NASA-CR-195526

A Small Satellite Design for Deep Space Network Testing and Training

(NASA-CR-195526) A SMALL SATELLITE DESIGN FOR DEEP SPACE NETWORK TESTING AND TRAINING Final Design Report (Texas Univ.) 114 p

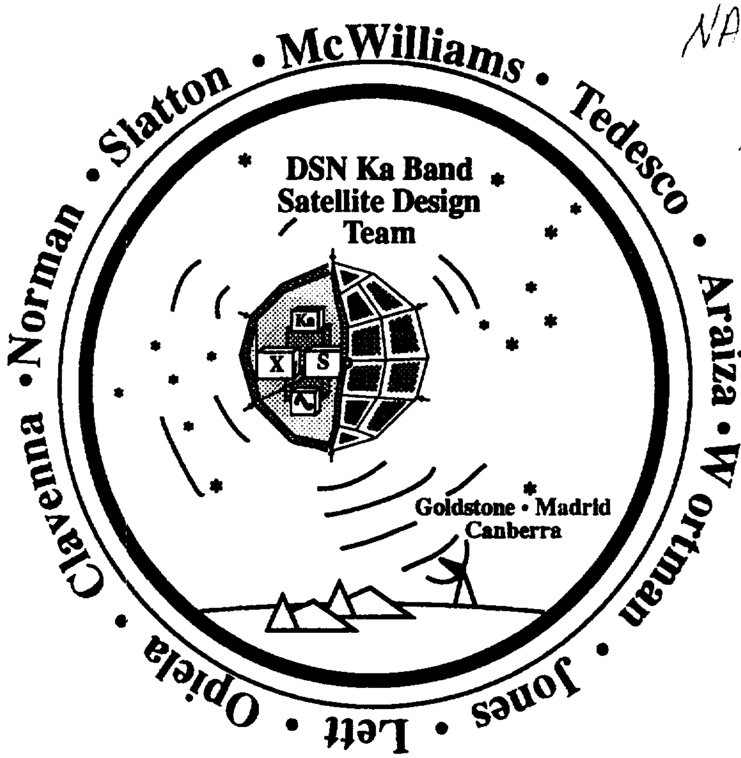
N94-24702

Unclas

G3/18 0204259

NASW-4435

P- 114



Mockingbird Designs

The University of Texas at Austin
Department of Aerospace Engineering

Final Design Report

A SMALL SATELLITE DESIGN FOR DEEP SPACE NETWORK TESTING AND TRAINING

Submitted to

Dr. George W. Botbyl
USRA Design Professor
The Department of Aerospace and
Engineering Mechanics
The University of Texas at Austin

by

The Mockingbird Design Team

Dennis McWilliams - Program Manager
Clint Slatton - Chief Engineer
Cassidy Norman - Chief Administrative Officer

Subsystem Leaders:
Joe Araiza
Jason Jones
Mark Tedesco

Engineers:
Michael Wortman
John Opiela
Pat Lett
Michael Clavenna

May 8, 1993

Abstract

With the continuing exploration of the Solar System and the re-emphasis on Earth focused missions, the need for faster data transmission rates has grown. Ka-Band could allow a higher data delivery rate over the current X-Band, however the adverse effects of the Earth's atmosphere on Ka are as yet unknown. The Deep Space Network and Jet Propulsion Lab have proposed to launch a small satellite that would simultaneously transmit X and Ka signals to test the viability of switching to Ka-Band. The Mockingbird Design Team at the University of Texas at Austin applied small satellite design principles to achieve this objective. The Mockingbird design, named BATSAT, incorporates simple, low-cost systems designed for university production and testing. The BATSAT satellite is a 0.64 m diameter, spherical panelled satellite, mounted with solar cells and omni-directional antennae. The antennae configuration negates the need for active attitude control or spin stabilization. The space-frame truss structure was designed for 11 g launch loads while allowing for easy construction and solar-panel mounting. The communication system transmits at 1 mW by carrying the required Ka and X-Band transmitters, as well as an S band transmitter used for DSN training. The power system provides the 8.6 W maximum power requirements via silicon solar arrays and nickel-cadmium batteries. The BATSAT satellite will be lofted into an 1163 km, 70° orbit by the Pegasus launch system. This orbit fulfills DSN dish slew rate requirements while keeping the satellite out of the heaviest regions of the Van Allen radiation belts. Each of the three DSN stations capable of receiving Ka-Band (Goldstone, Canberra, and Madrid) will have an average of 85 minutes of view-time per day over the satellites ten year design life. Mockingbird Designs hopes that its small satellite design will not only be applicable to this specific mission scenario, but that it could easily be modified for instrument capability for university, government, and/or commercial research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The Mockingbird Design team would like to thank the countless people who aided us in our design. Mockingbird would specifically like to thank:

Dr. George Botbyl, our project mentor at U.T., for giving us the freedom to attack the design problem with our own methods, while keeping us on a tight schedule. We would also like to thank Dr. Botbyl for taking this "hands off" approach to the senior design course; we all learned more from practicing the team concept than any class or book could teach us.

Dr. Paul Robinson at JPL for answering all of our questions concerning the mission's objectives and the mission background. We would also like to thank Dr. Robinson for his friendliness and genuine concern for the success of our project.

Dr. Wallace Fowler for helping The University of Texas get this mission as a senior design project, and for helping us out with countless design points concerning small satellite design.

Tony Economopolous, our graduate student project advisor, for his reminders and tough questions that made us really have to understand our design.

The Mockingbird Design team would like to thank these and all of the other people who helped us in our design by answering technical questions, offering advice, and reviewing our design.

EXECUTIVE SUMMARY

Mankind's quest for knowledge of space has led scientists to loft expensive, complex space probes that gather a multitude a data. Current spacecraft can gather more data than their communication system can transmit during limited transmit times. In order to increase efficiency as well as the amount of data a satellite can retrieve, faster data transmission methods must be found. The fastest data transmission rates now occur over X-band. However, a debate by scientists currently focuses on whether NASA should switch to another radio frequency, like Ka-Band, or if they should move on to a more advanced scheme such as laser communication. Mockingbird Designs hopes to aid the debate by studying Ka transmissions. Although the Ka-Band could offer higher data transmission rates, the effect of the atmosphere on the signal is unknown. Therefore Mockingbird designed and plans to produce a small satellite, named BATSAT, that will transmit a test signal over both Ka and X bands to study atmospheric signal attenuations.

The BATSAT satellite incorporates small satellite design principles to provide a simple, low-cost design ideal for university production and testing. The satellite is an 0.64 m diameter space-frame truss structure built of 6061-T6 aluminum truss members. The skin panels will be built of a honeycomb sandwich material, which will be mounted the outer truss structure using locking bolts. In lieu of an axial strut to support launch loads, an inner strut configuration will provide stiffness. The inner strut design also provides more space inside the spacecraft for component placement. The components will be placed in an insulated disk that will be isolated from the structure using nylon cords. Using a NASTRAN

structural model, Mockingbird found that the spacecraft has a large structural design margin while maintaining a low mass. This could be very beneficial if one wished to increase the component mass by adding scientific instruments.

The communication system includes Ka and X-Band transmitters that are used to carry the test signal. Mockingbird also plans to include an S band transmitter that will be used to help train DSN personnel. By purposely turning certain antennae off, DSN trainees could determine the attitude motion of the satellite via blinking techniques. The spacecraft will transmit the 1 mW test signal over four omni-directional antennae provided for each band. The increase in signal interference due to these antennae can be compensated for using filter techniques available at DSN, but most importantly these effects are distinguishable from atmospheric effects. Commands will be up-linked via an X-Band transponder and a step logic circuit will change the spacecraft configuration for different subsystems. Also, to insure that the satellite can always be in a known state, a reset command was designed to return the satellite to an initial state.

Thermal control is often a problem for small satellites. To compensate, Mockingbird Designs cold biased the BATSAT satellite. The outer surface will be covered with solar arrays, and all remaining surfaces will be painted white. This prevents the satellite from exceeding hot temperature limits. To prevent certain satellite components from getting to cold, small thermal strip heaters with a thermostat will be used to heat up components. Since all components will be placed in a circular disk, components can also be warmed via thermal blankets. Also, the circular disk can be radiation hardened to increase satellite reliability.

When the satellite is transmitting over both X and Ka-Bands with heaters on, it will need 8.6 W of power. This maximum power requirement will be fulfilled using silicon solar arrays and nickel-cadmium batteries. The solar arrays will be surface mounted to the honeycomb skin structure to offer omni-directional solar flux coverage. A peak power tracker will be used to smooth out the power from the arrays. Both the solar arrays and the batteries are designed for a 10 year lifetime. Four batteries will be used: one for the first five years, one for the second five years, and two redundant batteries.

The BATSAT satellite will be lofted into an 1163 km, 70° orbit by the Pegasus launch system. This orbit fulfills the DSN dish slew rate requirement of .4 deg/s while also keeping the satellite out of the heaviest regions of the Van Allen radiation belts. Currently, only the Goldstone, California DSN dish can receive in Ka-Band, but the Canberra, Australia and the Madrid, Spain dishes will soon be upgraded. Each of the three DSN stations capable of receiving Ka-Band (Goldstone, Canberra, and Madrid) will have an average of 85 minutes of view-time per day. A seven day repeating groundtrack will allow for easy planning and view time estimates. The Pegasus launch system by Orbital Sciences Corporation will provide the launch services for BATSAT. Pegasus offers the lowest priced commercial launch option while providing many performance options that decrease satellite complexity. While the Pegasus system is relatively cheap (around $9 million), Mockingbird Designs is researching cheaper options such as shared launch and military surplus.

The current BATSAT design offers an excellent spaced-based platform for testing the merits of Ka-Band transmissions. The satellite fulfills the mission goals while keeping complexity and costs down.

However, the most important aspect of the BATSAT satellite is its receptiveness to university design. By using students to design, fabricate, and test the satellite structure, costs can be kept to a bare minimum. Many of the electronic components have been built by other university groups and can be adapted to the BATSAT design. Even though this satellite was designed specifically for the DSN/JPL testing project, the small satellite can easily be modified to carry scientific instruments. Mockingbird hopes that other missions will wish to use the BATSAT design for their small satellite applications.

1.0 INTRODUCTION

1.1 Background and Mission Statement

In the search for higher data transmission rates for spacecraft, the Deep Space Network (DSN) and Jet Propulsion Laboratory (JPL) are investigating the use of alternate radio-frequency bands for satellite communication. The fastest data transmission rates currently available are through X-band, and most space probes communicate over this band. Ka-band allows for a faster transmission rate, but is more susceptible to atmospheric interference than X-band (see Figure 1.1). However, the precise effects of the atmosphere (i.e. clouds, rain, air) on Ka transmissions have not yet been characterized, and DSN must study whether the advantage of faster communication through Ka will be offset by signal degradation due to the atmosphere. In order to study this problem, DSN and JPL have proposed deploying a small satellite that would transmit an identical signal over both X and Ka-Bands. Mockingbird Designs has named the satellite project BATSAT. Reflecting on the goals of the DSN and JPL project, the mission statement for the BATSAT is:

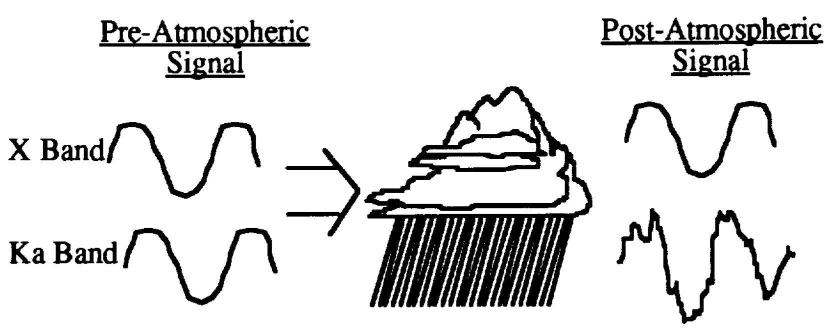


Figure 1.1: Atmospheric effects on radio transmissions.

- To provide simultaneous X and Ka-Band transmissions to the three 34-meter, high-efficiency DSN receivers to study the effects of the atmosphere on Ka-Band.

With simultaneous X and Ka-Band transmission, the atmospheric interference could be characterized by studying the comparative variations in the signals.

A secondary goal for the satellite is to aid in training new DSN personnel. By adding an S-Band transmitter, ground station trainees could use Doppler shift and blinking techniques on S-Band to determine the attitude and motion of the satellite. With 1 mW transmission power, BATSAT would look like a deep space probe and trainees could practice acquisition and attitude determination skills.

1.2 Project Scope and Goals

At the start of the project, the Mockingbird Design team set several goals to define the scope of the project. Mockingbird Designs is not the first design team to look at this mission. The Student Undergraduate Research Fellowship (SURF) presented their mission design in the SURFSAT project at California Institute of Technology. Mockingbird did not want to repeat or replace the work done by SURFSAT, but wanted to improve the design and offer different insight into the problem.

The primary goal of the project was to design the best space-based platform for studying Ka transmissions through the atmosphere. Other non-space based methods may be cheaper, but would not provide the wealth of data that a space platform will yield. Mockingbird also wanted to design a simple spacecraft using existing technology. Since the mission is very simple, there is no need for complex equipment or new technology. Both of these goals lead to the last, and perhaps most important goal: To design a spacecraft simple enough for college production. Throughout the design process, every decision was subject to this last consideration. The main focus of the team was to ensure that the design was simple enough for production in student materials labs and testing in university labs.

1.3 Spacecraft Requirements

Due to the scientific nature of the mission, the spacecraft must fulfill specific requirements. JPL established several requirements to guarantee that the scientific goals are satisfied. These requirements are as follows:

- Simultaneous transmission of X and Ka-Band
- 2-year minimum lifetime to characterize long term weather effects
- Low-cost, simple design.

In addition, the Deep Space Network also set several requirements to support its project objectives and limitations. These criteria include the following:

- A maximum dish slew rate of 0.4°/sec
- Signal power of 1 mW radiated by antenna
- S transmissions for training and research.

The BATSAT satellite must satisfy these criteria in order to fulfill its mission goals.

1.4 Mockingbird Performance Goals

Although JPL and the DSN set performance goals to ensure mission success, Mockingbird established its own performance criteria to improve the mission while incurring negligible cost increases. Specifically, Mockingbird designed the BATSAT spacecraft around several performance characteristics:

- A ten-year lifetime constrained by solar array degradation and nickel cadmium battery lifetime
- A seven-day repeating ground track, with an average view time of about 85 minutes per day per station
- Attitude determination using antennae interference patterns and blinking techniques.

Mockingbird has designed BATSAT to exceed JPL and DSN requirements, and to provide the best science data possible.

Mockingbird has also designed BATSAT to provide several enhanced performance options to accommodate JPL and DSN project modifications. Specifically, these optional design features are as follows:

- Passive instrument capability
- Options for multiple satellite launch to provide redundancy and to reduce mission costs
- A gravity gradient optional design for laser communication testing.

Mockingbird hopes that these options will allow JPL and DSN to vary the design as the need arises for greater scientific return at a lower cost. Also, if this design is built by university production, these options could easily be added.

1.5 Concerns

Currently, Mockingbird's biggest concern is reducing launch costs. Options include using a multiple launch system on a booster such as Ariane or Pegasus. A multiple launch would likely involve sharing the booster with one or two other small satellite payloads. The ORBCOMM satellites being launched into constellation by the Pegasus system could offer an attractive option. Since the orbit of BATSAT is critical to the mission design, these other satellites on a shared launch would need to have orbits above 1095 km altitude to satisfy the slew rate constraint. Another major design concern is satellite radiation hardening. Even though BATSAT's orbit will be well below the intense inner Van Allen Radiation Belt, some hardening will probably be needed to increase satellite lifetime. Radiation hardening analysis will be performed upon receipt of electronics hardware specifications.

The current satellite design is vulnerable to single point hardware failures that would destroy the mission. However, redundancy in hardware increases production costs and control complexity. Therefore redundancy will be accomplished through multiple satellites instead of multiple subsystems.

The current BATSAT design satisfies all criteria and requirements for the mission. Mockingbird Designs has confronted many technical hurdles to keep the design as inexpensive and reliable as possible. Mockingbird believes that the BATSAT project also fulfills the project goals of being simple and inexpensive. The design team feels that the University of Texas possesses all of the tools necessary to construct and test the satellite, and should continue design and construction.

2.0 STRUCTURES

2.1 Introduction

To design an appropriate structure for the BATSAT mission, three broad requirements were specified. The first requirement that the BATSAT structure must fulfill is to provide a physical platform for the payload. This requires that the structure fit inside the payload envelope of the Pegasus launch vehicle, provide enough volume to hold the internal components, and provide external mounts for solar cell arrays and antennae.

The second requirement is that the structure be able to survive the Pegasus launch environment. The structure will experience significant accelerations along both the rocket center-line and normal to the center-line. In addition, the BATSAT structure must have a fundamental frequency large enough so as not to resonate at launch vibration frequencies.

Finally, the BATSAT structure must have a suitable mass distribution. The launch vehicle manufacturer has constraints on the center of gravity location and how far it can move from its original position on the rocket center-line. Any structural deflections must be small enough not to violate the constraints on the center of gravity. Also, since BATSAT will be spin stabilized, the maximum moment of inertia must occur about the spin axis.

2.2 Structural Design

Because BATSAT should have a simple structure, a spherical design was chosen for the spacecraft. A spherical design allows for the uniform placement of antennae and solar cells over the surface, avoiding the need for active attitude control. In an effort to avoid potential pitfalls in the structural design process, the designs of similar spacecraft were studied.

The design of BATSAT's structure was an iterative process. During the conceptual design phase, a gravity gradient design was weighed against the spherical structure. Mockingbird decided that the gravity gradient design was overly complex, thus reducing mission reliability and increasing development costs. However, Mockingbird has kept the gravity gradient design as an alternative if a satellite pointing became a necessity. Once the spherical structure was selected as the primary design choice, study of the internal support structure began. The first design considered was similar to that of the Philco Corporation's Courier satellite [Courier]. This design consisted of a central axial member that was connected via pinned rods to a large equatorial support ring. Mockingbird concluded that such a design would not provide adequate support to the solar-cell-covered skin, possibly leading to local buckling of the skin during launch. The central axial member design was discarded in favor of a faceted-sphere frame design similar to that of AT&T Bell Laboratory's Telstar 1 [Brown: 245, 295], as shown in Figure 2.1. The faceted-sphere structure was selected as the primary BATSAT structural design. It provides well-supported mounting locations for the skin panels, and provides an internal cavity in which an instrument package can be placed. This design allows for easy mounting of solar panels, which greatly simplifies the construction process.

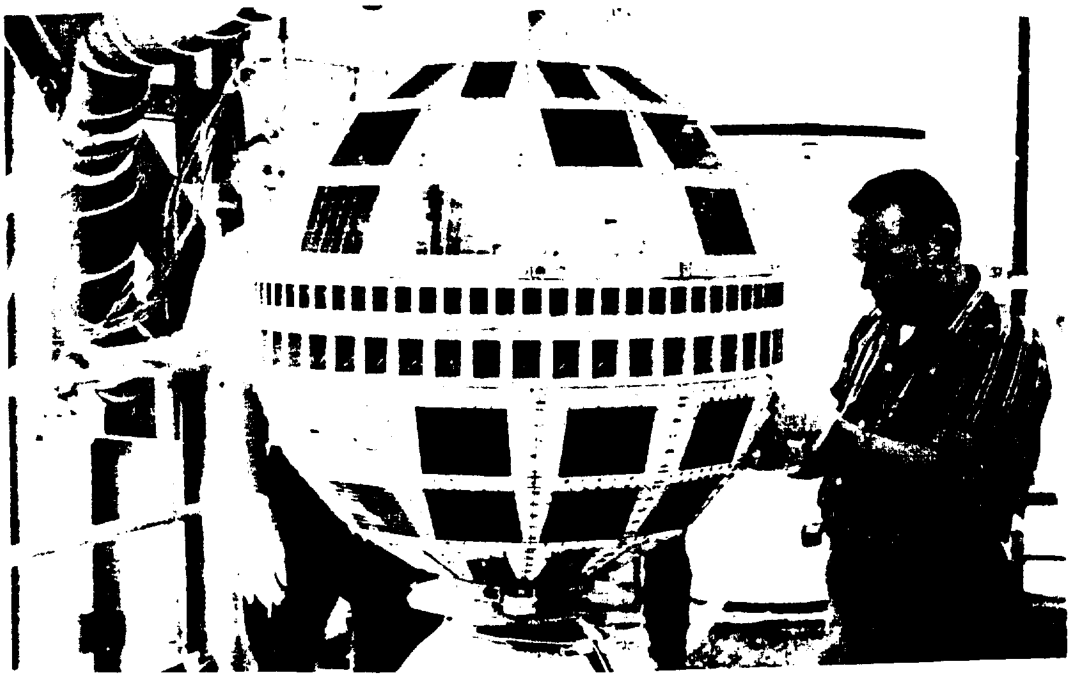


Figure 2.1: Bell's Telstar satellite.

The final BATSAT structural design is a variant of the Telstar 1 structure. The internal support is provided by an aluminum 6061-T6 space frame shown in Figure 2.2. The frame consists of twelve sections placed at 30° increments about the structure center-line (see Figure 2.2). The frame consists of 0.25" x 1.00" channel members welded together. Each frame section is connected to adjacent sections by circumferencial support members (Figure 2.3). The circumferencial members are aluminum 6061-T6 members with solid 0.125" x 1.00" cross sections. There are two sets of these members at each bend in the outer frame, and a single set at the launch ring interface.

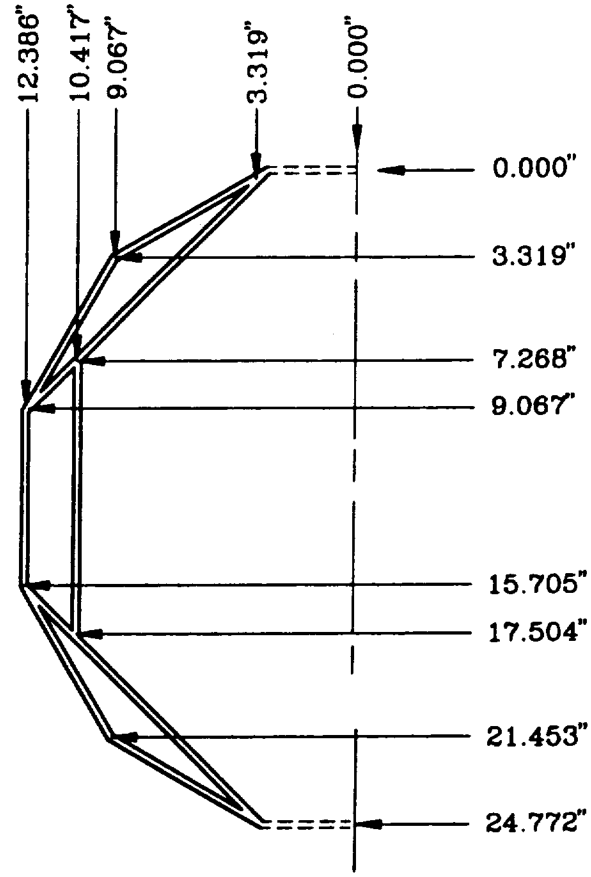


Figure 2.2: CAD Drawing of frame.

