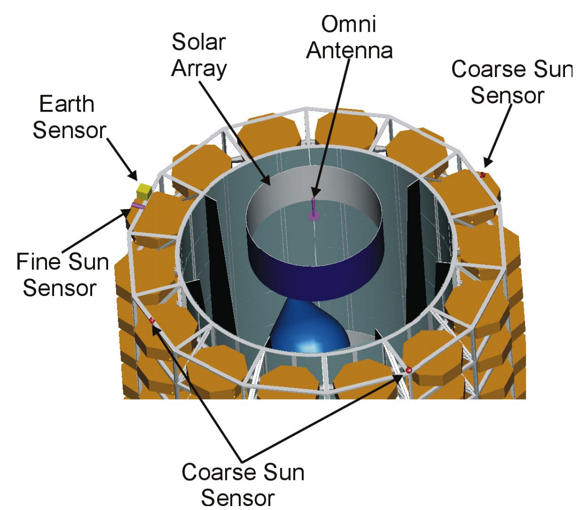


Figure 6.6.5 Aft View **Figure 6.6.6 Top View**

Also not shown are the avionics and the Power subsystem components. They will be mounted to the vertical gussets.

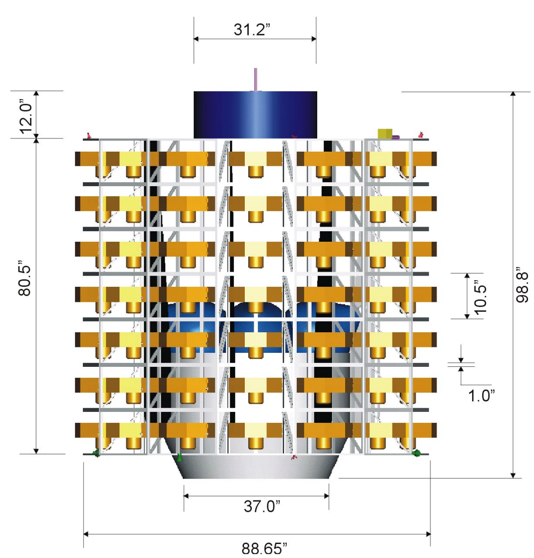


Figure 6.6.7

Figure 6.6.7 is a view of the Nanosat Dispenser Ship showing some of the major dimensions.

Tables 6.6-1, 6.6-2 and 6.6-3 list the mass properties of the dispenser ship. The moment of inertia has been calculated for the beginning as well as the end of life. As stated before, the data indicates the D.S. will be stable as a spinner.

Table 6.6-1

Elements	**Mass/Weight (lbs)**	
	lbs	Kg
Support Gussets	35	16
PAF	31.2	14
Propulsion Deck	11.7	5.3
Ring Assy. Upper (4 decks)	82	37
Ring Assy. Lower (3 decks)	129	59
Total	288.9	131.3

Table 6.6-2

NanoSat Estimated EOL Mass Moment of Inertias (lb*in^2)

I_xx	3.4097e+005	**I_xy**	2.8969e+002
I_yy	3.4116e+005	**I_yz**	-3.5556e+001
I_zz	3.6563e+005	**I_zx**	-9.2268e+001

Table 6.6-3

NanoSat Estimated BOL Mass Moment of Inertias (lb*in^2)

I_xx	3.2133e+006	**I_xy**	2.1969e+003
I_yy	3.2150e+006	**I_yz**	3.2234e+002
I_zz	3.7731e+006	**I_zx**	5.5133e+002

6.7 Thermal:

Similar to the Nanosat spacecraft, preliminary study results indicate that the Nanosat Dispener Ship (DS) thermal requirements can be accommodated with a passive thermal control system (blankets, heaters, and coatings). The multi-layer insulation will be used on top and bottom to reduce losses and gains from the environment. The cylindrical sides (shell) of the DS are not insulated. Heaters and MLI may be used to maintain propulsion lines and thrusters during orbit changes.

The thermal analysis used 0.3 for the Albedo factor, a solar constant of 1351.43 W/sq.m and a planet power of 237.805 W/sq.m.