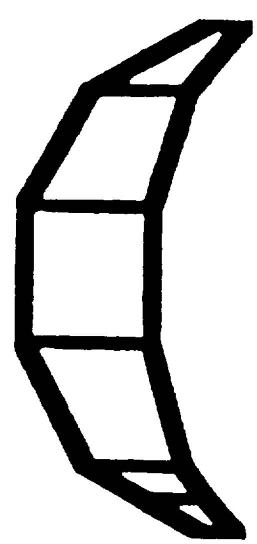


Figure 2.3: Picture of truss structure.

The structure has an overall diameter of 0.64 meters. Once the frame is constructed, skin panels, consisting of honeycomb material sandwiched between aluminum 6061-T6 plates, are attached to the frame via locking bolts. The use of locking bolts ensures that skin panels can be removed during assembly if necessary, but that thermal cycling will not cause slop once BATSAT is in orbit. Compliant washers will be placed between the frame and the skin panels to protect the solar cells from the launch vibrations. The truss structure will be built in two hemispherical sections to allow easy access to components during construction.

2.3 Initial Structural Modeling

To verify the BATSAT structural design, a NASTRAN computer model was developed (see Appendix A for a selected listing of the NASTRAN model). Table 2.1 lists the simplifications to the actual BATSAT design that were used to create the NASTRAN model.

Table 2.1: NASTRAN Model Simplifications

Item	BATSAT Structure	NASTRAN Model
Frame element cross sections	0.25" x 1.00" channel	0.25" x 0.25" solid
Circumferencial element cross sections	0.125" x 1.00" solid two sets at each bend	0.25" x 1.00" solid one set at each bend
Skin panels	Honeycomb and aluminum sheets	Single aluminum sheets 0.12" thick

The NASTRAN model was used to determine the structure's fundamental frequency and its response to the maximum launch accelerations. A FORTRAN program named MODIFY was written to generate the grid points for the NASTRAN model (see Appendix A for program listing). Both the NASTRAN code and MODIFY program assume fundamental SI units. The frame and circumferencial members were modeled using BAR elements, and the skin panels were modeled using QUAD4 and TRIA3 elements. Translational motion was constrained at the grid points where the launch ring would attach; no other grid points were constrained. The constrained grid points correspond to a launch ring with a 0.315 meter diameter. The actual ring turned out to be 0.245 meters in diameter, but the NASTRAN results should be approximately correct. The fundamental frequency of the BATSAT structure was found by running a separate, but linked NASTRAN program. The structural model was subjected to an 11 g acceleration in the direction of the Pegasus center-line, and a 3.5 g acceleration normal to the center-line. Figure 2.4 shows the spacecraft's z-axis, as well as the component containment structure mounted inside.

After running the NASTRAN model of the BATSAT structure, it was apparent that the structure would satisfy all constraints by several orders of magnitude. The maximum normal stress contours in the skin panels are plotted in Figure 2.5. No detailed analysis on skin panels was carried out due to time constraints. The contour plot was generated to help future Mockingbird engineers focus on high stress areas.

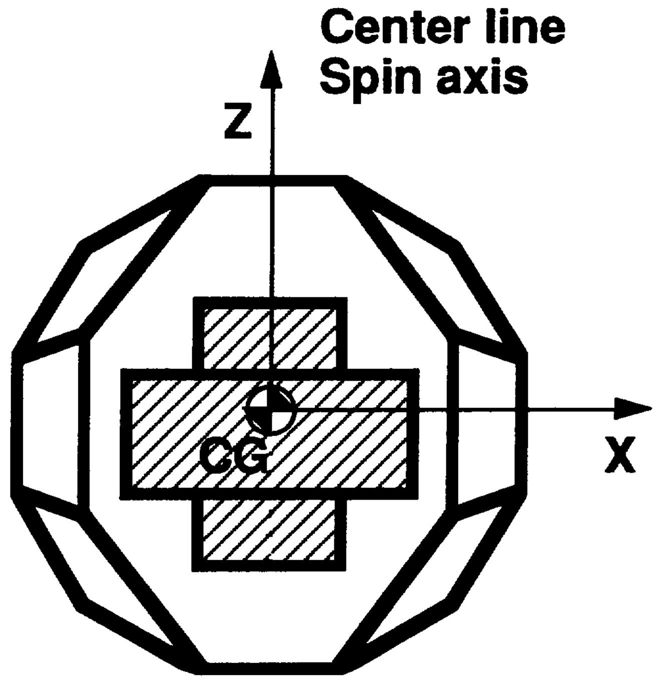


Figure 2.4: Z - axis of satellite structure along with component disk.

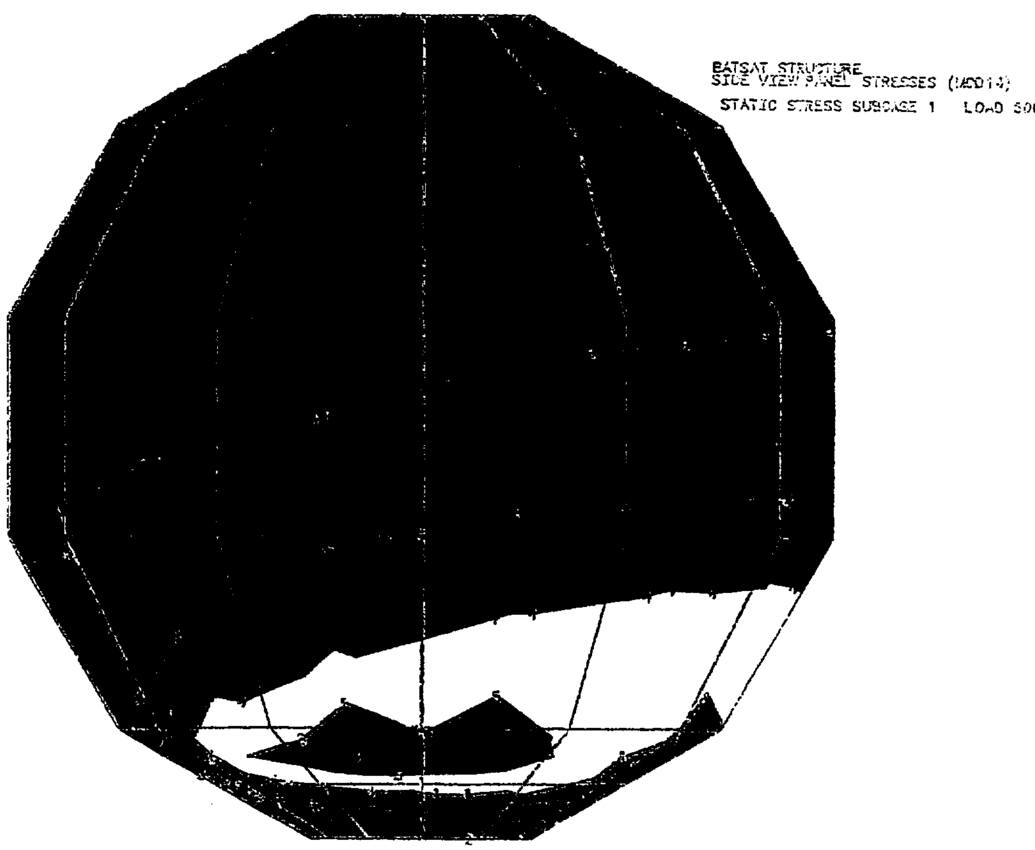


Figure 2.5: Color contour plot showing the relative stresses in the skin elements.

While the yield stress for 6061-T6 aluminum is 2.7E8 Pa [Gere and Timoshenko: 31], the maximum compressive and tensile axial stresses encountered were only 1.1E6 Pa and 2.69E5 Pa respectively. The critical buckling load for the longest members was 4.1E5 N, while the maximum compressive axial load encountered was 4.5E1 N. For the Pegasus, the fundamental frequency was constrained to be greater than 20 Hz. The fundamental frequency of the BATSAT structure was found to be 181 Hz. Figures 2.6 and 2.7 show views of the NASTRAN model's exterior.

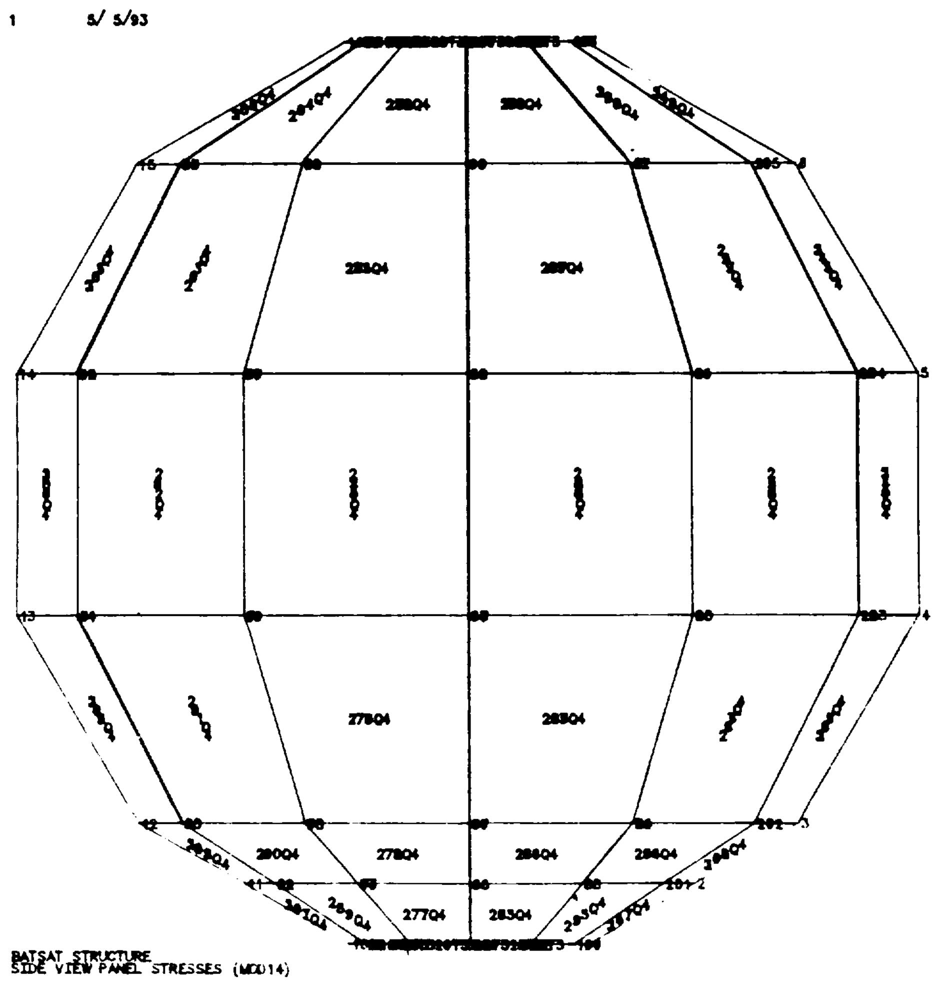


Figure 2.6: Side view of NASTRAN plot.

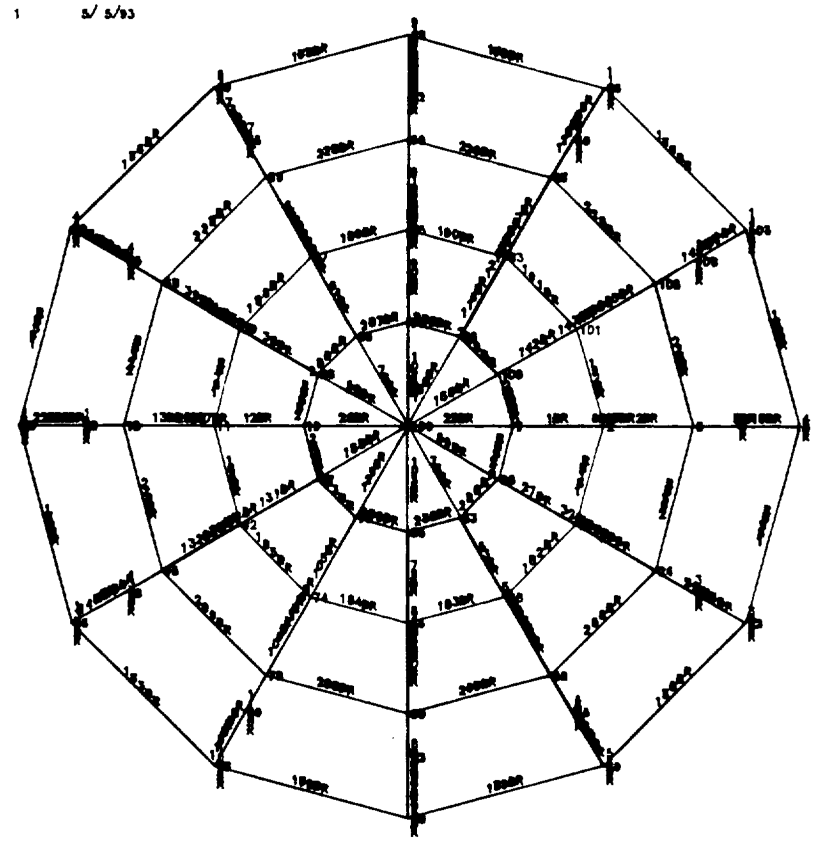


Figure 2.7: Top view of NASTRAN plot.

2.4 Structural Integration

To fulfill the BATSAT mission, the structural design was integrated with the communication, power, and spin stabilization requirements. For thermal control reasons, it is desirable to consolidate the electronic instruments into a single instrument package inside the BATSAT frame. Approximately 0.6 m^3 volume is needed to house the electronic communication and power equipment. Using this volume as a design constraint, the final design provides approximately 0.63 m^3 of volume for the electronic equipment. Figure 2.4 shows the component disk mounted inside the spacecraft structure. Once the instrument package is completed, it is mounted onto the structure via nylon cords, which will absorb much of the launch vibrations.

2.5 Spacecraft Overview

The mass budget for the final design is given in Table 2.2.

Table 2.2: Mass Budget

No.	Element	Comments, Heritage	Unit Mass	Total Mass
	Communication			**4.85 kg**
1	Ka Transmitter	SURFSAT, pre-tested	1.00 kg	1.00 kg
1	X Transmitter	SURFSAT, pre-tested	0.70 kg	0.70 kg
1	S Transmitter	SURFSAT, pre-tested	0.42 kg	0.42 kg
8	X Antenna	SURFSAT, pre-tested	0.06 kg	0.48 kg
8	Ka Antenna	SURFSAT, pre-tested	0.08 kg	0.64 kg
8	S Antenna	SURFSAT, pre-tested	0.08 kg	0.64 kg
0	Ku Antenna	SURFSAT, pre-tested	0.10 kg	0.00 kg
	Cables		0.97 kg	0.97 kg
	Power			**8.07 kg**
1	Peak Power trkr.	Off the shelf, space qual	3.00 kg	3.00 kg
1	Solar Array	Lockheed space qual. Si	1.95 kg	1.95 kg
2	Ni-Cad Batteries		1.40 kg	2.80 kg
	Cables		0.32 kg	0.32 kg
	Thermal & Radiation			**8.20 kg**
1	Blankets		3.00 kg	3.00 kg
2	Strip Heaters	Minco	0.10 kg	0.20 kg
1	Shielding		5.00 kg	5.00 kg
	Command Sys			**2.60 kg**
1	X Receiver	SURFSAT, pre-tested	0.60 kg	0.60 kg
1	Logic Circuits		2.0 kg	2.00 kg
	Structure	NASTRAN Model		**16.60 kg**
	Payload			**0.00 kg**
0	Grav Meter		10.00 kg	0.00 kg
0	Radiation Meter		10.00 kg	0.00 kg
0	Voltage Meter		3.00 kg	0.00 kg

Margin	20%

S/C Dry Weight	**48.4 kg**
Launch Adapter	17.0 kg
Boosted Weight	65.4 kg

Total Launch Mass =	**65.4 kg**

The masses of the electrical equipment were provided by the SURFSAT team at JPL, and the structure mass was computed by NASTRAN. After adding a 20% contingency factor and accounting for the launch adapter ring, the estimated total boosted mass is 65.4 kg. This mass is well below the Pegasus mass-to-orbit constraint for the BATSAT orbit.

Once the total BATSAT mass was determined, the distribution of that mass had to be specified. Orbital Sciences Corporation (OSC) requires that the payload center-of-gravity not move along the Pegasus' center-line more than 13 mm from its original position, and not more than 6.4 mm normal to the Pegasus' center-line [Pegasus User Guide, 5-10]. The NASTRAN model revealed a maximum structural deflection of 3.3E-5 meters. It is reasonable to conclude that even with relatively flexible nylon attachments, the center of gravity will remain within OSC's constraints.

To ensure stable spin, the maximum moment of inertia must occur about the z-spin axis (Figure 2.4). The maximum moment of inertia of the structure does not occur about the spin axis, but by placing the instruments in disk shaped packages, the maximum moment of inertia was made to occur about the spin axis. These moments of inertia are listed in Table 2.3.

Table 2.3 Moments of Inertia ($kg*m^2$)

	$I_{spin\ axis}$	$I_{lateral\ axis\ 1}$	$I_{lateral\ axis\ 2}$
Structure	1.028	1.118	1.118
Instrumentation	0.979	0.559	0.559
TOTAL	2.01	1.68	1.68

During production, the electronic components could be arranged such that

$$I_{\text{lateral axis 1}} \neq I_{\text{lateral axis 2}}$$

so that a marginally stable condition is avoided.

A full-scale segment of the BATSAT structure was manufactured to study possible production methods (see Figure 2.8). Based on this prototype, each of the twelve segments seen in Figure 2.2 will be constructed by welding individual members. A jig would then be constructed to hold these segments while they were joined together by welding the circumferencial members to the frame joints. In this manner, two hemispheres would be built. These two hemispheres would remain separate until the final stages of production to preserve accessibility to the instrument package. Once the hemispheres are joined, the skin panels are bolted onto the frame with locking bolts and compliant washers.

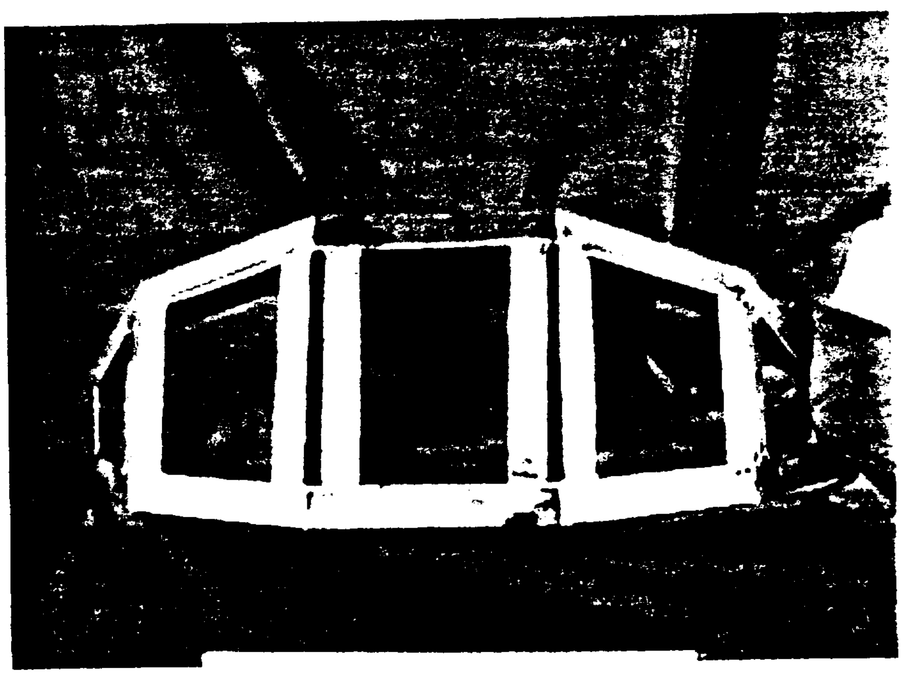


Figure 2.8: Welded structure built as production model.

2.6 Recommendations

Mockingbird Designs offers several recommendations can be made for continued work on the BATSAT structure:

- Replace the NASTRAN approximations for member cross sections and skin panel material with the actual final design values (see Table 2.1)

- Study skin panel stresses to check for local buckling and deflections great enough to break the glass covered solar cells mounted on the skin panels

- Model launch vibrations in a dynamic NASTRAN program

- Study manufacturing techniques to improve the manufacturability of the structure.

By continuing on these recommendations, Mockingbird feels that the BATSAT satellite will be an excellent generic small satellite, offering ease of production and low cost.

3.0 COMMUNICATION AND POWER DESIGN

3.1 Introduction

The communication hardware is the scientific payload for BATSAT. The communication power requirements determine the sizing of the power subsystem. If a passive sensor is added to the design, the increase in the power requirement will be minimal. All sizing numbers include a 20% contingency factor. Some of the communication and power hardware require active thermal control, which slightly increased BATSAT's power requirements through small thermal heaters.

3.2 Communication Design

The communication subsystem is described by its hardware and its operation modes. The hardware consists of electronic components, such as transmitters, receivers, and antennae. The operation modes determine which transmitters are on and which antennae are transmitting the signal.

An undergraduate research group at the California Institute of Technology has worked on this project before in the SURFSAT program. They bought and/or made the communication equipment that BATSAT will need. Mockingbird wants to integrate this equipment into the BATSAT design to reduce production costs.

BATSAT can transmit on three radio-frequency bands, Ka, X, and S. Table 3.1 details the communication equipment. The signal-to-noise ratio for all of the communication links is well within tolerance levels. The X-Band command receiver handles the instructions from ground stations.

Table 3.1: Communication Subsystem Characteristics

	Downlink Frequency (GHz)	Uplink Frequency (GHz)	Emitted Power (mW)	Signal to Noise Ratio
Transmitters				
Ka-Band	31.9096	-	1	42
X-Band	8.451	-	1	43
S-Band	2.2895	-	1	44
Command Receiver	-	7.19	-	28

[Source: SURFSAT PDR]

There are four satellite operation modes. In the primary mode, BATSAT will transmit on both X-Band and Ka-Band, using four antennae for each band. There are two S band operation modes. In training mode, BATSAT will transmit in S band with all four antennae. In attitude determination mode, BATSAT will transmit with only one antenna. This will allow DSN personnel to determine the attitude motion of the satellite by measuring the blinking signal. During off mode, the collected solar power will be dedicated to battery recharge and heaters.

3.3 Antenna Design

BATSAT wishes to use the antennae built and tested by the SURFSAT design group. This decision was made to minimize development costs and simplify the design procedure. These antennae meet the mission requirements and are easily integrated into the BATSAT design. Illustrations of two (S and Ka) of the SURFSAT antennae are shown in Appendix B.

BATSAT does not have attitude control therefore it will be subject to perturbations that may cause it to tumble. Consequently, the placement of the antennae must be such that the signal will be omni-directional. To meet this requirement, BATSAT will need four antennae for each transmitter. These antennae will be placed on the surface of BATSAT, equidistant from one another. The antennae will be mounted at the nodes of intersecting satellite panels. This configuration is illustrated in Figure 3.1. BATSAT has a set of redundant antennas for each transmitter, for a total of 28 antennas on the satellite, including the four X-Band receiving antennae.

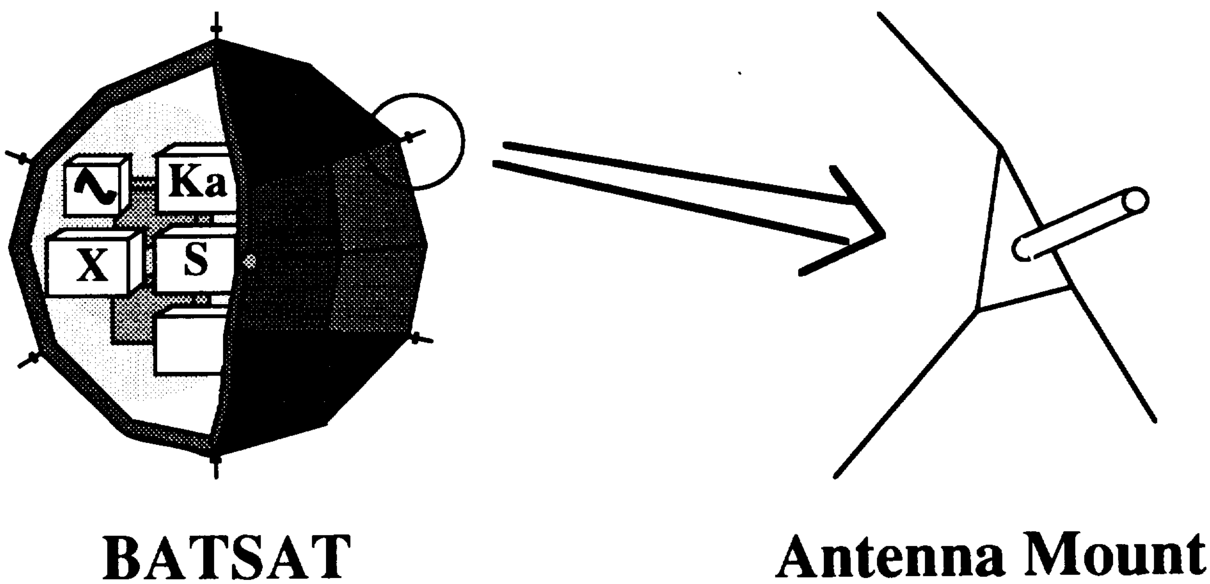


Figure 3.1: Antenna mounting schematic

An example of the radiation pattern for the omni-directional antenna is seen in Figure 3.2. Because four antennae will be transmitting at the same frequency at once, they will create an interference pattern. The interference pattern can be characterized, allowing an interference filter to be developed [Lundberg]. It is important to note that the interference effects on the signal are distinguishable from the attenuation effects of the atmosphere. Once the filter is designed, the atmospheric effects can be separated and analyzed from the normal signal variations due to the satellite itself.

Currently, the only DSN antenna that can handle Ka-Band is located in Goldstone, California. However, DSN intends to upgrade the stations in Madrid, Spain and Canberra, Australia to provide Ka-Band capability. All three of these high efficiency antennae are 34 m in diameter and have a slew rate of 0.4° per second The precise locations of the DSN stations are shown in Table 3.2. These antennae are currently used to communicate with deep space probes, such as Ulysses and Galileo, using X-Band frequencies.

Table 3.2: DSN Station Coordinates

DSN Station	Latitude	Longitude
Canberra	35.0 ° S	149.1 ° E
Goldstone	35.4 ° N	116.8 ° W
Madrid	39.5 ° N	3.5 ° W

In order to determine the attitude of the satellite, BATSAT can be commanded to enter attitude determination mode. During this mode, three of the S band antennae will switch off. By analyzing the blinking signal of the single S band transmission, the attitude of the satellite can be determined [Kinmam]. This option will also be useful for training operations at the DSN stations.

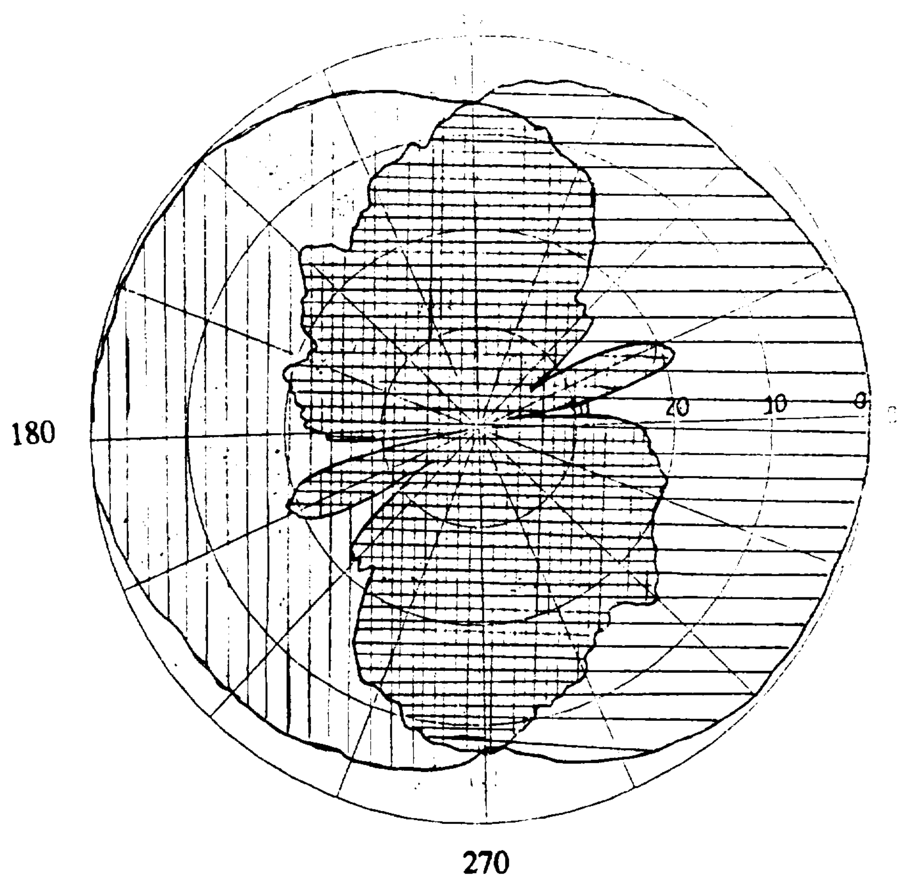


Figure 3.2: S band antenna radiation interference pattern
[Source: SURFSAT PDR]

3.4 Power System

The electrical power subsystem comprises three major parts: power generation, distribution, and storage. This subsystem must provide the capability to generate 8.6 W at the end of BATSAT's 10 year lifetime. It will also include the capability to operate during eclipse cycles.

3.4.1 Electric Power Generation

Since the design lifetime of BATSAT is ten years, the satellite will need to generate its own electric power during the mission. Primary, or non-rechargeable, batteries are not a suitable energy source, since the loads would drain the batteries before the end of the mission [Wertz and Larson:402]. Longer-lived sources of electricity include photovoltaic (solar) cells, thermodynamic-cycle engines, radioisotope thermoelectric generators (RTGs), and nuclear reactors. Considering safety, complexity, cost, and power requirements, photovoltaic cells are the most logical choice to provide power for BATSAT.

The primary constraint in sizing a solar array is the power required by the satellite. BATSAT must be able to transmit in one of two modes: X and Ka simultaneously, and S only. Maximum power consumption of the satellite is 8.6W. The solar array is therefore sized to provide 8.6W of power at the end of a ten-year lifetime.

For power collection, BATSAT will have surface-mounted, omni-directional solar arrays. Flight-qualified solar cells are made from either silicon (Si) or gallium-arsenide (GaAs). Si cells are inexpensive and have been used in space for nearly thirty years. These cells convert about 14% of the incident solar radiation into electricity. GaAs cells are more efficient (18% conversion) and more radiation-resistant than Si cells, but GaAs cells have not been flown extensively. GaAs cells also cost about seven times as much as Si cells [Wertz and Larson:354]. Therefore Silicon cells were chosen as the most cost-effective cell type for the BATSAT mission. Figure 3.3 shows a cross-section of a typical body-mounted solar cell. (Note that the layers of material in front of and behind the solar cell act as radiation shielding.)

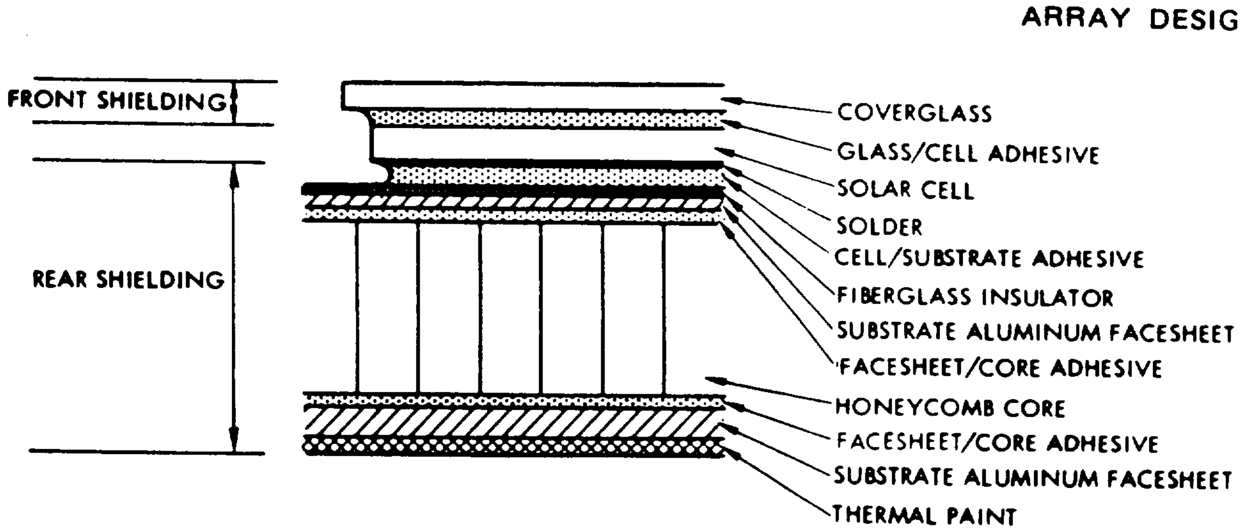


Figure 3.3: Typical solar cell cross-section [Rauschenbach:141].

The solar cell array is designed to generate certain voltage and current levels. The satellite's bus voltage is determined by the number of series-connected cells, or "strings" (see Figure 3.4). The bus current is determined by the number of parallel-connected strings [Wertz and Larson:399]. Parallel strings prevent total power loss if a single string fails. Isolation diodes between a string's cells prevent energy from lit cells from damaging shadowed cells. These design techniques lower the overall efficiency of the array, but are necessary for it to operate properly [Wertz and Larson:400].

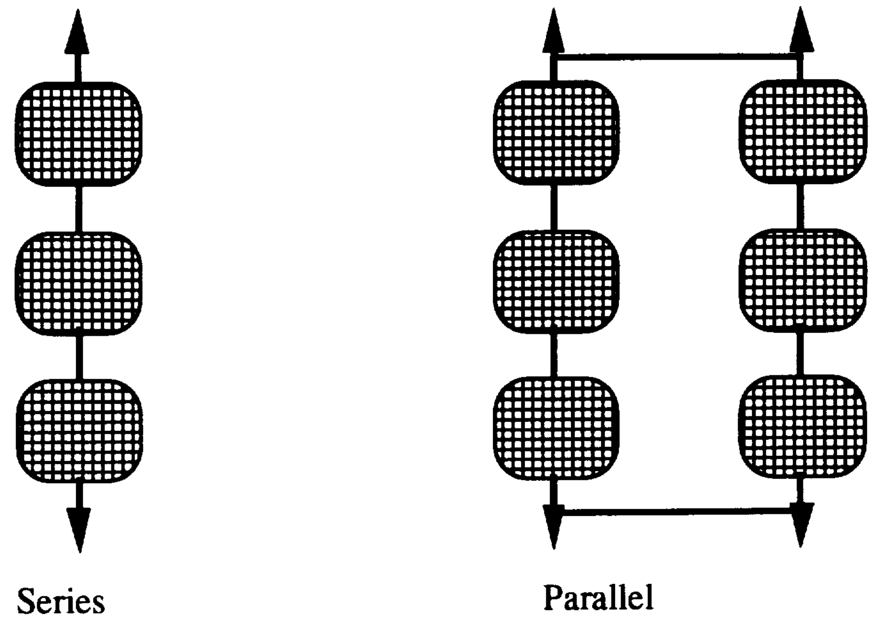


Figure 3.4: Series "string" and parallel-connected strings.

The approximate solar array area was found by using an algorithm from *Space Mission Analysis and Design* [Wertz and Larson:356-58]. The various parameters and assumptions used in the spreadsheet calculations may be found in Appendix B, along with the generated data. The sizing yielded an area of 0.687 m^2 for an omni-directional (spherical) array of silicon solar cells. This area corresponds to a sphere of radius equal to 0.24 m. BATSAT is larger than this ideal size, since it requires extra volume for the instrument package (see Section 2.4). Stabilized, Sun - pointing arrays could be built with less surface area, but such complexity is not necessary for BATSAT. The body-mounted silicon array will provide the 8.6W maximum required power for up to ten years.

3.4.2 Power Distribution

The power output of the solar array will vary as BATSAT rotates in the sunlight. A steady power level can be provided by either direct energy transfer or peak-power tracking. Electrical power must then be controlled and distributed to the various loads. Direct energy transfer (DET) uses shunt resistors to dissipate power not being used by the satellite's systems. The DET method is simpler than most methods, but produces waste heat. The peak-power tracker (PPT) "tracks" the solar array's peak-power point to match the satellite's power demands [Wertz and Larson:407], as shown in Figure 3.5. The more efficient PPT is the design choice for BATSAT power regulation.

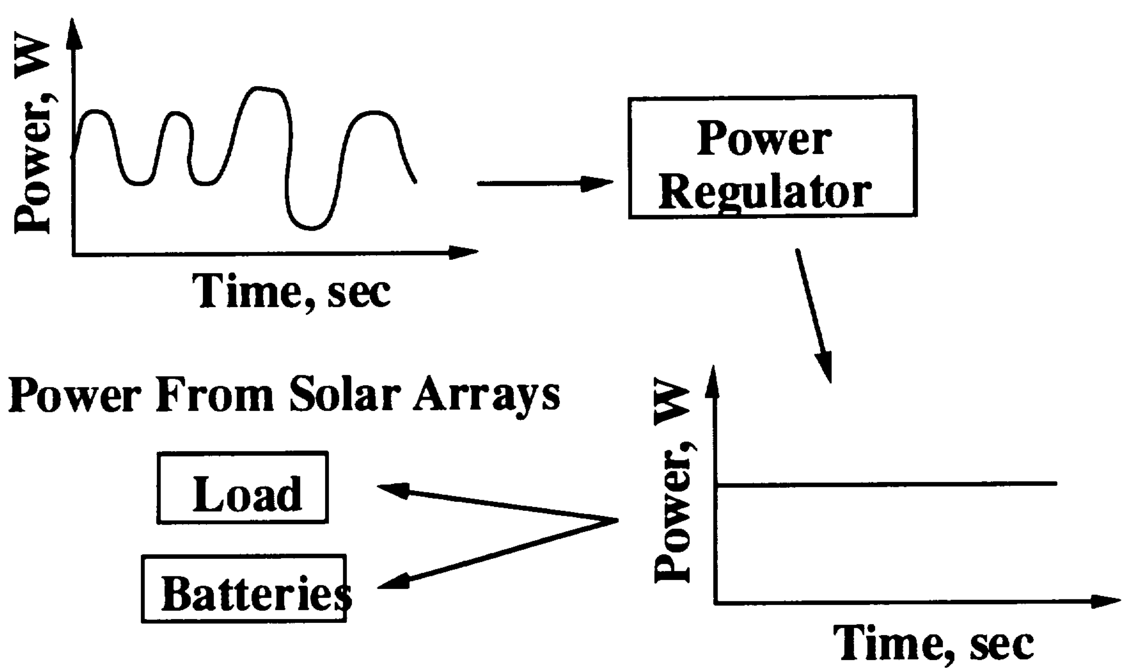


Figure 3.5: Diagram of BATSAT power system.

In addition to a power converter, BATSAT requires a command receiver, relays, wiring, and fuses. The receiver and relays allow ground operators to control the various transmitters. Fuses protect the electronic subsystems in the event of a short circuit.

The loads (payload and battery recharging) require specific voltages from the power source. Since voltage regulators produce electromagnetic interference when used with peak-power trackers, BATSAT will have an unregulated power subsystem. Because the power is unregulated, the load bus voltage must be the same as the voltage of the batteries [Wertz and Larson:407]. Some loads may require further DC-DC conversion to overcome this voltage limitation.

3.4.3 Energy Storage

BATSAT will be equipped with rechargeable batteries in order to operate continuously throughout its mission. The voltage of a battery is determined by the number of series-connected cells in the battery; bus current is determined by the number of batteries in parallel. BATSAT will use nickel-cadmium (NiCd) batteries. NiCd batteries have low energy density, but they are used extensively and are currently the only non-experimental batteries qualified for low Earth orbit [Wertz and Larson:403].

The life cycle of a battery system is the number of times the satellite may switch between charging and discharging of the batteries, and is the primary constraint when sizing the batteries. The longer the cycle life, the less the batteries may be discharged in any one cycle. For a battery lifetime of five years in low Earth orbit, experience shows that the maximum depth of battery discharge is about 20%, as shown in Figure 3.6.

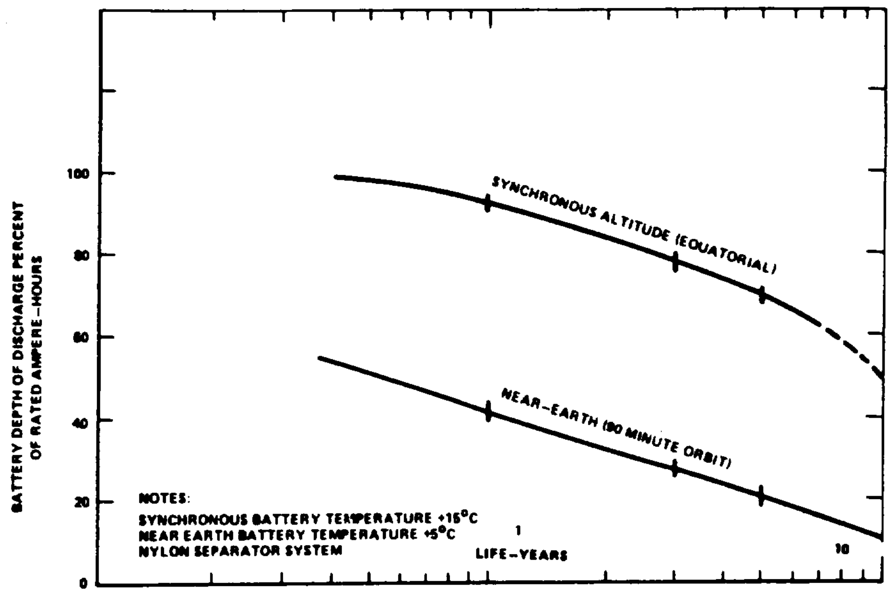


Figure 3.6: Maximum design use of spacecraft NiCd batteries [Source: Chetty:158].

The batteries must have a capacity of 2.06 Amp-hours (see Appendix B for the battery sizing approximation). General Electric manufactures a NiCd cell with a capacity of 3A-h. Connecting twelve of these 1.25V cells in series would provide BATSAT's 15V bus voltage. Normally satellites have a 27.5 V bus voltage, but most of the communication equipment designed by SURFSAT utilizes 15V. One 3A-h cell has a mass of 0.155 kg and a volume of about 70 cm^3, so the twelve-cell battery is about 1.86 kg and 840 cm^3. Additional batteries will provide extra capacity and redundancy. More batteries of lower capacity could provide the same initial capacity and partial redundancy. The lower-capacity batteries, however, would have a larger total mass and volume than the higher-capacity batteries [Chetty: 159]. BATSAT will have two 3A-h batteries operating at any given time. A second set of two batteries will be activated once the first set degrades below an acceptable level. This second set of batteries will allow nighttime operation over the entire ten-year lifetime of BATSAT.

The batteries will be recharged by the solar cells during the lit cycle. Since BATSAT's batteries are not designed to operate more than five years, a simple and inexpensive parallel charging system will be used. Parallel charging does not permit control of the charging current in individual batteries, and can increase battery degradation [Wertz and Larson:409]. Considering BATSAT's size, mass, and lifetime constraints, however, the parallel charger is the best choice.

Rechargeable nickel-cadmium batteries, charging in parallel, are the simplest and most reliable method of storing energy for BATSAT. NiCd batteries work best between temperatures of 5°C and 20°C [Wertz and Larson:318]; the BATSAT thermal environment should be maintained in this range. Also, the batteries will degrade over time, and will not perform well after five years. Therefore the satellite is designed to switch to a second set of batteries after the first set degrades.

3.5 Thermal Control

Figure 3.7 shows BATSAT's thermal environment. Table 3.3 shows the EXCEL spreadsheet used to calculate the thermal flux experienced by BATSAT and the maximum and minimum temperatures experienced. Table 3.4 contains the maximum and minimum allowable temperatures. The table also shows whether BATSAT violates these temperatures. As shown in the tables, both the communications equipment and the batteries violate the minimum allowable temperatures , while only the batteries violate the maximum temperature constraint.