The following parameters and thermal characteristics were used in the thermal analysis:

Parameter and Characteristics	Comments
Orbit	Perigee = 3 $R_{e,}$ Apogee = 20 $R_{e,}$ Inclination Angle = 7.5° Period = 2.43 Days, No eclipse
Mission Life time	2 months
ACS	Spin stabilized, spin rate of at least 20 RPM and spin axis aligned to ±5° of ecliptic pole. Short excursions TBD from this design attitude can be tolerated.
Temperatures	DS Operating temperature range of 0° to +50°C Nanosat temperature requirement of –20 to +50°C for survival, non-operating mode,
Thermal Configuration	Nanosats are mounted around the drum of the DS, but isolated from birdcage and DS shell Nanosats are not powered up while on the DS Components are mounted internally on decks, which are in turn conductively coupled to the DS shell. The shell is radiatively and conductively coupled to the top and bottom decks Berthing Ring is conductively coupled to the DS shell The nozzle is coupled to the bottom deck.
Solar Array	The DS solar array is coupled to the top deck. Operating temperature -100 to +40°C (+80°C survival upper limit)
Power Dissipation	The DS dissipates a total of 100 watts, orbit average, assumed distributed evenly on the DS shell

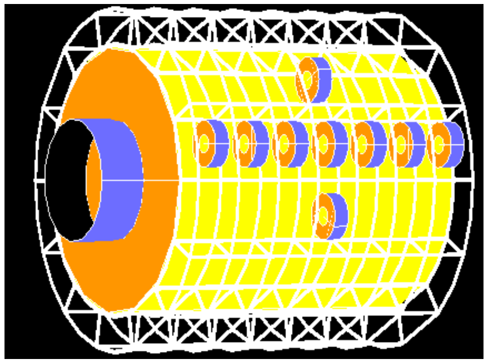


Figure 6.7.1 Dispenser Ship Model

Figure 6.7.1 is a snapshot of the dispenser ship model that was created in TSS. The model did not include any of the internal components of the Dispenser ship and the Nanosat components were modeled as a lump node. The dispenser ship was comprised of the following components:
a shell or body, which acts as the radiator
a solar array ring mounted on the top
a nozzle on the bottom
a Berthing Ring structure
a deck to close out the top
a bottom deck that holds the nozzle
MLI was used on the outside of the top and bottom decks and the exterior surface of the nozzle. The surface properties for the dispenser ship are displayed in Table 6.7-1. The dispenser ship was built using design parameters supplied by the mechanical system (see the mechanical section for dimensions, etc.) Once the dispenser ship model was built, Nanosats were placed in nine of the ninety-eight bays. In order to determine the effect of the energy reflected between the dispenser ship shell, individual Nanosats, and the bird cage, one column was completely filled and then one was placed on either side of the fourth Nanosat. The Nanosat thermal design has been previously studied and will not be addressed in this document, other than to ensure that the dispenser ship design keeps the Nanosats within their hot and cold boundaries.

Table 6.7-1 DS Surface Properties

Item	Internal Surfaces	External Surfaces
Shell/Body	Black Paint, ε=0.87, α=0.92	Black Paint, ε=0.87, α=0.92
Solar Array	Black Paint, ε=0.87, α=0.92	Solar Cells, ε=0.87, α=0.87
Birdcage		White Paint, ε=0.87, α=0.24
Top Deck	Black Paint, ε=0.87, α=0.92	MLI (Kapton), ε=0.76, α=1.0
Bottom Deck	Black Paint, ε=0.87, α=0.92	MLI (Kapton), ε=0.76, α=1.0
Nozzle	Black Paint, ε=0.87, α=0.92	MLI (Kapton), ε=0.76, α=1.0

First, it's worth mentioning that very top level analysis was completed. For the most part, each component of the dispenser was modeled as a single node and the individual spacecraft were modeled as five nodes each. For components that are mounted externally, have a high watt density, or have tight temperature control requirements, a more detailed model would need to be completed.

Preliminary results indicate that the Nanosats mounted in the top ring run slightly warmer than the others, while the ones in the bottom ring run the coolest. For the dispenser ship, its temperature is set by the high energy absorbed by the shell and it's conductive coupling to the birdcage. Since the surfaces of the Berthing Ring were painted white, they ran colder than any of the other surfaces. When the dispenser ship was conductively coupled to the Berthing Ring its temperatures were on the order of 10°C colder than when it was isolated from the Berthing Ring. Therefore, the coupling between the shell and Berthing Ring is important and should be examined more closely in future studies. Nonetheless, the simple design described above, is reliable and appears to meet temperature requirements for the dispenser ship as well as the Nanosats. Further parametric analysis should be conducted with a more detailed model.

7.0 Rational for the Above

The subsystems as described in section 6, in aggregate, meet the requirements for the D.S. design. As describer in section 6, all systems will meet their performance requirements. Although some subsystems came in above their mass an/or power allocations, others came in lower. The net effect yielded a lighter system dissipating slightly more power than allocated. Table 7.0-1 summarizes the mass and power for each of the subsystems.