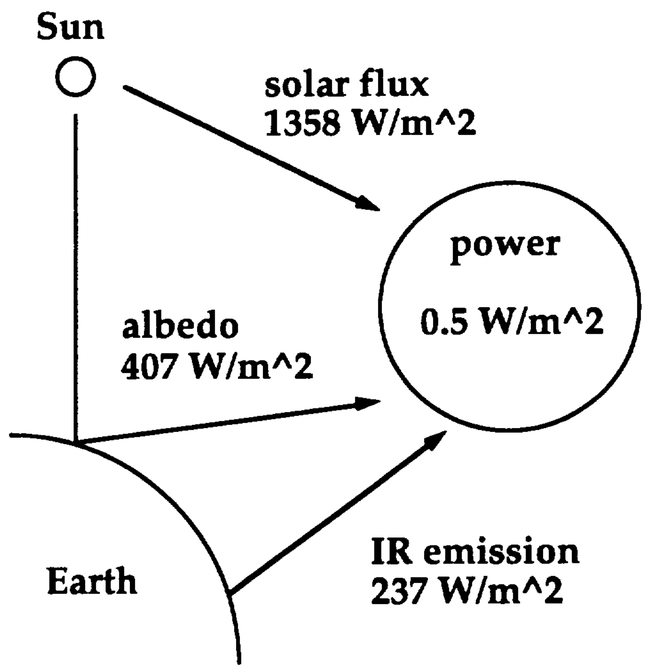


Figure 3.7: BATSAT's thermal environment

BATSAT must employ both active and passive thermal control in order to meet both of the temperature constraints. The exterior of BATSAT will be cold biased by painting the surface not covered by solar cells with white paint. This will ensure that none of the maximum allowable temperatures are reached. Some of the components will now require heating in order to remain above the minimum temperatures. To accomplish this, the batteries and communication equipment will be insulated with a thermal blanket, and strip heaters will be attached to the individual components. These heaters will be connected to a thermostat which will turn them on and off as required. Tables 3.5 and 3.6 show the cold biased thermal environment of BATSAT.

Table 3.3: BATSAT's Thermal Model Spread Sheet

quantity	symbol	value	units	comments
solar constant	Gs	1363	W/m^2	worst case hot (wch)
		1353	W/m^2	worst case cold (wcc)
Earth IR emission	ql	258	W/m^2	wch
		216	W/m^2	wcc
albedo	a	0.35	none	35% multiplier of solar constant wch
		0.25	none	25% multiplier of solar constant wch
electric pow. dissapt'n	Qw	0.52	Watts	assumed value of 5% of peak power (10.4 W) wch
		0	Watts	everything off wcc
Stefan-Boltzman const	s	5.7E-08	W/(m^2•K^4)	
solar absorptivity	a	0.805		100% solar array surface
IR emissivity	e	0.825		100% solar array surface
angular radius of Earth	r	1.00844	radians	derived from arcsin[RE/(h+RE)]
Earth radius	RE	6378000	meters	
altitude	h	1161000	meters	
Sun -Earth factor	Ka	0.98296	none	accounts for collimated solar energy off of spherical Earth Ka=.664+.521(rho)-.203(rho)^2
solar array efficiency	h	0.1	none	reasonable value
diameter of sphere S/C	D	0.3	meters	
Worst Case Hot Temp (Tmax) =		33.55638455	degrees C	
Worst Case Cold Temp (Tmin) =		-90.9764684	degrees C	

(source: Wertz & Larson pg. 423-425)

Table 3.4: Allowable temperature ranges

Component	Temp Range (deg C)	hot limit exceeded	cold limit exceeded
electronics	0 to 40	no	yes
batteries	5 to 20	yes	yes
solar arrays	(-100) to 100	no	no
structures	(-45) to 65	no	yes

(source: Wertz & Larson pg. 410)

Table 3.5: BATSAT cold biased thermal environment

Quantity	symbol	value	units	comments
solar constant	Gsh	1363	W/m^2	worst case hot (wch)
	Gsc	1353	W/m^2	worst case cold (wcc)
Earth IR emission	qlh	258	W/m^2	wch
	qlc	216	W/m^2	wcc
albedo	ah	0.35	none	35% multiplier of solar constant wch
	ac	0.25	none	25% multiplier of solar constant wch
electric pow. dissapt'n	Qwh	1.1334	Watts	assumed value of 15% of peak power wch
	Qwc	0	Watts	everything off wcc
Stefan-Boltzman const	σ	6E-08	W/(m^2•K^4)	
solar absorptivity	alpha	0.68		for 80% solar and 20% wt. paint
IR emissivity	ε	0.863		for 80% solar and 20% wt. paint
angular radius of Earth	ρ	1.008	radians	derived from arcsin[RE/(h+RE)]
altitude	h	1163.1	meters	
Sun -Earth factor	Ka	0.9829	none	accounts for collimated solar energy off of spherical Earth Ka=.664+.521(rho)-.203(rho)^2
diameter of sperical S/C	D	0.47	meters	
Worst Case Hot Temp (Tmax) =		19.6 °C		
Worst Case Cold Temp (Tmin) =		-91.3 °C		

Table 3.6: Allowable temperature ranges

Component	Temp Range (deg C)	hot limit exceeded	cold limit exceeded
electronics	0,40	n	y
baterries	5,20	n	y
solar arrays	(-100),100	n	n
structures	(-45),65	n	y

3.6 Command System

BATSAT uses a 4 pulse-cyclic command system for each of the four major sections: power, transmitters, redundant antennae, and sensor. The ground station sends individual pulses to the satellite, and the command system cycles through the modes of a particular system until the desired mode is reached. One of the problems of this type of command system is that the ground station is not always able to determine the command state of the satellite. Therefore, BATSAT's command system has a reset option, which will return the system to an origin state, and then commanding can begin. If a pulse is sent to nodes on the individual logic circuits, the cyclic logic circuits will all reset to an initial state.

The power system will also have an automatic toggle to the solar arrays if the batteries fail during operation. This toggle ability allows the satellite to provide power for the command receiver when the satellite comes out of an eclipse period. Figure 3.8 is a simplified block diagram of the command system.

The communication-system commands allow BATSAT to transmit over the operational modes discussed earlier. The antenna commands provide the capability to switch from the primary to the redundant set of antennas. This switch can be performed for two sets of antennas. The first set is the X and Ka-Band antennas. Since BATSAT will always be transmitting over these two bands simultaneously, BATSAT will switch both sets from primary to redundant at the same time. BATSAT also has the ability to switch from primary to redundant antennas for the S band system.

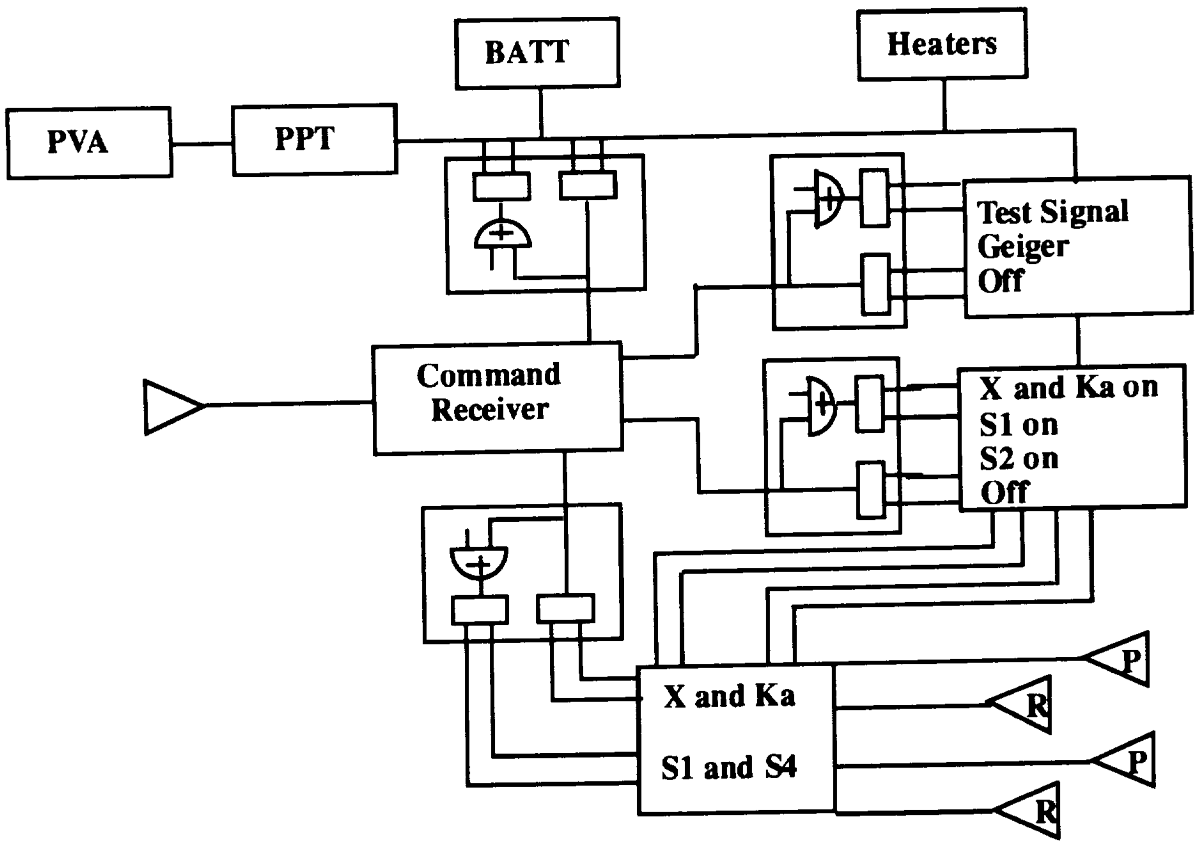


Figure 3.8: Simplified BATSAT command system and system block diagram.

3.7 Recommendations

Future groups that work on this project will need to characterize the interference patterns generated by the multiple antennae. This will entail building a mock satellite, placing the antennae as they will be on BATSAT, and then transmitting and characterizing the signal received. This process will help generate the filter for operations. Also, the SURFSAT communication equipment needs to be better integrated into the BATSAT design. Finally, future groups will need to generate more detailed schematics of the power system. Mockingbird's work in this area has basically been at a block diagram level. If the satellite is to be produced at UT, a detailed wiring schematic will need to be made. The University plans to use student design courses in the Electrical Engineering Department to design, build, and test the extra electronics hardware needed by BATSAT.

4.0 ORBIT DETERMINATION

4.1 Requirements and Constraints

In order to determine the most appropriate orbit for BATSAT, the requirements and constraints imposed by the mission goals were considered. The maximum slew rate of the 34-meter DSN dishes that will be used to observe the satellite is 0.4°/sec. Figure 4.1 is a plot of the necessary dish slew rate as a function of altitude; it shows that the minimum possible altitude that fulfills this constraint is 1095 km. On the upper end of the altitude scale, the Van Allen Radiation Belts become a problem. The intensity of the Van Allen belts increases considerably beyond an altitude of 1276 km (see Figure 4.2). These two constraints limit the orbit altitude to a range of less than 200 km. Fortunately, there also happens to be a lower concentration of space debris in this altitude range (Figure 4.3). The final constraint on the BATSAT orbit is the locations of the DSN dishes. A minimum orbit inclination of 40° is required to pass over each of the three DSN dishes at Goldstone, Canberra, and Madrid.

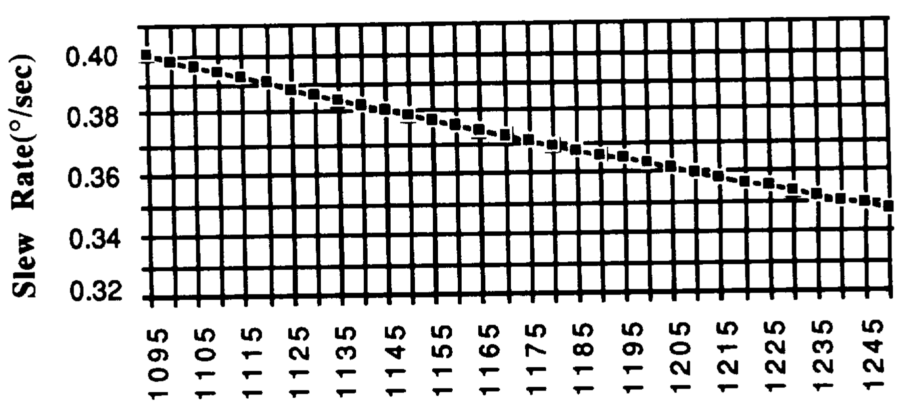


Figure 4.1: Groundstation Slew Rate vs. Satellite Altitude

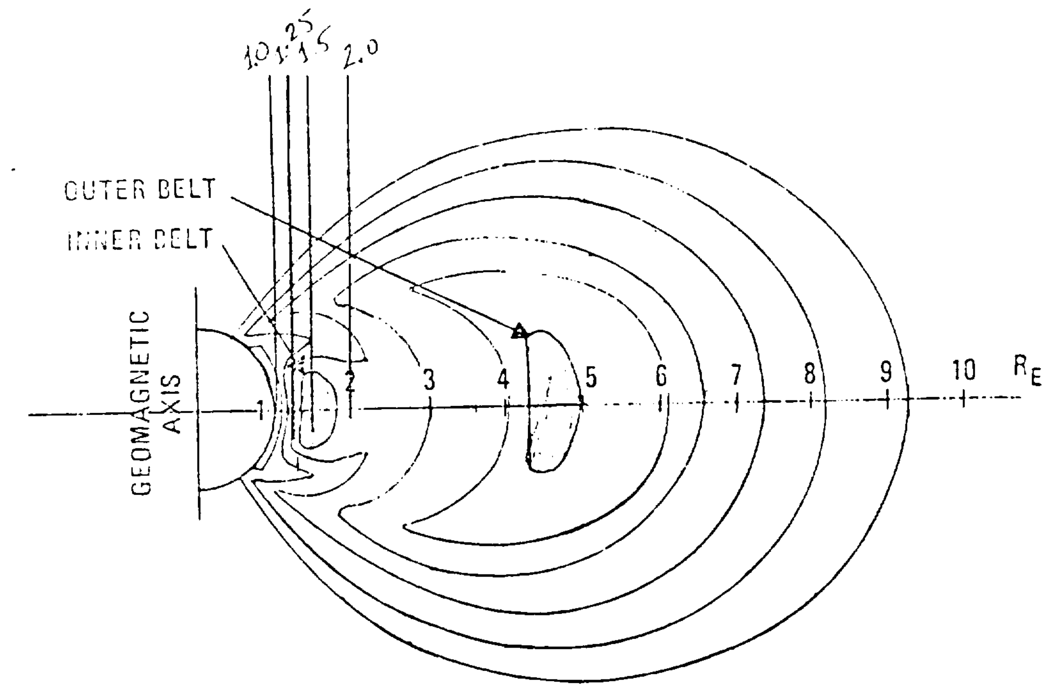


Figure 4.2: Van Allen Radiation Belt intensity vs. altitude
[Source: NASA, 1989]

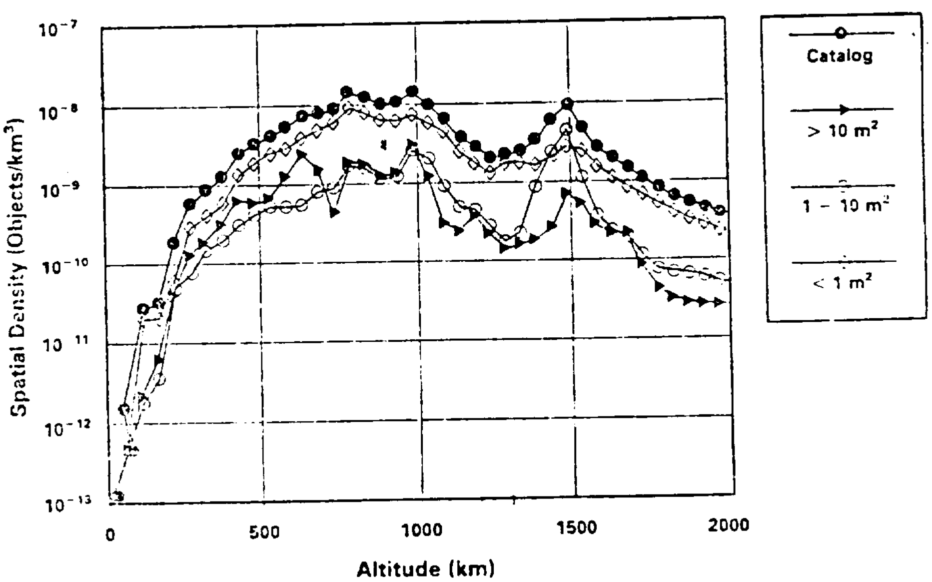


Figure 4.3: Orbital debris density vs. altitude.
[Source: Wertz and Larson]

4.2 Orbital Parameters

The orbital parameters chosen for this mission are based upon a seven-day repeat groundtrack cycle. The altitude of the orbit is 1163 km, with a corresponding semi-major axis of 7541 km. The orbit eccentricity is zero and the inclination is 70°. This orbit has a 1.81 hour orbital period with a corresponding slew rate of 0.375°/sec. The decay rate of this orbit, shown in Figure 4.4, is approximately 0.25 km/yr.

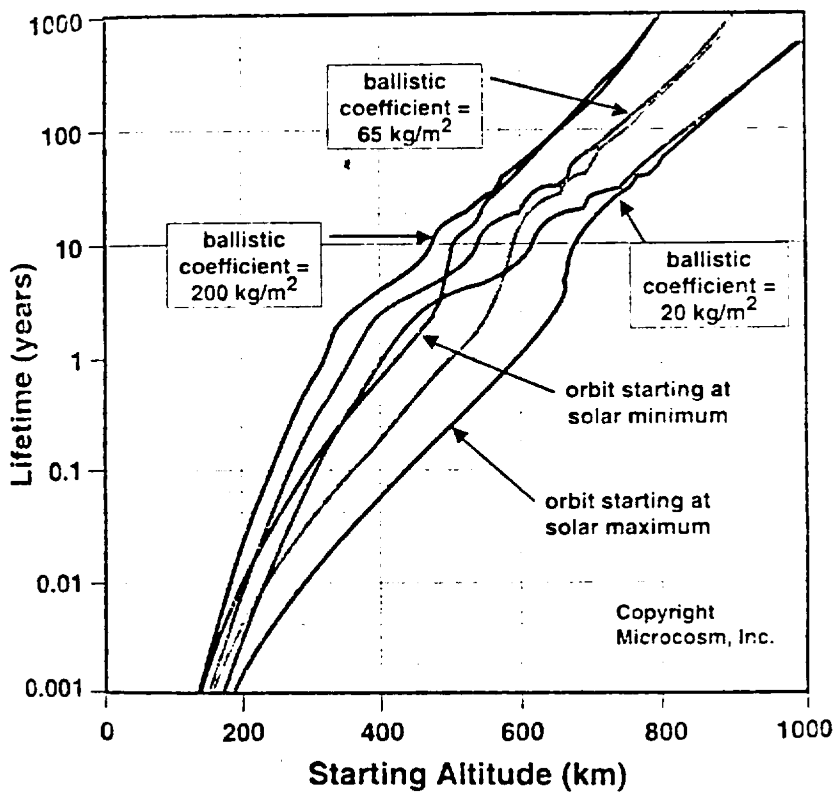


Figure 4.4: Orbital decay rate.
[Source: Wertz and Larson]

4.3 Groundtrack Characteristics

A seven-day repeat groundtrack was chosen in order to make it easier to predict the viewing time for the DSN dishes, and to simplify tracking schedules. BATSAT will make 92 revolutions every 7 days. Figure 4.5 is a 1-day plot of the groundtracks for the orbit selected. The three DSN dishes will each receive an average of 85 minutes of data per day for a total of about 28 hours of data per week.

4.4 Future Work

Several questions must be addressed prior to the BATSAT launch. In order to avoid the risk of colliding with other satellites, the availability of the 1163 altitude for BATSAT must be checked. Also, more information about the groundstation viewing capabilities is needed to confirm the current time estimates. In addition, the eclipse periods for the orbit need to be compared to groundstation viewtimes so that the BATSAT battery requirements can be better determined.

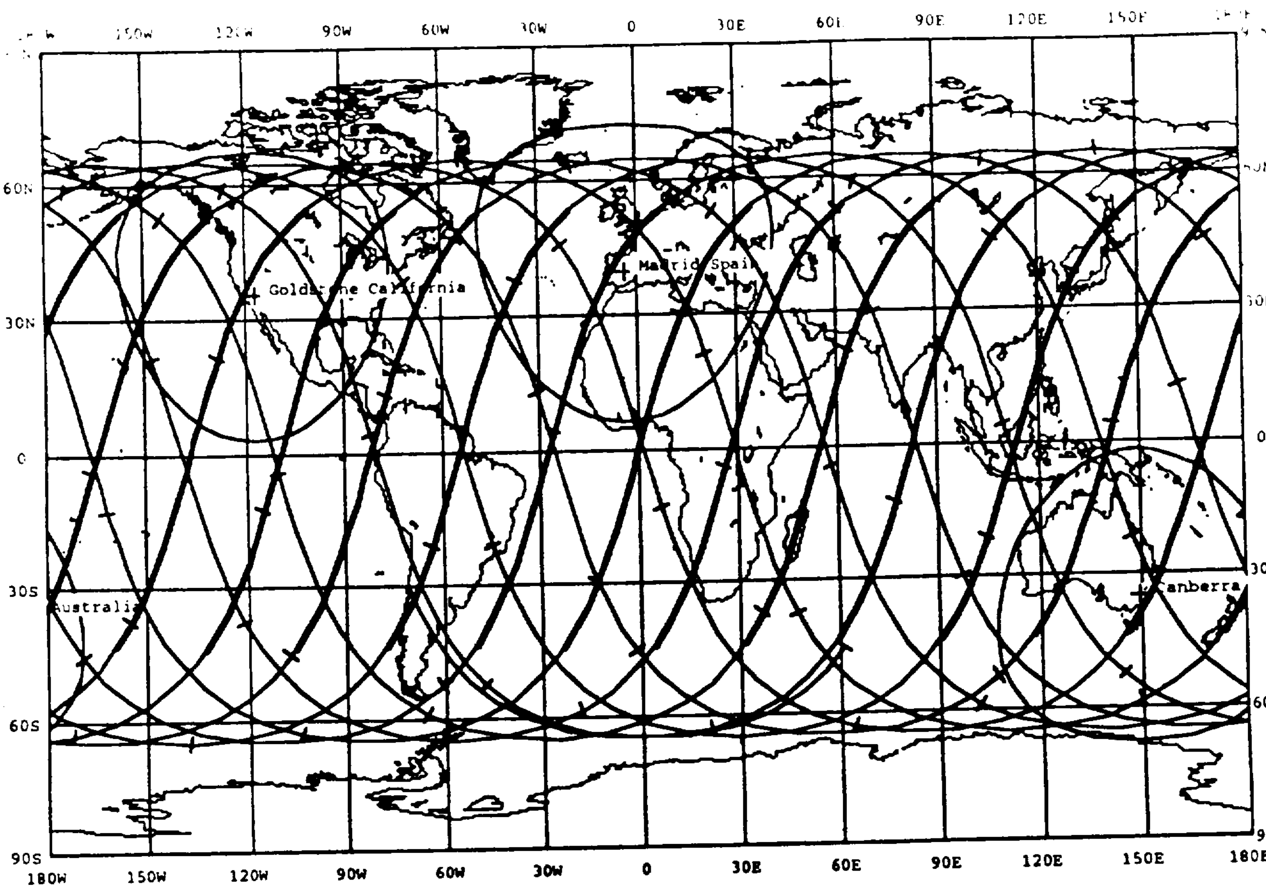


Figure 4.5: Groundtrack plot of BATSAT for one day.

5.0 LAUNCH SELECTION

Many factors were involved in determining the best launch choice for the BATSAT mission. Clearly, the launch vehicle must be capable of lifting the required mass to the requisite altitude with the appropriate inclination. The vehicle must also be able to accommodate the size and shape of its payload. Other considerations include:

- Reliability, availability, and cost of launch vehicle
- Environmental conditions during launch
- Attitude control and spin stabilization
- Orbital injection accuracy
- Launch integration flexibility.

Because of the superiority of the Pegasus launch vehicle in all of the decision factors, Mockingbird Designs has chosen the Pegasus as the primary launch choice for the BATSAT mission (see Figure 5.1).

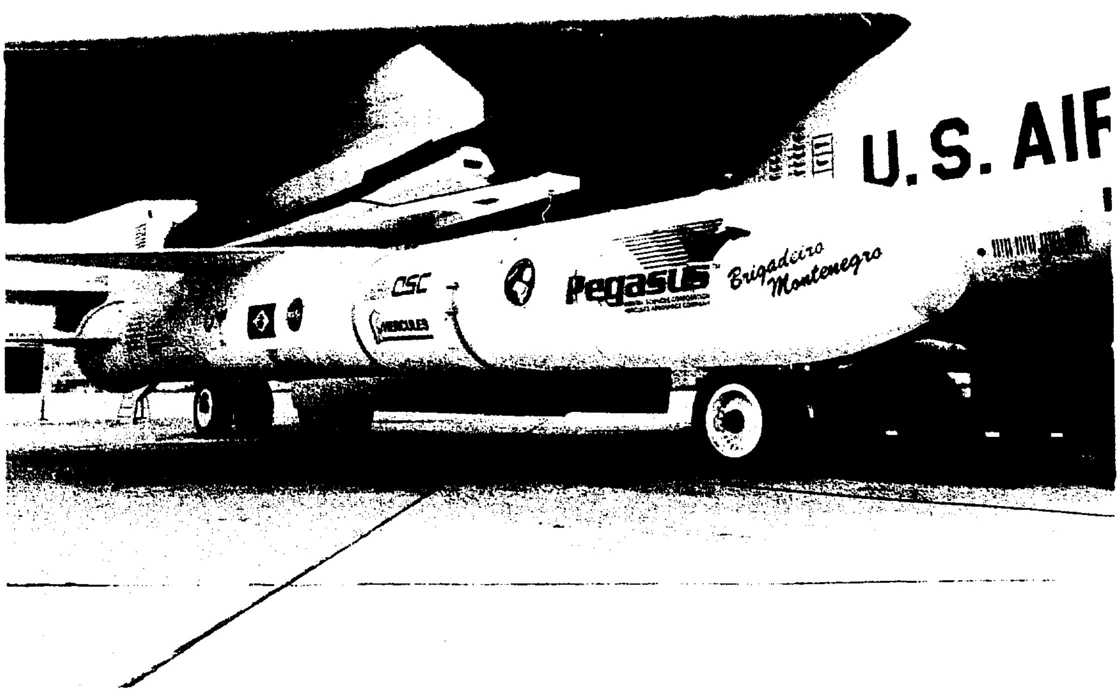


Figure 5.1: Pegasus Space Booster under the wing of B-52

5.1 Primary Launch Scenario

Pegasus is a three-stage, solid propellant space booster that uses inertial guidance. The booster is made entirely of composites, and unlike other launch vehicles, it has a wing as shown in Figure 5.2. The rocket is mounted to a modified Lockheed L-1011 carrier operating out of the west coast integration site at Edwards Air Force Base, California. Prior to ignition, the aircraft approaches level flight at about 41,000 ft and Mach 0.8, at any location in the Western Test Range. Appendix D contains an example launch profile timeline for a Pegasus mission.

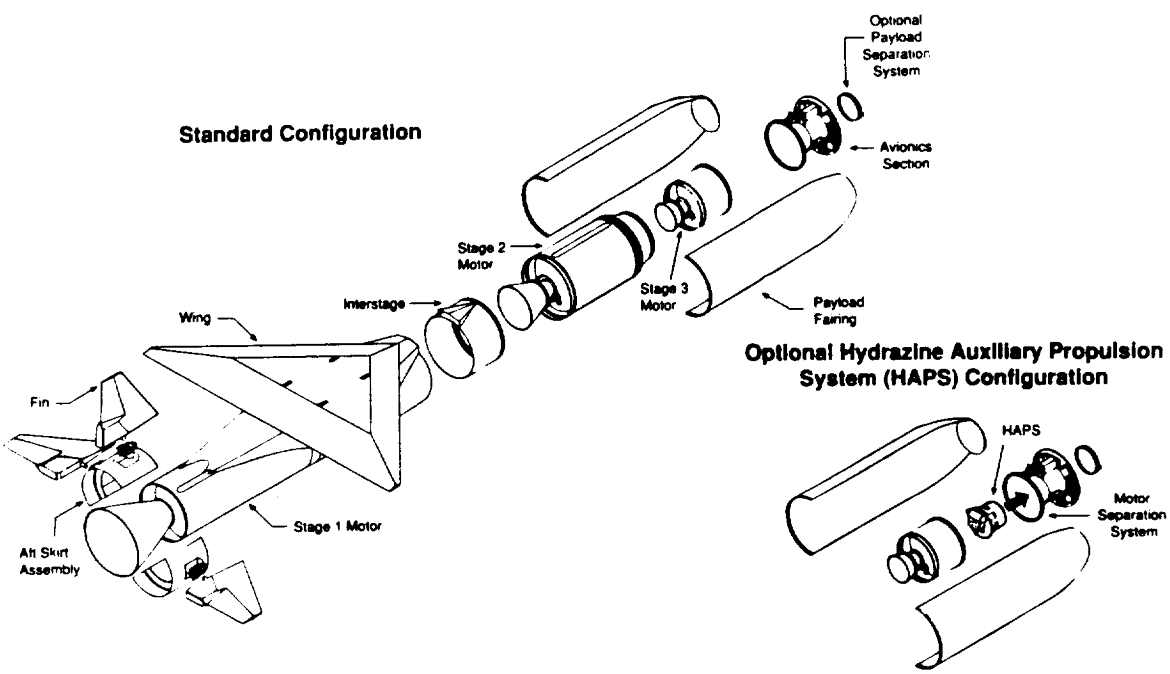


Figure 5.2: Exploded-view of Pegasus booster.

After release from the aircraft and ignition of its first stage motor, Pegasus' autonomous guidance and flight control system controls all of the maneuvers necessary to insert payloads into a wide range of orbital configurations. Advanced propulsion, structural and avionics technologies, and an optimized, lift-assisted trajectory give Pegasus roughly twice the lifting capability of other small launch vehicles, with superior performance and cost efficiency [Isakowitz: p218]. In addition to the technical advantages of the Pegasus launch vehicle, its parent company, Orbital Sciences Corporation (OSC), provides full engineering and management support, including mission planning, structural integration, and a full range of standard and optional mission services [Pegasus User's Guide:2-1].

The cost of Pegasus is estimated between \$7-\$12 million (1990\$), making it one of the least expensive small launch vehicles [Isakowitz:p219]. The reason for the wide variation in cost is because of the highly flexible nature of the Pegasus launch vehicle. Since BATSAT will use the optional Hydrazine Auxiliary Propulsion Stage (at an extra cost of about \$1.5 million), OSC estimates a \$9 million launch cost for the BATSAT mission [OSC fax].

5.1.1 Launch Performance

The most important characteristic of a launch vehicle is its lifting capacity. Figure 5.2 is a plot of Pegasus lift capability to polar orbit [Pegasus User's Guide:3-4]. For an orbit of 1200 km altitude and 70° inclination, the basic three-stage Pegasus configuration can lift about 70 kg payload mass, sufficient for BATSAT mission requirements. With the standard configuration, Pegasus injection accuracy (for 3 normal standard deviations) into low Earth orbit is roughly ±50 km altitude and ±0.5° inclination [Pegasus User's Guide:3-6]. In addition, for launches in 1993 and later, Pegasus will be using production lot 2 motors that will improve payload performance by 8% to 20% above that for lot 1 motors (the ones that the data describe) [Pegasus User's Guide:3-3].

For the BATSAT mission, Pegasus will be configured with the optional Hydrazine Auxiliary Propulsion System (HAPS). HAPS improves injection accuracy by a factor of ten and increases payload capability to higher orbits (see Figures 5.3 and 5.4). HAPS consists of a hydrazine propulsion subsystem and a Stage 3 separation subsystem, and is mounted inside the Pegasus avionics structure. After burn-out and separation of the Stage 3 motor, the HAPS thrusters are used to provide additional velocity and to perform precise orbit injection with an accuracy better than ±0.5° for spin axis pointing [Pegasus User's Guide:2-8].

Either an inertial-fixed or spin-stabilized attitude can be chosen, with a maximum spin rate of approximately 160 rpm. The actual maximum spin rate and rotation accuracy depends on the moment of inertia of the payload and the amount of the HAPS propulsion budget needed for other attitude control maneuvers [Pegasus User's Guide:3-6]. Mockingbird must determine the optimal satellite spin rate based upon thermal and communication constraints.

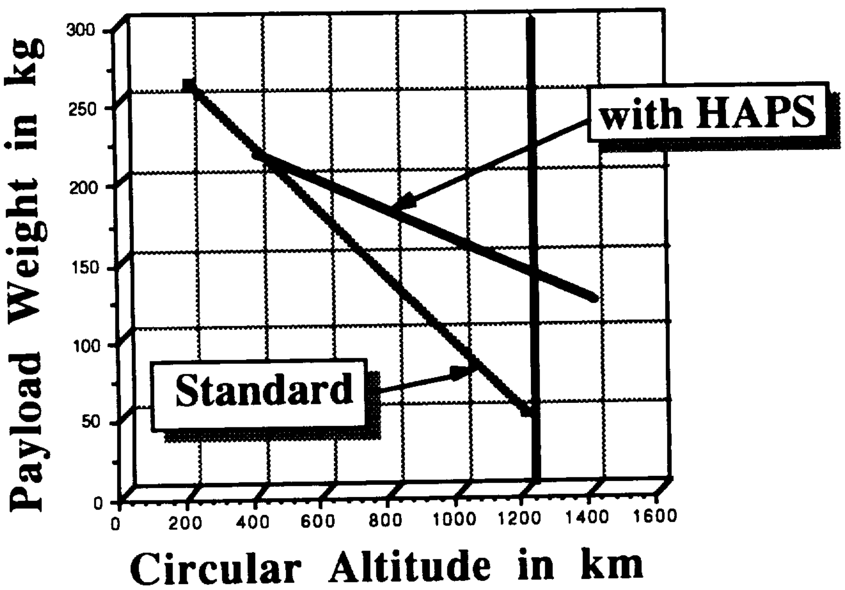


Figure 5.3: Pegasus lifting capability to circular polar orbits.

3σ variation	Standard	with HAPS
Altitude	± 50 km	± 5.6 km
Inclination	± .5°	± .05°

Figure 5.4: Orbital injection accuracy for Pegasus.

5.1.2 Payload Integration

The Pegasus payload fairing provides ample room for BATSAT. In fact, there is enough excess space to allow a second (and perhaps a third) payload to share a launch using the HAPS. Figure 5.5 shows the rough dimensions of the Pegasus payload fairing [Pegasus User's Guide:5-4].

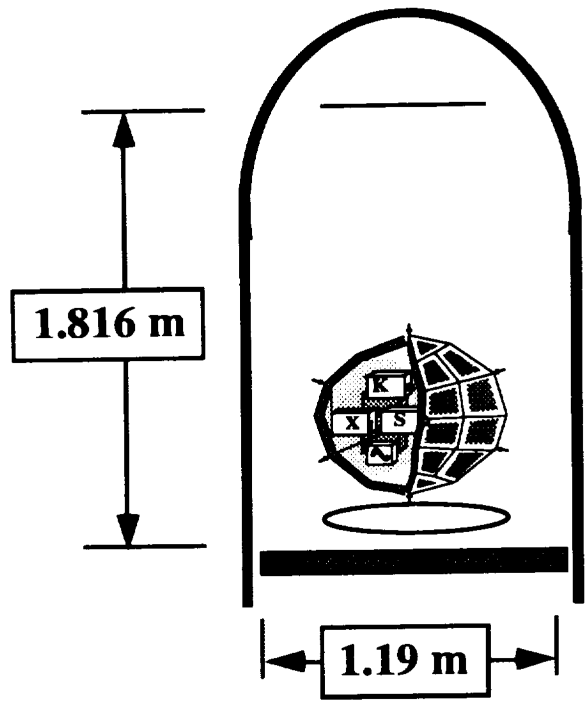


Figure 5.5: Payload fairing dimensions for Pegasus

OSC provides all hardware and integration services necessary to attach BATSAT to Pegasus [Pegasus User's Guide:5-2]. OSC offers a standard mechanical separation interface and will provide an adapter and all necessary attachment hardware and will perform all integration functions [Pegasus User's Guide:5-6]. The interface is a Marmon clamp design with a 24.5 cm diameter bolt circle (see Figure 5.6)

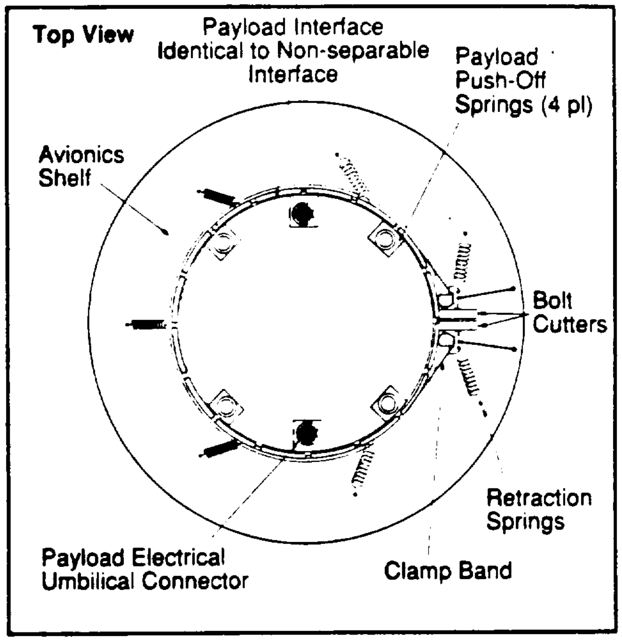


Figure 5.6: Separable payload interface.

Since BATSAT uses the standard Pegasus payload separation system, OSC will control the entire spacecraft separation process. At the time of separation, redundant bolt cutters sever the connections to the avionics subsystem, and the payload is ejected by four push-off springs supplying an initial force of 334 N (75 lbf) each, with sufficient energy to give BATSAT a separation velocity of more than 3 m/s [Pegasus User's Guide:5-7]. HAPS then performs a collision and contamination avoidance maneuver to avoid damaging the separated payload [Pegasus User's Guide:3-6].

5.1.3 Launch Constraints

The *Pegasus Payload User's Guide* provides extensive detail on the payload environment during L-1011 captive carry and launch, as well as structural design constraints on the payload. The *User 's Guide* details the payload structural safety factors required by OSC; Appendix D contains a table summarizing these requirements [Pegasus User's Guide:4-1]. Constraints caused by launch availability are minimal due to the open launch manifest and flexibility of the Pegasus.

The payload acceleration environment during ground operations and captive carry is mild and does not exceed 1.5 g's. The static axial accelerations for the end of Stage 2 and Stage 3 burns vary with payload mass, and have a maximum of 11 g's acceleration for a mass of 50 kg [Pegasus User's Guide:4-3]; since BATSAT will have a mass in this range, this was taken as the design constraint. In addition, launch accelerations in the lateral directions can reach 3 g's [Pegasus User's Guide: 4-3]. Appendix D, contains plots describing the acceleration, acoustic, shock, and vibration environments [Pegasus User's Guide].

The payload thermal environment is maintained between 64°F and 84°F, with less than 50% humidity, through ground operations and captive flight. The L-1011 provides filtered air-conditioning during captive flight through an A/C port in the Pegasus payload fairing [Pegasus User's Guide:4-6]. OSC has a comprehensive contamination control program to minimize the payload's exposure to contamination through orbital insertion and separation; the primary means of protection are through passive barriers in the payload fairing [Pegasus User's Guide:4-7].

Payload radio-frequency transmissions are not permitted prior to separation of the payload for standard services [Pegasus User's Guide:5-11]. Fortunately, BATSAT will not require any communication prior to separation.

There are few structural constraints that BATSAT must meet to use the Pegasus launch vehicle. To satisfy bending and buckling load constraints on the avionics and HAPS structures, BATSAT's center of mass is required to be within 2.5 cm of the vehicle centerline [Pegasus User's Guide:5-10]. In addition, strict mass property measurement tolerances must be adhered to; these are tabulated in Appendix D. Most important for the BATSAT preliminary design is the constraint on payload stiffness. To avoid dynamic coupling of the payload modes with the 12 Hz natural frequency of the Pegasus vehicle, BATSAT must be designed with a structural stiffness that will ensure that the fundamental frequency in the transverse direction is greater than 20 Hz [Pegasus User's Guide:5-11].

Section 2.0 of this report details how the BATSAT structural design deals with the Pegasus payload constraints. With the current design, BATSAT satisfies the mass center-line, acceleration, and frequency constraints by large margins of safety.

5.2 Secondary Launch Options

5.2.1 Piggyback

Early in the BATSAT design, the option of attaching to another satellite or its spent rocket booster was considered as a possible method of reducing launch costs. The SURFSAT preliminary design choice involves a piggyback on the booster stage used to deploy the LAGEOS satellite. There are several major problems with this option that resulted in its rejection by Mockingbird.

If BATSAT were attached to another object without attitude control, BATSAT's antennae would often be shielded from the Earth, resulting in signal blinking that would interfere with data acquisition by the DSN dishes. Mockingbird prefers consistent, continuous data transmission to satisfy the mission goals. Also, the large booster stage could shadow the solar cells, causing irregular and unpredictable power.

Another serious constraint imposed by a piggyback option is that BATSAT would be dependent upon the orbit and launch choices made by the primary payload. This would result in unacceptable interference with Mockingbird's design efforts and project autonomy. In addition, integration would be complicated and could not be handled satisfactorily during preliminary design.

5.2.2 Scout Launch Option

The Solid Controlled Orbital Utility Test (SCOUT) launch vehicle is a four-stage space booster capable of lifting over 100 kg to the BATSAT primary orbit choice (1163 km altitude, 70° inclination) [Isakowitz:238]. SCOUT has an open loop inertial guidance system located on the third stage. The fourth stage is spin stabilized and the optional fifth stage has an attitude control system [Isakowitz:234]. Several different payload fairing sizes are available, the largest of which is slightly smaller than the Pegasus fairing [Isakowitz:236]. SCOUT has estimated launch costs of $10-$12 million (1990$); this price is more than the $9 million estimated launch costs for Pegasus. The SCOUT vehicle fulfills the requirements of a launch vehicle for BATSAT, but since it offers no advantages over the Pegasus, and is in some ways inferior to it, Mockingbird has rejected it as a launch option.

5.2.3 Military Options

One alluring option available to Mockingbird is the use of military surplus to loft BATSAT into orbit. With an increasing surplus of conventional and nuclear rockets, the U.S. Government has hinted that these rockets could be used for peaceful space applications. Since BATSAT will be a university sponsored project, the government may be more willing to allow this option. A very promising rocket is the SPARTAN, which has been successfully used to launch payloads to orbit. However, built as an interceptor, the SPARTAN's launch loads approach an imposing 22 g's. Mockingbird plans to research this possible option, along with other military surplus possibilities.

5.2.4 Shared Launch

Another promising possibility for reducing the launch costs for BATSAT is to share a launch vehicle with other small payloads that require a similar orbital altitude. Possible launch vehicles being investigated for this option include Ariane, Pegasus, and OSC's new Taurus booster. In order to preserve the design choices that have already been made, the focus has been on the Pegasus shared launch option.

Pegasus payload interfaces can accommodate multiple payloads on a single flight. To date, as many as seven independently deployed spacecraft have been manifested on a single mission [User's Guide:5-10]. OSC maintains a manifest of future missions whose volume and performance requirements offer a margin for additional payloads. An example of a possible shared launch option is launching BATSAT in conjunction with one or two high inclination ORBCOMM satellites (see Figure 5.7). ORBCOMM is a global communications network that consists of a constellation of 26 small satellites to be launched over the next two years [Thompson:15].

Figure 5.7: ORBCOMM satellites.

Since BATSAT's current design volume is less than half the size of the Pegasus payload fairing, it is possible that a secondary payload could be found to share the launch vehicle. Both Stage 3 Reaction Control and the HAPS propulsion subsystem have the capability to incrementally orient the final stage for the deployment of multiple spacecraft with independent attitude requirements [User's Guide:3-6]. For additional cost, OSC will provide structures for mounting, pointing, and/or independently deploying multiple payloads [User's Guide:5-10].

6.0 MANAGEMENT AND COST

6.1 Management Goals

Due to limited time and a complex project, efficient management of the BATSAT program was essential. The Mockingbird management team implemented a dynamic program plan to fulfill the BATSAT Mission Statement. The management goal was to promote efficient work in the group, evenly distribute work to the entire team, prevent communication bottlenecks, and to identify and remedy potential problems before they happened. The primary method of achieving this goal is to promote good communication of information and problems between individual subsystem groups as well as with management. Therefore a strong communication hierarchy was established by Mockingbird management at the beginning of the project.

6.2 Program Organization

The upper management remained constant throughout the program lifetime, which is essential to program efficiency and organization. Figure 6.1 shows the Mockingbird organizational structure at the end of the project. The three major management positions were the Program Manager, Chief Engineer, and the Chief Administrative Officer. Dennis McWilliams, Mockingbird's Program Manager, served as Mockingbird's primary point of contact throughout the project. He kept the contract monitor informed of major organizational changes, work progress, and any major problems. The Program Manager set project goals, defined project milestones, assigned workloads, and adjusted manpower. The

Program Manager also assigned initial action items for individual groups until the groups became more self-sufficient.

The Chief Engineer (CE) for the project was Clint Slatton. Mr. Slatton managed the technical problems of the project by serving as liaison between Mockingbird and technical contacts in industry. The CE took the milestones and project goals from the Program Manager and turned them into precise technical action items. The Chief Engineer also served as the bridge between subsystem leaders and management. Therefore the CE was a major communication link between the engineering level and management level.