Final as Designed Mass and Power

Subsystem	Mass Kg	Power Watts
ACS	7.1	13.8
C&DH	12	2
Communications	7.8	7.2
Power	5.6	32
Propulsion	50	-
Harness	4.5	0
Thermal	4.5	5
Structure	131	0
Total As Designed	216.9	60
Total As Allocated	266.8	55.5*

*The As Designed power exceeds the allocated by 4.5 watts. This does not present a problem since the arrays have been designed to deliver 100W orbital average.

8.0Future Studies

This feasibility study was conducted with the understanding of the science mission requirements as they existed at the time when the study was undertaken. The conclusions derived from this study may change as the mission requirements change, however, valuable insight into the engineering problems associated in the design of a dispenser ship were gained. The strategy of Nanosat deployment, using posigrade and retrograde Nanosat firings, (making the propulsion requirements of the Nanosats more uniform) and the mission scenario for obtaining a maximum number of Nanosats in orbit are clear examples.

8.1Mission Analysis

There is a strong possibility that the Delta II 7925 can insert a larger mass in the selected orbit. This additional mass is on the order of 200 Kg. The OLS office should be contacted to determine if this potential can be realized. The effect the increased lift would have on the Nanosat missions (more Nanosats?, different orbits?) would need to be studied.

A method has been proposed for separating the Nanosats that are in identical orbits. More work is needed to determine, the separation requirements, the mission constraints and the angular separation that can be achieved.

The orbital maneuvers were assumed to be the results of impulses applied to the Nanosats at perigee. The effect of staggered firings, needed by the tracking stations, is not consistent with the analysis. The effect of the staggered firings on the final orbits needs to be analyzed.

To maximize the number of Nanosats in orbit a minimum energy orbit transfer method was selected. It resulted in an orbit with a 7.5° inclination to the Earth's equator while having the line of apses pointing to the sun. Although it met the requirements specifications, it did it in a manner which would produce eclipses which are many hours long. This mission scenario must be reviewed.

The availability of ground stations during the perigee passes was not studied. The effect of availability on the deployment strategy and mission time needs investigation.

8.2 Mechanisms:

Much work has been done of the Nanaosat release mechanisms. However, the task of assigning an error budget to each phase of the release scenario which deals with, pointing, thrust misalignment, conning of the Nanosat spin axis, propellant Isp uncertainties, dispenser ship orbit uncertainties etc., has yet to be compiled. The goal of the budget will be to determine the subsystem requirements needed to placed the Nanosats in orbits whose apogees are to within ±1/2 ER of the nominal.

Although reference 4 presents the kinematics of the Nanosat/D.S release mechanism and sows feasibility, the details of the release mechanism have yet to be determined. To define the mechanism a design of the mechanism that includes how it attaches to known points on the structure must be completed.

8.3 Subsystems:

Once the mission requirements have been firmly established, by the science team, the preliminary subsystem design task should be reiterated. The depth of the new design should be commensurate with the firmness of the science mission statement.

9.0 Conclusions:

Using a theDispenser Ship detailed in this report and a Delta 7925, it is feasible to put 92 Nanosats into the orbits inclined 71/2° to the Earth's equator with perigees of 3ER and apogees ranging from 12ER to 60 ER.

The rule of thumb (ROT) used to estimate the weight of the subsystems, structure and inert mass of the propulsion system were fairly accurate.. Table 9.0-1 shows the rule of thumb estimates used by Mission Analysis and the As Designed estimates shown in Section 6 of this report.

Component	ROT Mass Kg	Section 6 Mass Kg
Structure	194	131
Inert Propulsion	60	50
C&DH + ACS + Power + Solar Array	90	35.9

The mass of the structure does not include secondary structure. Allowing the spreadsheet value of 27 Kg for secondary structure and 20% margin the section 6 structure estimate should be 190 which is close to the ROT estimate. The inert propulsion mass is also very close if a 20% margin is included. The big discrepancy between the ROT mass and the As Designed mass, is in the avionics mass. Adding 20% margin to the As Designed mass of 35.9 Kg and subtracting it from the ROT mass yields a difference of 47 Kg. This saving was realized by the use of the light weighted C&DH system. The rationale for using the light weighted C&DH was given in the C&DH subsystem section.

Since there is a 47 Kg savings, 4 or 5 more Nanosats could be placed in to orbit. The lift capability and room in the berthing ring are available.