The Chief Administrative Officer (CAO), Cassidy Norman, was in charge of organizing all project records, analyzing personnel reports, computing program costs, and maintaining the project notebook. The CAO also kept track of the completion of action items, and established a Gantt Chart showing different non-technical due dates for the project.

The remaining organizational structure was broken down into several subsystem groups that were modified throughout the project to meet project needs. Each subsystem group was headed by a subsystem leader who assigned work to subordinate engineers. Prior to Preliminary Design Review 1, the subsystems were CPS (Communication, Power, and Structure), Orbits, and Launch Systems. After PDR1, the Launch Systems group and Orbits group saw a decrease in man-hours, while the CPS group saw an increase in man-hours. Therefore the CPS group was split into a Communication and Power group and a Structures group. Engineers were transferred from the Launch Systems and Orbit Groups to fill workload requirements with no loss in efficiency or organization. This change is reflected in the organizational chart shown in Figure 6.1.

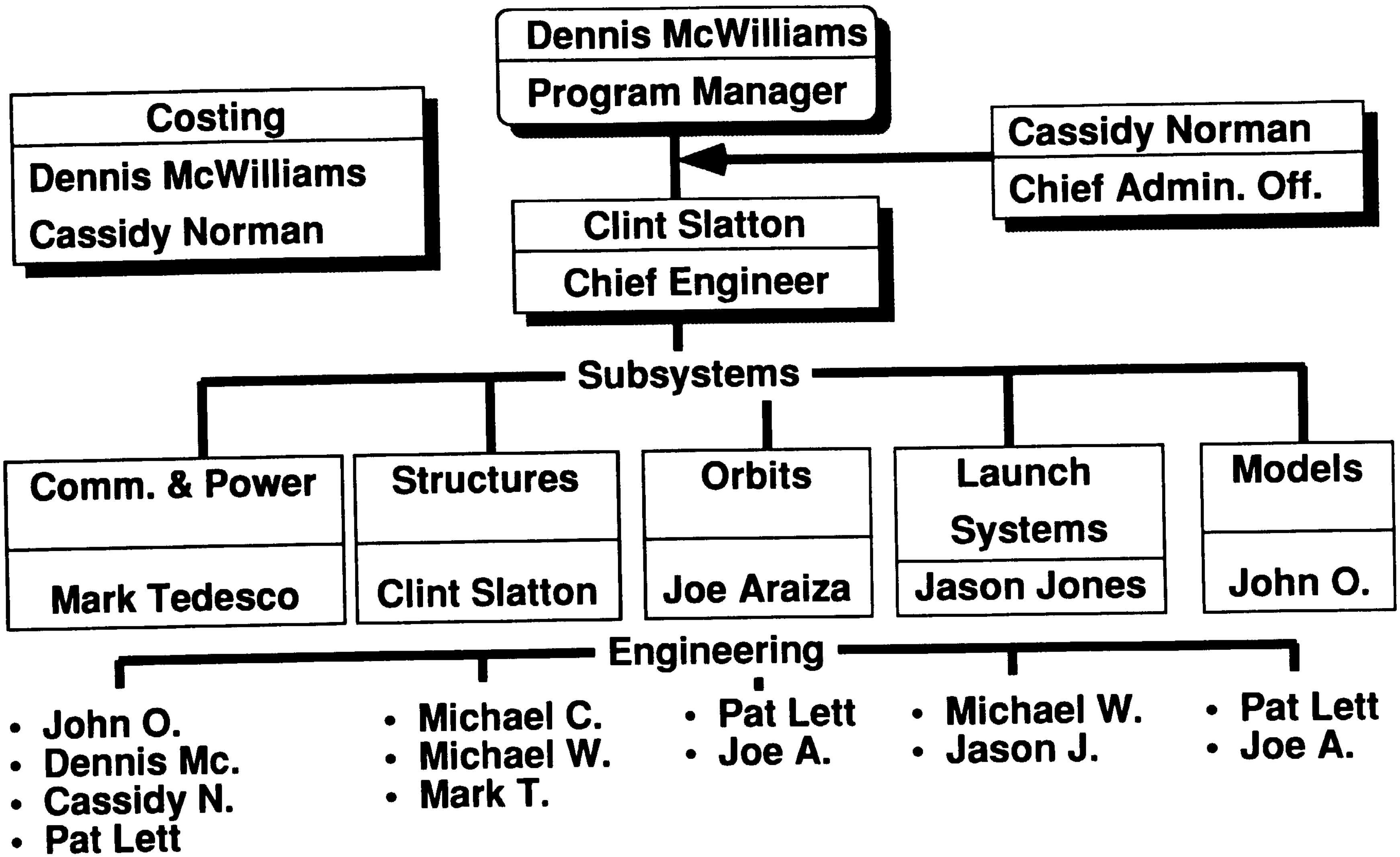


Figure 6.1: Project organization after PDR 1.

6.3 Communication Aids

Several techniques were used to maintain a strong communication link throughout the team. To keep project complexity and salary costs low, only ten people were assigned to this project. Since the team size was small, the team members could be involved in several different groups to intertwine the organizational structure. In order to increase the effective strength of our team as well as improve communication, all members served in two positions in the program. Upper managers (PM, CE, and CAO) served as engineers in the Subsystem Groups, and subsystem leaders served as engineers in other subsystem groups if possible. All other personnel served as engineers in two different subsystem groups. During the course of the project, the engineers could easily be switched from one subsystem group to another without serious loss in efficiency. This could be accomplished because all subsystem design choices were discussed during team meetings, and therefore all team members knew the technical concerns of other systems.

The organizational chart reveals the quick access managers had to the engineers. Broad project goals were set at the upper management level, and these goals were transformed into specific tasks, or action items, by the Program Manager and Chief Engineer. The action items were given numbers specific to the subsystem group they pertained to. The actions were assigned via memos and recorded on a list to provide a written record. Upon completion of an item it was checked complete and left on the list for record. The action item method provided good communication between management and engineers, and kept the group on schedule. It also allowed managers to study the work load in each department and see if more manpower was needed in a certain area. Engineers also had an easy and short communication link to upper management. Engineers could relay problems to their subsystem leader, who in turn gave the message to management. During critical times in a subsystem's design, each subsystem group contained one upper-level manager working as an engineer. Therefore these manager-engineers could directly see the problems and successes of a group. Finally, all team members attended the Mockingbird Team meeting every Monday, Wednesday, and Friday (and more if needed). During these meetings all members could bring up problems and questions concerning engineering, scheduling, or management.

6.4 Program Control and Schedule

The BATSAT Project required a well planned schedule and control scheme. Due to the nature of designing a satellite system, many subsystem design tasks depend on the choice for another subsystem. Thus certain subsystem work had to be completed before other work could begin. Also, these requirements had to be completed before certain critical dates such as Preliminary Design Reviews 1 and 2, Final Review, Final Report, etc. These constraints made a PERT chart invaluable for the effective management of the project. The overall PERT chart used for the Mockingbird BATSAT Project is given in Figure 6.2. This PERT chart lists the major project milestones along the critical path, and shows which project tasks had to be completed before others could begin. The dates given in boldface were critical dates and for the most part remained constant. They provided bounds on the other subsystem tasks that had to be completed beforehand. The PERT Chart also provided the basis for a program Gantt chart given in Figure 6.3. The Gantt chart was posted in the Mockingbird office and was reviewed during the daily meetings. These tools provided a basis for a tight work schedule and let management foresee any problems should a specific milestone date slip. Table 6.1 shows certain project milestones, their estimated start and stop times, and the actual start and stop times. For the most part the project did stay on its tight schedule, which is one reason it was so successful.

Table 6.1: Project Milestone Schedule

BATSAT Design Project Task	**Sched. Start**	**Actual Start**	**Sched. Finish**	**Actual Finish**
Conceptual Design Review	1/19	1/19	2/12	2/12
Proposal	2/12	2/12	3/1	3/1
Orbit Choice	2/14	2/14	3/2	3/2
Launch System Choice	2/14	2/14	3/3	3/3
Preliminary Structure Design	2/14	2/14	3/5	3/5
Main Power Design	2/14	2/14	3/3	3/3
Transponder Integration	3/4	3/4	3/4	3/4
Antenna Design	3/4	3/4	3/4	3/4
PDR1 Oral Report	3/19	**3/23**	3/19	**3/23**
PDR1 Written Report	3/12	3/12	3/29	**4/2**
Payload Integration	3/10	3/10	4/16	4/16
Structure Integration	3/10	3/10	4/16	4/16
Model Construction	3/24	3/24	4/24	**5/6**
Spacecraft Integration	4/19	4/19	4/24	**4/19**
PDR2 Oral Report	4/26	4/26	4/26	4/26
PDR2 Written Report	4/26	4/26	5/3	**5/11**
NASA/USRA Presentation	5/3	**5/7**	5/3	**5/7**

NOTE : The tasks and dates in bold font represent changes to the original project schedule.

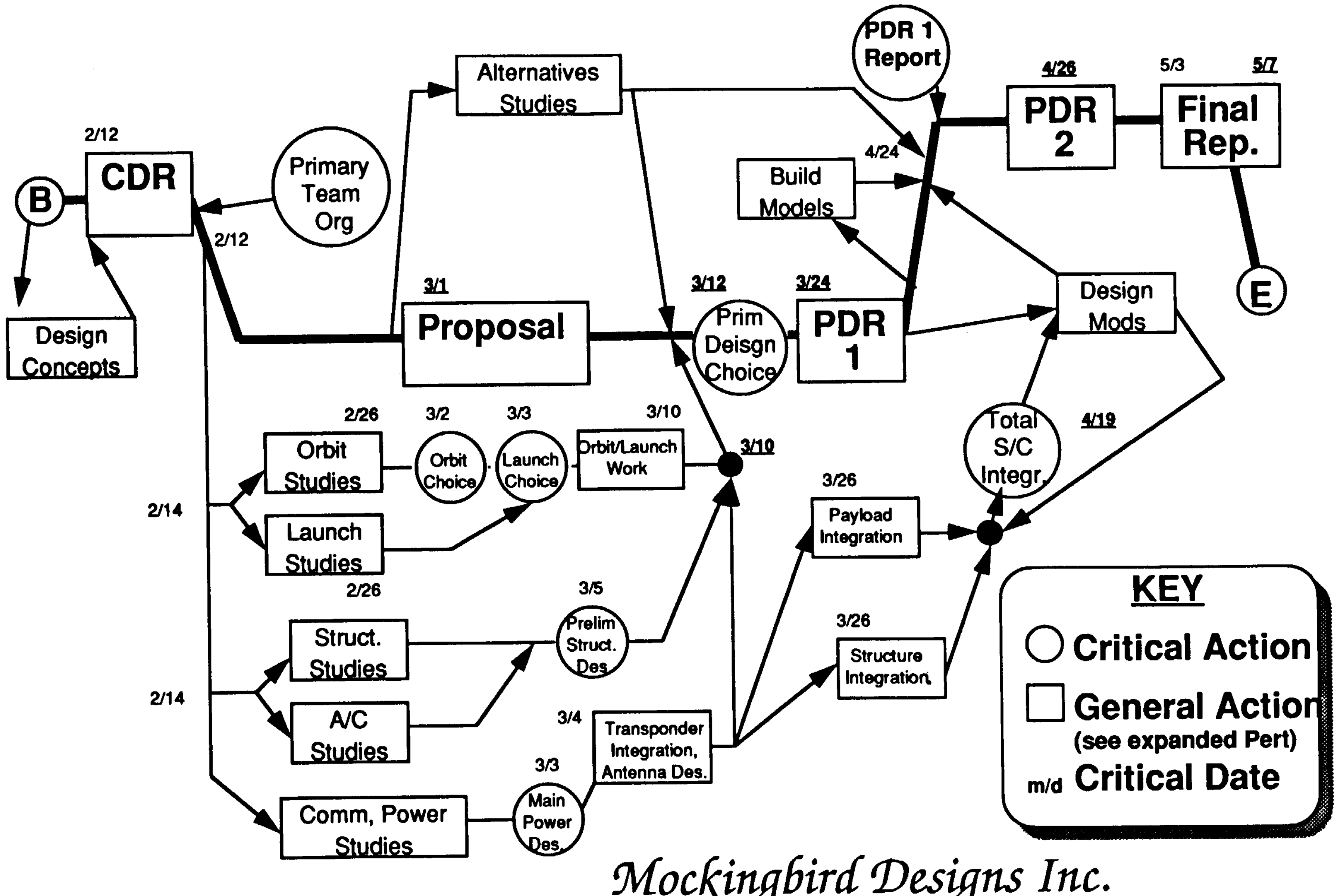


Figure 6.2 : Pert Chart for BATSAT Project.

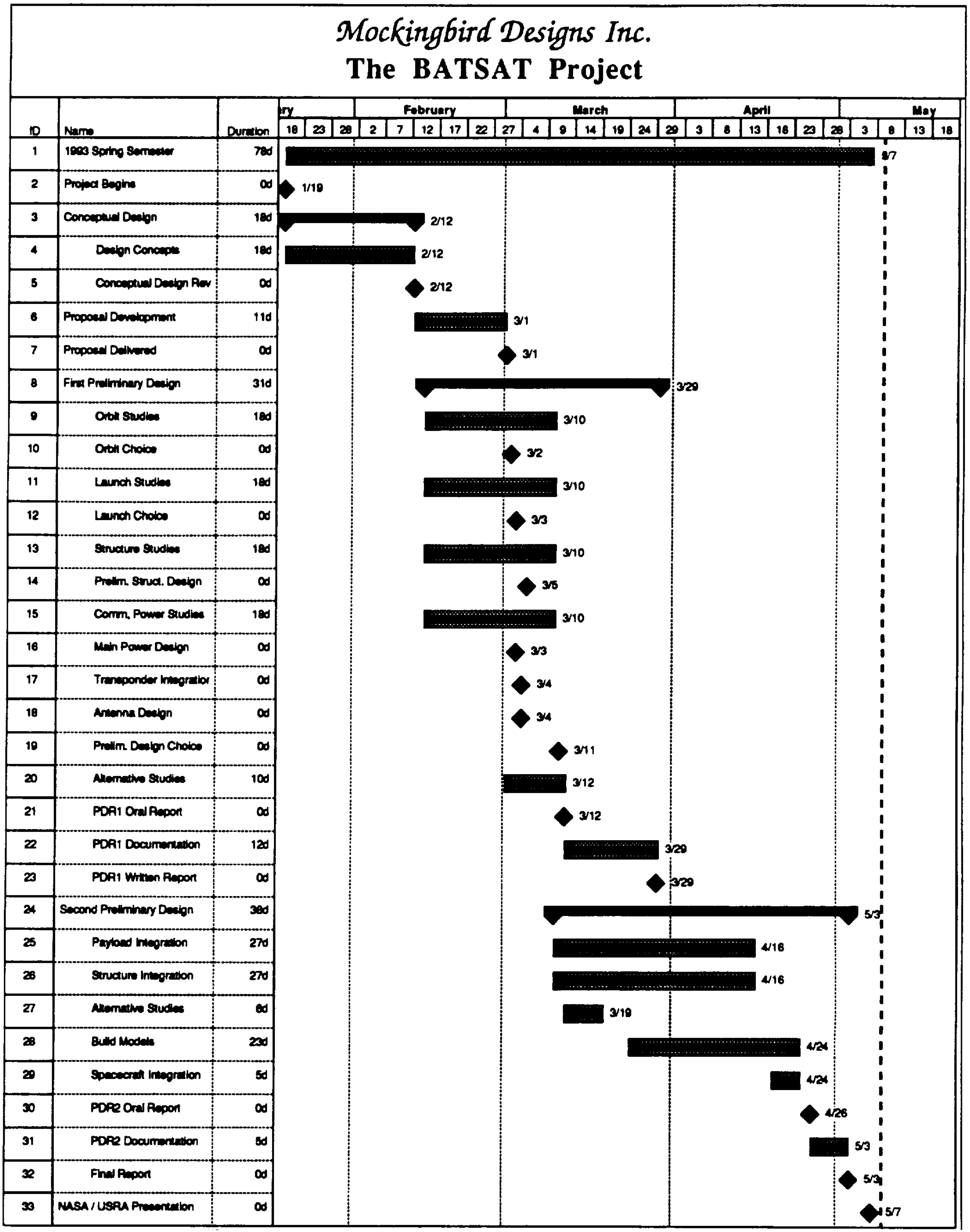


Figure 6.3: Gantt Chart for BATSAT project.

6.5 Project Integration

The integration scheme for the BATSAT was different from previous projects. Due to the strong communication link between subsystems, BATSAT could be designed with integration in mind. From the beginning of the design of a subsystem, a subsystem leader would consult with other subsystem leaders who would give constraints based on their subsystem. Therefore the satellite was integrated throughout the design. However, an integration period was still required to provide a final check to the design to make sure all subsystems were compatible with each other. This was performed during integration meetings during the time period shown on the PERT chart. All team members would attend the integration meetings. The Program Manager identified components and systems that had common bonds, and the subsystem leaders would check compatibility.

6.6 Production Cost Estimates

Mockingbird Designs had originally planned to do a detailed cost analysis using cost estimation relationship models. These models can be used to estimate subsystem costs through an equation based upon a certain parameter. For example, satellite structure costs are computed by using an equation that relates structure mass to cost. These equations, or CER's, are based on historical data collected over many different satellite projects and cover all subsystems, development and personnel costs, and even software and mission-ops costs. Parametric cost equations are usually exponential curve fits based on this historical data.

Mockingbird conducted an initial cost estimate using a cost analysis model found in Wertz and Larson [Ch. 20]. This model was based on the USAF Unmanned Spacecraft Model [Wertz and Larson, 663] historical data. However, the results of the model did not offer a realistic estimate of BATSAT's cost. This happened for several reasons. First, most BATSAT subsystems did not fall in the applicable range of the parametric equations, or CER's. Also, the cost model assumed normal commercial production and purchasing guidelines. Since BATSAT will be produced using student design and testing with university support, costs will be much lower. Finally, the cost model used was based upon large, complex satellite systems and does not take into account the simplicity and small size of the BATSAT satellite. A more accurate cost model would have used CER's based upon small satellite systems.

In order to get a feel of the satellite production costs, Mockingbird studied several other small satellite programs. Several universities have built small satellite systems at low costs. The OSCAR, GLOMR, and Microsat were all developed using student support and had production costs (not including ground segment costs) of under $300,000 [Wertz and Larson:732]. Since most of the communications hardware needed by BATSAT has been designed by Caltech, and the structure will be built and tested by a university, Mockingbird believes that the total satellite production and testing costs (excluding launch) will fall well below $200,000. By seeking off the shelf, outdated components for donation, the cost of the program could again be decreased significantly. Using student design courses for production, management, and testing will also greatly reduce personnel costs.

6.7 Project Costs

Figure 6.4 plots the total estimated and actual project costs throughout the project. Figures 6.5 and 6.6 show the associated personnel costs and material costs, respectively. The project costs varied above and below the straight line projected costs shown in the cost plot. The increase in weekly costs were usually associated with due dates throughout the design. As shown by the plot, the total project cost is $22,714. Most of this cost is estimated personnel costs based on the GS pay scale. However, since the personnel were students the actual cost of this project primarily included material costs of around $300.

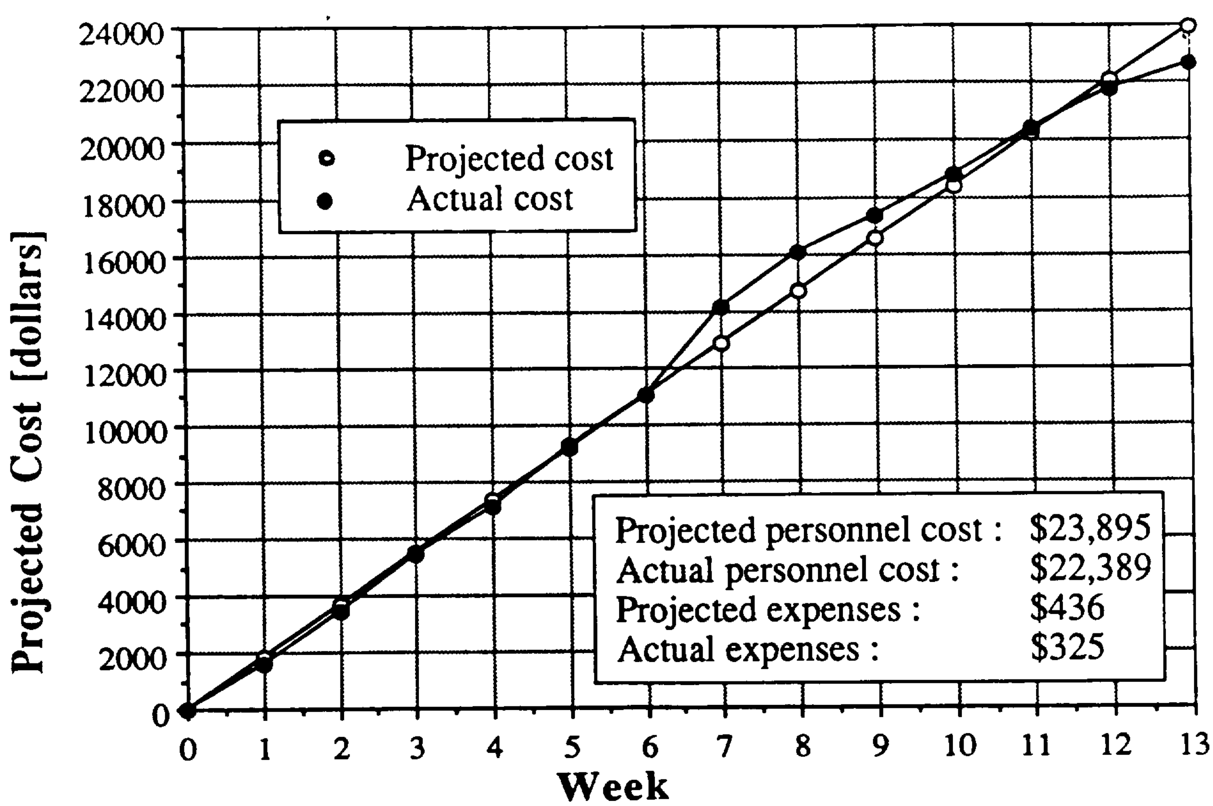


Figure 6.4: Cost of BATSAT Design

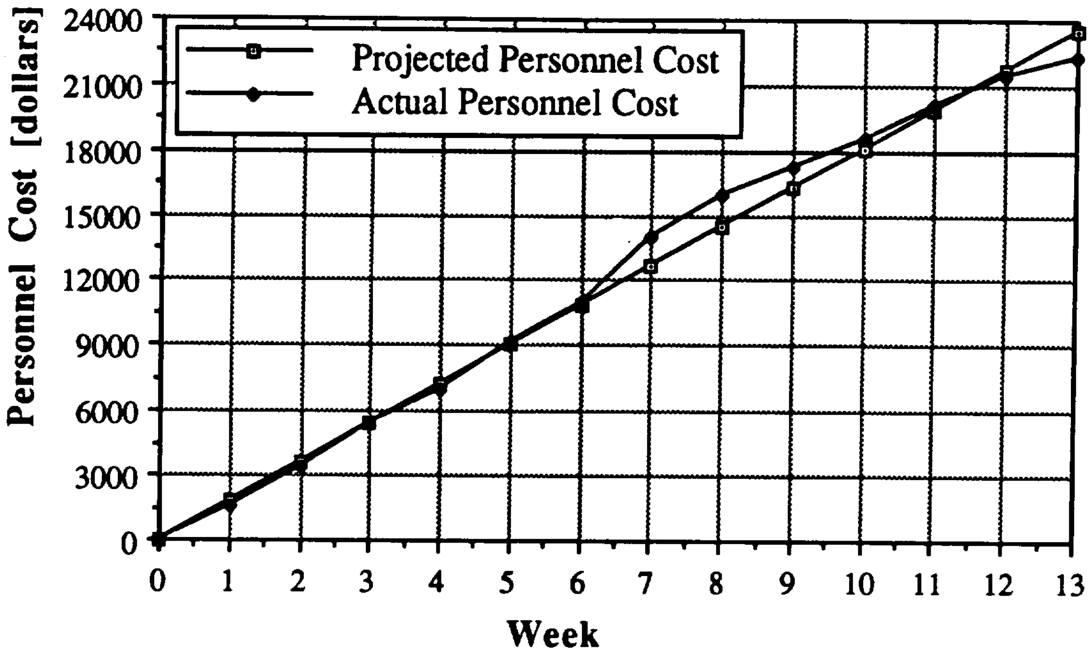


Figure 6.5: Personnel costs of BATSAT design

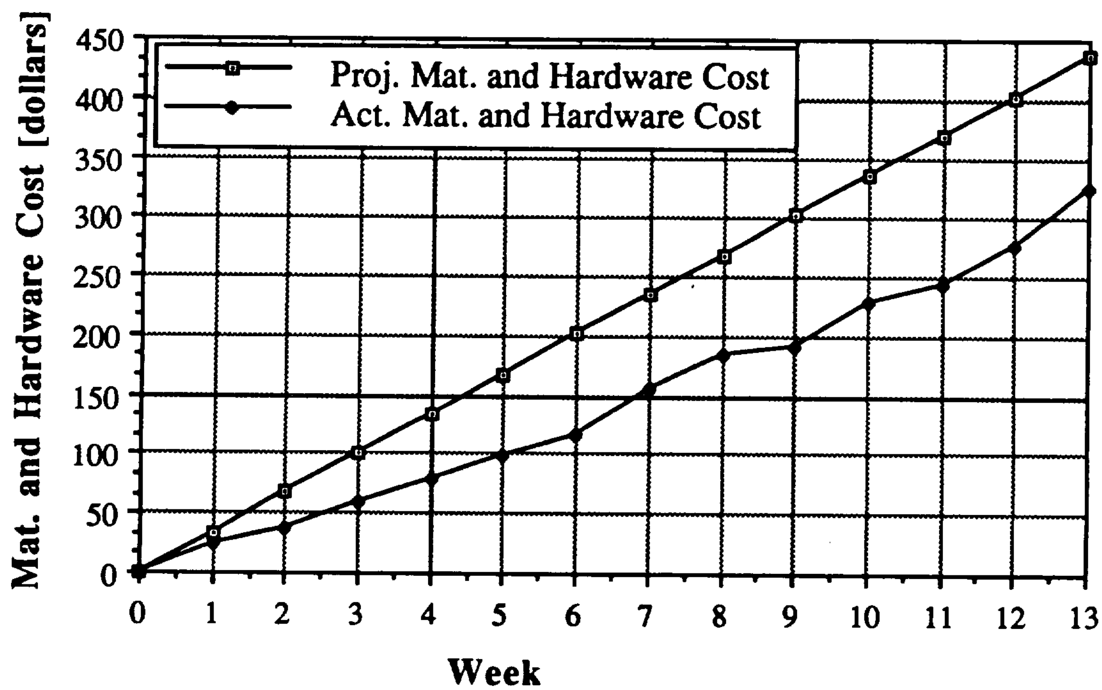


Figure 6.6: Material costs for BATSAT project.

7.0 RECOMMENDATIONS AND CONCLUSIONS

Mockingbird Designs' main goal is to have the BATSAT satellite built by a university design team. Mockingbird feels that the Aerospace Labs at the University of Texas at Austin offer an excellent environment for satellite construction. The Mockingbird team hopes that the BATSAT design process will continue in the classroom and move into the structures laboratory. By combining the USRA Spacecraft design course with the Structural Testing course, the BATSAT satellite could easily be built by the University using undergraduate design. Mockingbird has already spoken to the head of the Structural Design and Testing lab, and the BATSAT satellite may become a senior design topic in the course.

Mockingbird feels that the first step in continuing the satellite project is to begin acquiring and building satellite components and the satellite structure. Members of the USRA have offered to help the University obtain satellite components from excess NASA inventory. Mockingbird hopes to initially secure a peak power tracker, thermal heaters, and silicon solar cells from NASA surplus. As mentioned previously, the SURFSAT design team has already built much of the communication hardware. Mockingbird hopes to begin dialogue with Caltech to try and integrate different aspects of the SURFSAT design with the BATSAT design.

As stated earlier, Mockingbird has already built part of the truss structure as a proof of concept exercise. Mockingbird hopes to simplify production of the satellite by modifying the design. By consulting with the Mechanical Engineering Department at the University, Mockingbird hopes to improve the manufacturability of the spacecraft. By making the structure as generic as possible, other missions could more easily be adapted to the BATSAT design. Mockingbird hopes that these recommendations are acted upon quickly so that the current design team can help in the transition.

The current strain on satellite transmission speeds makes increasing data transmission rates for satellites an important mission. Whether Ka-Band transmissions will offer the needed speed is still unknown, but Mockingbird is confident that BATSAT will provide a wealth of information to help answer this question. Mockingbird Designs feels that the future of the space industry lies in small satellites. The BATSAT design, although designed for a specific mission, reveals many of the benefits of small satellites. By making space applications economically viable for more commercial enterprises, more uses will be exploited and mankind will move more quickly to the skies.

REFERENCES

Brown, M. P., *Compendium of Communication and Broadcast Satellites: 1958 to 1980*. New York: IEEE Press. 1981.

Chetty, P.R.K., *Satellite Technology and Its Applications*. 2nd edition. Blue Ridge Summit, PA: TAB Professional and Reference Books. 1991.

Courier Satellite for Global Communications, Electrical Engineering, November 1960, vol. 79, pgs 948-949.

Gere, J. M. and Timoshenko, S. P. , *Mechanics of Materials*. Boston: PWS KENT. 3rd ed. 1990.

Isakowitz, Steven J., with the AIAA Space Transportation Systems Technical Committee. *International Guide to Space Launch Systems*. Washington, DC: AIAA Publishing. 1991.

Kinman, Peter. Jet Propulsion Laboratory. Telecommunications Division. Interview on April 7, 1993.

Lundberg, Dr. John. Department of Aerospace Engineering, University of Texas at Autsin. Interview in March, 1993.

MSC/NASTRAN User's Manual , MacNeal-Schwendler Corp., Los Angeles, 1989, vol. 1 & 2 .

Mislinski, Phil. Orbital Sciences Corporation. Fairfax, VA. Fax sheet received March 28, 1993.

Pegasus User's Guide. Orbital Sciences Corporation. Fairfax, VA.

Rauschenbach, Hans S., *Solar Cell Array Design Handbook*. (Van Nostrand Reinhold Co., New York, 1980).

Wertz James R., and Wiley J. Larson, ed. *Space Mission Analysis and Design*. (Klewer Academic Publishers, Boston, 1991).

CONTACTS

Vit Babushka, Department of Aerospace Engineering, University of Texas at Austin.

Greg Barton, Draper Laboratory, Exploration Programs Office, NASA Johnson Space Center.

Dave Bergeron, Space Industries Inc.

Bret Drake, Exploration Programs Office, NASA Johnson Space Center.

Dr. Wallace Fowler, Department of Aerospace Engineering, University of Texas at Austin.

Peter Kinman, Jet Propulsion Lab, Telecommunications.

Professor Hao Ling, Department of Electrical Engineering, University of Texas at Austin.

Hum Mandell, Exploration Programs Office, NASA Johnson Space Center.

Dr. Hans Mark, Department of Aerospace Engineering, University of Texas at Austin.

Phil Mislinski, Orbital Sciences Corporation.

Dr. Paul Robinson, Jet Propulsion Lab.

Dr. Rex Ridenoux, Jet Propulsion Lab.

Appendix A

FORTRAN Program MODIFY

```
      program modify
*-----------------------------------------------------------------------
* This program creates a NASTRAN input file for the BATSAT structure
* given the parameters:
*
*       L       -       Primary length of circumferential element
*       r       -       Inner center element length
*       d       -       distance from L to r
*
*
* (Written by Michael J. Wortman, 4-20-93)
*-----------------------------------------------------------------------

      double precision L,r,d,theta,grid,g,x,a
      dimension grid(110,3),g(18,3),x(18,3)

      open(11,file='mod8.dat',status='unknown')
*
* Write preliminary NASTRAN data
*
      write(11,*)'NASTRAN SYSTEM(5)=39'
      write(11,*)'ID STATICS,TEST'
      write(11,*)'SOL 24'
      write(11,*)'TIME 3'
      write(11,*)'CEND'
      write(11,*)'TITLE=ASE274 - MODEL 1'
      write(11,*)'SUBTITLE=MODEL 1 STATIC'
      write(11,*)'DISP=ALL'
      write(11,*)'ELFORCE=ALL'
      write(11,*)'ELSTRESS=ALL'
      write(11,*)'LOAD=500'
      write(11,*)'OLOAD=ALL'
      write(11,*)'SUBCASE 1'
      write(11,*)'SPC=102'
      write(11,*)'OUTPUT(PLOT)'
      write(11,*)'PLOTTER NAST'
      write(11,*)'SET 1=ALL'
      write(11,*)'AXES X,Y,Z'
      write(11,*)'VIEW 0.,0.,0.'
      write(11,*)'FIND SCALE,ORIGIN 1,SET 1'
      write(11,*)'PLOT SET 1,ORIGIN 1,LABEL BOTH'
      write(11,*)'PLOT STATIC DEFORMATION 0, SET 1, ORIGIN 1, LABEL
     +BOTH'
      write(11,*)'$L= ',L
      write(11,*)'$r= ',r
      write(11,*)'$d= ',d
      write(11,*)'$theta= ',theta
      write(11,*)'BEGIN BULK'
      write(11,*)'$1.......2.......3.......4.......5.......6.......7.
     +.......8.......9.......10'
      write(11,120) 1,10,13,1,0.0,0.0,1.0
      write(11,120) 2,10,16,6,0.0,0.0,1.0
      write(11,120) 3,10,6,10,0.0,0.0,1.0
      write(11,120) 4,10,10,20,0.0,0.0,1.0
      write(11,120) 5,10,20,24,0.0,0.0,1.0
      write(11,120) 6,10,24,28,0.0,0.0,1.0
      write(11,120) 7,10,28,30,0.0,0.0,1.0
      write(11,120) 8,10,14,5,0.0,0.0,1.0
      write(11,120) 9,10,5,9,0.0,0.0,1.0
      write(11,120) 10,10,9,18,0.0,0.0,1.0
      write(11,120) 11,10,18,22,0.0,0.0,1.0
      write(11,120) 12,10,22,26,0.0,0.0,1.0
      write(11,120) 13,10,26,30,0.0,0.0,1.0
      write(11,120) 14,10,13,2,0.0,0.0,1.0
      write(11,120) 15,10,17,7,1.0,0.0,0.0
      write(11,120) 16,10,7,11,1.0,0.0,0.0
```

```
      write(11,120) 17,10,11,21,1.0,0.0,0.0
      write(11,120) 18,10,21,25,1.0,0.0,0.0
      write(11,120) 19,10,25,29,1.0,0.0,0.0
      write(11,120) 20,10,29,30,1.0,0.0,0.0
      write(11,120) 21,10,15,8,1.0,0.0,0.0
      write(11,120) 22,10,8,12,1.0,0.0,0.0
      write(11,120) 23,10,12,19,1.0,0.0,0.0
      write(11,120) 24,10,19,23,1.0,0.0,0.0
      write(11,120) 25,10,23,27,1.0,0.0,0.0
      write(11,120) 26,10,27,30,1.0,0.0,0.0
      write(11,120) 27,10,1,14,0.0,0.0,1.0
      write(11,120) 28,10,3,15,0.0,0.0,1.0
      write(11,120) 29,10,2,16,0.0,0.0,1.0
      write(11,120) 30,10,4,17,1.0,0.0,0.0
      write(11,120) 31,10,1,31,0.0,0.0,1.0
      write(11,120) 32,10,31,35,0.0,0.0,1.0
      write(11,120) 33,10,35,26,0.0,0.0,1.0
      write(11,120) 34,10,31,9,0.0,0.0,1.0
      write(11,120) 35,10,35,18,0.0,0.0,1.0
      write(11,120) 36,10,3,32,1.0,0.0,0.0
      write(11,120) 37,10,32,36,1.0,0.0,0.0
      write(11,120) 38,10,36,27,1.0,0.0,0.0
      write(11,120) 39,10,32,12,1.0,0.0,0.0
      write(11,120) 40,10,36,19,1.0,0.0,0.0
      write(11,120) 41,10,2,33,0.0,0.0,1.0
      write(11,120) 42,10,33,37,0.0,0.0,1.0
      write(11,120) 43,10,37,28,0.0,0.0,1.0
      write(11,120) 44,10,33,10,0.0,0.0,1.0
      write(11,120) 45,10,37,20,0.0,0.0,1.0
      write(11,120) 46,10,4,34,1.0,0.0,0.0
      write(11,120) 47,10,34,38,1.0,0.0,0.0
      write(11,120) 48,10,38,29,1.0,0.0,0.0
      write(11,120) 49,10,34,11,1.0,0.0,0.0
      write(11,120) 50,10,38,21,1.0,0.0,0.0
      write(11,120) 51,10,13,3,1.0,0.0,0.0
      write(11,120) 52,10,13,4,1.0,0.0,0.0
      write(11,*)'$'
      write(11,*)'GRAV    100         83.3    0.0     0.0
     +  -1.0'
      write(11,*)'GRAV    200         34.3    1.0     0.0
     +  0.0'
      write(11,*)'$'
      write(11,*)'$1......2.......3.......4.......5.......6.......7.
     +......8.......9.......10'
*
* Determine grid points
*
      print*,'Primary length (L) = '
      read*,L
      print*,'Inner Length (R) = '
      read*,r
      print*,'Distance between L and R = '
      read*,d

      a=2*acos(-1.)/12

      g(1,1)=L/2.
      g(1,3)=0.
      g(2,1)=L/2+L/2*cos(a)
      g(2,3)=L/2*sin(a)
      g(3,1)=L/2+L*cos(a)
      g(3,3)=L*sin(a)
      g(4,1)=g(3,1)+L*cos(2*a)
      g(4,3)=g(3,3)+L*sin(2*a)
      g(5,1)=g(4,1)
      g(5,3)=g(4,3)+L
```

```
      g(6,1)=g(3,1)
      g(6,3)=g(5,3)+L*cos(a)
      g(7,1)=g(1,1)
      g(7,3)=g(6,3)+L*cos(2*a)
      g(8,1)=g(5,1)-d
      g(8,3)=g(7,3)/2+r/2
      g(9,1)=g(4,1)-d
      g(9,3)=g(7,3)/2-r/2

      do 10 i=10,18
          g(i,1)=-g(i-9,1)
          g(i,3)=g(i-9,3)
 10   continue

      do 15 i=1,18
          g(i,2)=0.
 15   continue

      do 20 i=1,18
          grid(i,1)=g(i,1)
          grid(i,2)=g(i,2)
          grid(i,3)=g(i,3)
 20   continue
*
* Rotation loop
*
      j=0
      theta=0.

 100  j=j+1
      theta=theta+acos(-1.)/6
      call rotate(g,theta,x)

      do 25 i=1,18
          grid(i+18*j,1)=x(i,1)
          grid(i+18*j,2)=x(i,2)
          grid(i+18*j,3)=x(i,3)
 25   continue

      if(j.ne.5)go to 100
*
* Write results.
*
      do 30 i=1,108
          write(11,130) i,grid(i,1),grid(i,2),grid(i,3)
 30   continue

      write(11,130) 109,0.,0.,0.
      write(11,130) 110,0.,0.,grid(7,3)
*
* Finish final section of file.
*
      write(11,*)'$'
      write(11,*)'$1.......2.......3.......4.......5.......6.......7.
     +.......8.......9.......10'
      write(11,*) '$'
      write(11,*)'LOAD    500     1.0     1.0     100'
      write(11,*)'MAT1    20      70.0E9  26.0E9  0.33    2700.0  23
     +.0E-6'
      write(11,*)'PBAR    10      20      7.07E-4 3.98E-8 3.98E-8 7.
     +95E-8'
      write(11,*)'SPC1    102'
      write(11,*)'PARAM   COUPMASS1'
      write(11,*)'PARAM   GRDPNT  0'
      write(11,*)'PARAM   USETPRT 1'
      write(11,*)'ENDDATA'
```
A4 A4

```
 120    format(1x,'CBAR',t10,i2,t18,i2,t26,i2,t34,i2,t42,f3.1,t50,f3.1,t58,
     +            f3.1)
 130    format(1x,'GRID',t10,i3,t25,f8.4,t33,f8.4,t41,f8.4)

        stop
        end

*-----------------------------------------------------------------------
*-----------------------------------------------------------------------
        subroutine rotate(p,beta,q)
        double precision beta,p,q
        dimension p(18,3),q(18,3)
*
* This subroutine computes a plane of grid points by rotating a given
* set of points in the x-z plane by the angle beta.
*
        do 10 i=1,18
            q(i,1)=p(i,1)*cos(beta)+p(i,2)*sin(beta)
            q(i,2)=-p(i,1)*sin(beta)+p(i,2)*cos(beta)
            q(i,3)=p(i,3)
 10     continue

        return
        end
```

Appendix A, cont.

NASTRAN Static Model Listing

```
NASTRAN
ID STATICS,TEST
SOL 101
TIME 3
CEND
TITLE=BATSAT STRUCTURE
SUBTITLE=SIDE VIEW PANEL STRESSES (MOD14)
DISP=ALL
ELFORCE=ALL
ELSTRESS=ALL
LOAD=500
OLOAD=ALL
SUBCASE 1
SPC=102
OUTPUT(PLOT)
PLOTTER NAST
SET 1=QUAD4,TRIA3
AXES MY,X,Z
VIEW 0.,0.,0.
FIND SCALE,ORIGIN 1,SET 1
CONTOUR MAJPRIN,EVEN 6,MAX,COMMON
PLOT SET 1,ORIGIN 1,LABEL BOTH
PLOT CONTOUR,SET 1,SHAPE
BEGIN BULK
$L= .1686m      r= .26m         d= .05m          diameter =0.62923m
$1......2.......3.......4.......5.......6.......7.......8.......9.......10
$
CBAR    1       10      1       2       0.0000  1.0000  0.0000
CBAR    2       10      2       3       0.0000  1.0000  0.0000
CBAR    3       10      3       4       0.0000  1.0000  0.0000
CBAR    4       10      4       5       0.0000  1.0000  0.0000
CBAR    5       10      5       6       0.0000  1.0000  0.0000
CBAR    6       10      6       7       0.0000  1.0000  0.0000
CBAR    7       10      7       8       0.0000  1.0000  0.0000
CBAR    8       10      8       9       0.0000  1.0000  0.0000
CBAR    9       10      9       1       0.0000  1.0000  0.0000
CBAR    10      10      8       5       0.0000  1.0000  0.0000
CBAR    11      10      9       4       0.0000  1.0000  0.0000
CBAR    12      10      10      11      0.0000  1.0000  0.0000
CBAR    13      10      11      12      0.0000  1.0000  0.0000
CBAR    14      10      12      13      0.0000  1.0000  0.0000
CBAR    15      10      13      14      0.0000  1.0000  0.0000
CBAR    16      10      14      15      0.0000  1.0000  0.0000
CBAR    17      10      15      16      0.0000  1.0000  0.0000
CBAR    18      10      16      17      0.0000  1.0000  0.0000
CBAR    19      10      17      18      0.0000  1.0000  0.0000
CBAR    20      10      18      10      0.0000  1.0000  0.0000
CBAR    21      10      17      14      0.0000  1.0000  0.0000
CBAR    22      10      18      13      0.0000  1.0000  0.0000
CBAR    23      10      1       109     0.0000  1.0000  0.0000
CBAR    24      10      10      109     0.0000  1.0000  0.0000
CBAR    25      10      7       110     0.0000  1.0000  0.0000
CBAR    26      10      16      110     0.0000  1.0000  0.0000
CBAR    27      10      19      20      -0.5000 0.8660  0.0000
CBAR    28      10      20      21      -0.5000 0.8660  0.0000
CBAR    29      10      21      22      -0.5000 0.8660  0.0000
CBAR    30      10      22      23      -0.5000 0.8660  0.0000
CBAR    31      10      23      24      -0.5000 0.8660  0.0000
CBAR    32      10      24      25      -0.5000 0.8660  0.0000
CBAR    33      10      25      26      -0.5000 0.8660  0.0000
CBAR    34      10      26      27      -0.5000 0.8660  0.0000
CBAR    35      10      27      19      -0.5000 0.8660  0.0000
CBAR    36      10      26      23      -0.5000 0.8660  0.0000
CBAR    37      10      27      22      -0.5000 0.8660  0.0000
CBAR    38      10      28      29      -0.5000 0.8660  0.0000
CBAR    39      10      29      30      -0.5000 0.8660  0.0000
```

CBAR	40	10	30	31	-0.5000 0.8660	0.0000
CBAR	41	10	31	32	-0.5000 0.8660	0.0000
CBAR	42	10	32	33	-0.5000 0.8660	0.0000
CBAR	43	10	33	34	-0.5000 0.8660	0.0000
CBAR	44	10	34	35	-0.5000 0.8660	0.0000
CBAR	45	10	35	36	-0.5000 0.8660	0.0000
CBAR	46	10	36	28	-0.5000 0.8660	0.0000
CBAR	47	10	35	32	-0.5000 0.8660	0.0000
CBAR	48	10	36	31	-0.5000 0.8660	0.0000
CBAR	49	10	19	109	-0.5000 0.8660	0.0000
CBAR	50	10	28	109	-0.5000 0.8660	0.0000
CBAR	51	10	25	110	-0.5000 0.8660	0.0000
CBAR	52	10	34	110	-0.5000 0.8660	0.0000
CBAR	53	10	37	38	-0.8660 0.5000	0.0000
CBAR	54	10	38	39	-0.8660 0.5000	0.0000
CBAR	55	10	39	40	-0.8660 0.5000	0.0000
CBAR	56	10	40	41	-0.8660 0.5000	0.0000
CBAR	57	10	41	42	-0.8660 0.5000	0.0000
CBAR	58	10	42	43	-0.8660 0.5000	0.0000
CBAR	59	10	43	44	-0.8660 0.5000	0.0000
CBAR	60	10	44	45	-0.8660 0.5000	0.0000
CBAR	61	10	45	37	-0.8660 0.5000	0.0000
CBAR	62	10	44	41	-0.8660 0.5000	0.0000
CBAR	63	10	45	40	-0.8660 0.5000	0.0000
CBAR	64	10	46	47	-0.8660 0.5000	0.0000
CBAR	65	10	47	48	-0.8660 0.5000	0.0000
CBAR	66	10	48	49	-0.8660 0.5000	0.0000
CBAR	67	10	49	50	-0.8660 0.5000	0.0000
CBAR	68	10	50	51	-0.8660 0.5000	0.0000
CBAR	69	10	51	52	-0.8660 0.5000	0.0000
CBAR	70	10	52	53	-0.8660 0.5000	0.0000
CBAR	71	10	53	54	-0.8660 0.5000	0.0000
CBAR	72	10	54	46	-0.8660 0.5000	0.0000
CBAR	73	10	53	50	-0.8660 0.5000	0.0000
CBAR	74	10	54	49	-0.8660 0.5000	0.0000
CBAR	75	10	37	109	-0.8660 0.5000	0.0000
CBAR	76	10	46	109	-0.8660 0.5000	0.0000
CBAR	77	10	43	110	-0.8660 0.5000	0.0000
CBAR	78	10	52	110	-0.8660 0.5000	0.0000
CBAR	79	10	55	56	-1.0000 0.0000	0.0000
CBAR	80	10	56	57	-1.0000 0.0000	0.0000
CBAR	81	10	57	58	-1.0000 0.0000	0.0000
CBAR	82	10	58	59	-1.0000 0.0000	0.0000
CBAR	83	10	59	60	-1.0000 0.0000	0.0000
CBAR	84	10	60	61	-1.0000 0.0000	0.0000
CBAR	85	10	61	62	-1.0000 0.0000	0.0000
CBAR	86	10	62	63	-1.0000 0.0000	0.0000
CBAR	87	10	63	55	-1.0000 0.0000	0.0000
CBAR	88	10	62	59	-1.0000 0.0000	0.0000
CBAR	89	10	63	58	-1.0000 0.0000	0.0000
CBAR	90	10	64	65	-1.0000 0.0000	0.0000
CBAR	91	10	65	66	-1.0000 0.0000	0.0000
CBAR	92	10	66	67	-1.0000 0.0000	0.0000
CBAR	93	10	67	68	-1.0000 0.0000	0.0000
CBAR	94	10	68	69	-1.0000 0.0000	0.0000
CBAR	95	10	69	70	-1.0000 0.0000	0.0000
CBAR	96	10	70	71	-1.0000 0.0000	0.0000
CBAR	97	10	71	72	-1.0000 0.0000	0.0000
CBAR	98	10	72	64	-1.0000 0.0000	0.0000
CBAR	99	10	71	68	-1.0000 0.0000	0.0000
CBAR	100	10	72	67	-1.0000 0.0000	0.0000
CBAR	101	10	55	109	-1.0000 0.0000	0.0000
CBAR	102	10	64	109	-1.0000 0.0000	0.0000
CBAR	103	10	61	110	-1.0000 0.0000	0.0000
CBAR	104	10	70	110	-1.0000 0.0000	0.0000
CBAR	105	10	73	74	-0.8660 -0.5000	0.0000

```
CBAR    106     10      74      75      -0.8660 -0.5000 0.0000
CBAR    107     10      75      76      -0.8660 -0.5000 0.0000
CBAR    108     10      76      77      -0.8660 -0.5000 0.0000
CBAR    109     10      77      78      -0.8660 -0.5000 0.0000
CBAR    110     10      78      79      -0.8660 -0.5000 0.0000
CBAR    111     10      79      80      -0.8660 -0.5000 0.0000
CBAR    112     10      80      81      -0.8660 -0.5000 0.0000
CBAR    113     10      81      73      -0.8660 -0.5000 0.0000
CBAR    114     10      80      77      -0.8660 -0.5000 0.0000
CBAR    115     10      81      76      -0.8660 -0.5000 0.0000
CBAR    116     10      82      83      -0.8660 -0.5000 0.0000
CBAR    117     10      83      84      -0.8660 -0.5000 0.0000
CBAR    118     10      84      85      -0.8660 -0.5000 0.0000
CBAR    119     10      85      86      -0.8660 -0.5000 0.0000
CBAR    120     10      86      87      -0.8660 -0.5000 0.0000
CBAR    121     10      87      88      -0.8660 -0.5000 0.0000
CBAR    122     10      88      89      -0.8660 -0.5000 0.0000
CBAR    123     10      89      90      -0.8660 -0.5000 0.0000
CBAR    124     10      90      82      -0.8660 -0.5000 0.0000
CBAR    125     10      89      86      -0.8660 -0.5000 0.0000
CBAR    126     10      90      85      -0.8660 -0.5000 0.0000
CBAR    127     10      73      109     -0.8660 -0.5000 0.0000
CBAR    128     10      82      109     -0.8660 -0.5000 0.0000
CBAR    129     10      79      110     -0.8660 -0.5000 0.0000
CBAR    130     10      88      110     -0.8660 -0.5000 0.0000
CBAR    131     10      91      92      -0.5000 -0.8660 0.0000
CBAR    132     10      92      93      -0.5000 -0.8660 0.0000
CBAR    133     10      93      94      -0.5000 -0.8660 0.0000
CBAR    134     10      94      95      -0.5000 -0.8660 0.0000
CBAR    135     10      95      96      -0.5000 -0.8660 0.0000
CBAR    136     10      96      97      -0.5000 -0.8660 0.0000
CBAR    137     10      97      98      -0.5000 -0.8660 0.0000
CBAR    138     10      98      99      -0.5000 -0.8660 0.0000
CBAR    139     10      99      91      -0.5000 -0.8660 0.0000
CBAR    140     10      98      95      -0.5000 -0.8660 0.0000
CBAR    141     10      99      94      -0.5000 -0.8660 0.0000
CBAR    142     10      100     101     -0.5000 -0.8660 0.0000
CBAR    143     10      101     102     -0.5000 -0.8660 0.0000
CBAR    144     10      102     103     -0.5000 -0.8660 0.0000
CBAR    145     10      103     104     -0.5000 -0.8660 0.0000
CBAR    146     10      104     105     -0.5000 -0.8660 0.0000
CBAR    147     10      105     106     -0.5000 -0.8660 0.0000
CBAR    148     10      106     107     -0.5000 -0.8660 0.0000
CBAR    149     10      107     108     -0.5000 -0.8660 0.0000
CBAR    150     10      108     100     -0.5000 -0.8660 0.0000
CBAR    151     10      107     104     -0.5000 -0.8660 0.0000
CBAR    152     10      108     103     -0.5000 -0.8660 0.0000
CBAR    153     10      91      109     -0.5000 -0.8660 0.0000
CBAR    154     10      100     109     -0.5000 -0.8660 0.0000
CBAR    155     10      97      110     -0.5000 -0.8660 0.0000
CBAR    156     10      106     110     -0.5000 -0.8660 0.0000
$
$
$
CBAR    157     20      4       22      0.0000  0.0000  1.0000
CBAR    158     20      22      40      0.0000  0.0000  1.0000
CBAR    159     20      40      58      0.0000  0.0000  1.0000
CBAR    160     20      58      76      0.0000  0.0000  1.0000
CBAR    161     20      76      94      0.0000  0.0000  1.0000
CBAR    162     20      94      13      0.0000  0.0000  1.0000
CBAR    163     20      13      31      0.0000  0.0000  1.0000
CBAR    164     20      31      49      0.0000  0.0000  1.0000
CBAR    165     20      49      67      0.0000  0.0000  1.0000
CBAR    166     20      67      85      0.0000  0.0000  1.0000
CBAR    167     20      85      103     0.0000  0.0000  1.0000
CBAR    168     20      103     4       0.0000  0.0000  1.0000
```

```
$
CBAR    169     20      5       23      0.0000  0.0000  1.0000
CBAR    170     20      23      41      0.0000  0.0000  1.0000
CBAR    171     20      41      59      0.0000  0.0000  1.0000
CBAR    172     20      59      77      0.0000  0.0000  1.0000
CBAR    173     20      77      95      0.0000  0.0000  1.0000
CBAR    174     20      95      14      0.0000  0.0000  1.0000
CBAR    175     20      14      32      0.0000  0.0000  1.0000
CBAR    176     20      32      50      0.0000  0.0000  1.0000
CBAR    177     20      50      68      0.0000  0.0000  1.0000
CBAR    178     20      68      86      0.0000  0.0000  1.0000
CBAR    179     20      86      104     0.0000  0.0000  1.0000
CBAR    180     20      104     5       0.0000  0.0000  1.0000
$
CBAR    181     20      2       20      0.0000  0.0000  1.0000
CBAR    182     20      20      38      0.0000  0.0000  1.0000
CBAR    183     20      38      56      0.0000  0.0000  1.0000
CBAR    184     20      56      74      0.0000  0.0000  1.0000
CBAR    185     20      74      92      0.0000  0.0000  1.0000
CBAR    186     20      92      11      0.0000  0.0000  1.0000
CBAR    187     20      11      29      0.0000  0.0000  1.0000
CBAR    188     20      29      47      0.0000  0.0000  1.0000
CBAR    189     20      47      65      0.0000  0.0000  1.0000
CBAR    190     20      65      83      0.0000  0.0000  1.0000
CBAR    191     20      83      101     0.0000  0.0000  1.0000
CBAR    192     20      101     2       0.0000  0.0000  1.0000
$
CBAR    193     20      1       19      0.0000  0.0000  1.0000
CBAR    194     20      19      37      0.0000  0.0000  1.0000
CBAR    195     20      37      55      0.0000  0.0000  1.0000
CBAR    196     20      55      73      0.0000  0.0000  1.0000
CBAR    197     20      73      91      0.0000  0.0000  1.0000
CBAR    198     20      91      10      0.0000  0.0000  1.0000
CBAR    199     20      10      28      0.0000  0.0000  1.0000
CBAR    200     20      28      46      0.0000  0.0000  1.0000
CBAR    201     20      46      64      0.0000  0.0000  1.0000
CBAR    202     20      64      82      0.0000  0.0000  1.0000
CBAR    203     20      82      100     0.0000  0.0000  1.0000
CBAR    204     20      100     1       0.0000  0.0000  1.0000
$
CBAR    205     20      3       21      0.0000  0.0000  1.0000
CBAR    206     20      21      39      0.0000  0.0000  1.0000
CBAR    207     20      39      57      0.0000  0.0000  1.0000
CBAR    208     20      57      75      0.0000  0.0000  1.0000
CBAR    209     20      75      93      0.0000  0.0000  1.0000
CBAR    210     20      93      12      0.0000  0.0000  1.0000
CBAR    211     20      12      30      0.0000  0.0000  1.0000
CBAR    212     20      30      48      0.0000  0.0000  1.0000
CBAR    213     20      48      66      0.0000  0.0000  1.0000
CBAR    214     20      66      84      0.0000  0.0000  1.0000
CBAR    215     20      84      102     0.0000  0.0000  1.0000
CBAR    216     20      102     3       0.0000  0.0000  1.0000
$
CBAR    217     20      6       24      0.0000  0.0000  1.0000
CBAR    218     20      24      42      0.0000  0.0000  1.0000
CBAR    219     20      42      60      0.0000  0.0000  1.0000
CBAR    220     20      60      78      0.0000  0.0000  1.0000
CBAR    221     20      78      96      0.0000  0.0000  1.0000
CBAR    222     20      96      15      0.0000  0.0000  1.0000
CBAR    223     20      15      33      0.0000  0.0000  1.0000
CBAR    224     20      33      51      0.0000  0.0000  1.0000
CBAR    225     20      51      69      0.0000  0.0000  1.0000
CBAR    226     20      69      87      0.0000  0.0000  1.0000
CBAR    227     20      87      105     0.0000  0.0000  1.0000
CBAR    228     20      105     6       0.0000  0.0000  1.0000
$
```

```
CBAR    229     20      7       25      0.0000  0.0000  1.0000
CBAR    230     20      25      43      0.0000  0.0000  1.0000
CBAR    231     20      43      61      0.0000  0.0000  1.0000
CBAR    232     20      61      79      0.0000  0.0000  1.0000
CBAR    233     20      79      97      0.0000  0.0000  1.0000
CBAR    234     20      97      16      0.0000  0.0000  1.0000
CBAR    235     20      16      34      0.0000  0.0000  1.0000
CBAR    236     20      34      52      0.0000  0.0000  1.0000
CBAR    237     20      52      70      0.0000  0.0000  1.0000
CBAR    238     20      70      88      0.0000  0.0000  1.0000
CBAR    239     20      88      106     0.0000  0.0000  1.0000
CBAR    240     20      106     7       0.0000  0.0000  1.0000
$
$
$
CQUAD4  241     30      1       19      20      2
CQUAD4  242     30      2       20      21      3
CQUAD4  243     30      3       21      22      4
CQUAD4  244     30      4       22      23      5
CQUAD4  245     30      5       23      24      6
CQUAD4  246     30      6       24      25      7
$
CQUAD4  247     30      10      28      29      11
CQUAD4  248     30      11      29      30      12
CQUAD4  249     30      12      30      31      13
CQUAD4  250     30      13      31      32      14
CQUAD4  251     30      14      32      33      15
CQUAD4  252     30      15      33      34      16
$
CQUAD4  253     30      19      37      38      20
CQUAD4  254     30      20      38      39      21
CQUAD4  255     30      21      39      40      22
CQUAD4  256     30      22      40      41      23
CQUAD4  257     30      23      41      42      24
CQUAD4  258     30      24      42      43      25
$
CQUAD4  259     30      28      46      47      29
CQUAD4  260     30      29      47      48      30
CQUAD4  261     30      30      48      49      31
CQUAD4  262     30      31      49      50      32
CQUAD4  263     30      32      50      51      33
CQUAD4  264     30      33      51      52      34
$
CQUAD4  265     30      37      55      56      38
CQUAD4  266     30      38      56      57      39
CQUAD4  267     30      39      57      58      40
CQUAD4  268     30      40      58      59      41
CQUAD4  269     30      41      59      60      42
CQUAD4  270     30      42      60      61      43
$
CQUAD4  271     30      46      64      65      47
CQUAD4  272     30      47      65      66      48
CQUAD4  273     30      48      66      67      49
CQUAD4  274     30      49      67      68      50
CQUAD4  275     30      50      68      69      51
CQUAD4  276     30      51      69      70      52

$
CQUAD4  277     30      55      73      74      56
CQUAD4  278     30      56      74      75      57
CQUAD4  279     30      57      75      76      58
CQUAD4  280     30      58      76      77      59
CQUAD4  281     30      59      77      78      60
CQUAD4  282     30      60      78      79      61
$
CQUAD4  283     30      64      82      83      65
```

```
CQUAD4  284     30      65      83      84      66
CQUAD4  285     30      66      84      85      67
CQUAD4  286     30      67      85      86      68
CQUAD4  287     30      68      86      87      69
CQUAD4  288     30      69      87      88      70
$
CQUAD4  289     30      73      91      92      74
CQUAD4  290     30      74      92      93      75
CQUAD4  291     30      75      93      94      76
CQUAD4  292     30      76      94      95      77
CQUAD4  293     30      77      95      96      78
CQUAD4  294     30      78      96      97      79
$
CQUAD4  295     30      82      100     101     83
CQUAD4  296     30      83      101     102     84
CQUAD4  297     30      84      102     103     85
CQUAD4  298     30      85      103     104     86
CQUAD4  299     30      86      104     105     87
CQUAD4  300     30      87      105     106     88
$
CQUAD4  301     30      91      10      11      92
CQUAD4  302     30      92      11      12      93
CQUAD4  303     30      93      12      13      94
CQUAD4  304     30      94      13      14      95
CQUAD4  305     30      95      14      15      96
CQUAD4  306     30      96      15      16      97
$
CQUAD4  307     30      100     1       2       101
CQUAD4  308     30      101     2       3       102
CQUAD4  309     30      102     3       4       103
CQUAD4  310     30      103     4       5       104
CQUAD4  311     30      104     5       6       105
CQUAD4  312     30      105     6       7       106
$
$
CTRIA3  313     40      109     1       19
CTRIA3  314     40      109     19      37
CTRIA3  315     40      109     37      55
CTRIA3  316     40      109     55      73
CTRIA3  317     40      109     73      91
CTRIA3  318     40      109     91      10
CTRIA3  319     40      109     10      28
CTRIA3  320     40      109     28      46
CTRIA3  321     40      109     46      64
CTRIA3  322     40      109     64      82
CTRIA3  323     40      109     82      100
CTRIA3  324     40      109     100     1
$
CTRIA3  325     40      110     7       25
CTRIA3  326     40      110     25      43
CTRIA3  327     40      110     43      61
CTRIA3  328     40      110     61      79
CTRIA3  329     40      110     79      97
CTRIA3  330     40      110     97      16
CTRIA3  331     40      110     16      34
CTRIA3  332     40      110     34      52
CTRIA3  333     40      110     52      70
CTRIA3  334     40      110     70      88
CTRIA3  335     40      110     88      106
CTRIA3  336     40      110     106     7
$
$
GRAV    100             107.91  0.0     0.0     -1.0
GRAV    200             34.3    1.0     0.0     0.0
$
$1......2.......3.......4.......5.......6.......7.......8.......9.......10
```

GRID	1	0.0843	0.0000	0.0000	
GRID	2	0.1574	0.0000	0.0422	123
GRID	3	0.2304	0.0000	0.0844	
GRID	4	0.3148	0.0000	0.2304	
GRID	5	0.3148	0.0000	0.3991	
GRID	6	0.2304	0.0000	0.5452	
GRID	7	0.0843	0.0000	0.6296	
GRID	8	0.2648	0.0000	0.4448	
GRID	9	0.2648	0.0000	0.1848	
GRID	10	-0.0843	0.0000	0.0000	
GRID	11	-0.1574	0.0000	0.0422	123
GRID	12	-0.2304	0.0000	0.0844	
GRID	13	-0.3148	0.0000	0.2304	
GRID	14	-0.3148	0.0000	0.3991	
GRID	15	-0.2304	0.0000	0.5452	
GRID	16	-0.0843	0.0000	0.6296	
GRID	17	-0.2648	0.0000	0.4448	
GRID	18	-0.2648	0.0000	0.1848	
GRID	19	0.0730	-0.0422	0.0000	
GRID	20	0.1363	-0.0787	0.0422	123
GRID	21	0.1996	-0.1152	0.0844	
GRID	22	0.2726	-0.1574	0.2304	
GRID	23	0.2726	-0.1574	0.3991	
GRID	24	0.1996	-0.1152	0.5452	
GRID	25	0.0730	-0.0422	0.6296	
GRID	26	0.2293	-0.1324	0.4448	
GRID	27	0.2293	-0.1324	0.1848	
GRID	28	-0.0730	0.0422	0.0000	
GRID	29	-0.1363	0.0787	0.0422	123
GRID	30	-0.1996	0.1152	0.0844	
GRID	31	-0.2726	0.1574	0.2304	
GRID	32	-0.2726	0.1574	0.3991	
GRID	33	-0.1996	0.1152	0.5452	
GRID	34	-0.0730	0.0422	0.6296	
GRID	35	-0.2293	0.1324	0.4448	
GRID	36	-0.2293	0.1324	0.1848	
GRID	37	0.0422	-0.0730	0.0000	
GRID	38	0.0787	-0.1363	0.0422	123
GRID	39	0.1152	-0.1996	0.0844	
GRID	40	0.1574	-0.2726	0.2304	
GRID	41	0.1574	-0.2726	0.3991	
GRID	42	0.1152	-0.1996	0.5452	
GRID	43	0.0422	-0.0730	0.6296	
GRID	44	0.1324	-0.2293	0.4448	
GRID	45	0.1324	-0.2293	0.1848	
GRID	46	-0.0422	0.0730	0.0000	
GRID	47	-0.0787	0.1363	0.0422	123
GRID	48	-0.1152	0.1996	0.0844	
GRID	49	-0.1574	0.2726	0.2304	
GRID	50	-0.1574	0.2726	0.3991	
GRID	51	-0.1152	0.1996	0.5452	
GRID	52	-0.0422	0.0730	0.6296	
GRID	53	-0.1324	0.2293	0.4448	
GRID	54	-0.1324	0.2293	0.1848	
GRID	55	0.0000	-0.0843	0.0000	
GRID	56	0.0000	-0.1574	0.0422	123
GRID	57	0.0000	-0.2304	0.0844	
GRID	58	0.0000	-0.3148	0.2304	
GRID	59	0.0000	-0.3148	0.3991	
GRID	60	0.0000	-0.2304	0.5452	
GRID	61	0.0000	-0.0843	0.6296	
GRID	62	0.0000	-0.2648	0.4448	
GRID	63	0.0000	-0.2648	0.1848	
GRID	64	0.0000	0.0843	0.0000	
GRID	65	0.0000	0.1574	0.0422	123
GRID	66	0.0000	0.2304	0.0844	

```
GRID     67              0.0000  0.3148  0.2304
GRID     68              0.0000  0.3148  0.3991
GRID     69              0.0000  0.2304  0.5452
GRID     70              0.0000  0.0843  0.6296
GRID     71              0.0000  0.2648  0.4448
GRID     72              0.0000  0.2648  0.1848
GRID     73             -0.0422 -0.0730  0.0000
GRID     74             -0.0787 -0.1363  0.0422         123
GRID     75             -0.1152 -0.1996  0.0844
GRID     76             -0.1574 -0.2726  0.2304
GRID     77             -0.1574 -0.2726  0.3991
GRID     78             -0.1152 -0.1996  0.5452
GRID     79             -0.0422 -0.0730  0.6296
GRID     80             -0.1324 -0.2293  0.4448
GRID     81             -0.1324 -0.2293  0.1848
GRID     82              0.0422  0.0730  0.0000
GRID     83              0.0787  0.1363  0.0422         123
GRID     84              0.1152  0.1996  0.0844
GRID     85              0.1574  0.2726  0.2304
GRID     86              0.1574  0.2726  0.3991
GRID     87              0.1152  0.1996  0.5452
GRID     88              0.0422  0.0730  0.6296
GRID     89              0.1324  0.2293  0.4448
GRID     90              0.1324  0.2293  0.1848
GRID     91             -0.0730 -0.0422  0.0000
GRID     92             -0.1363 -0.0787  0.0422         123
GRID     93             -0.1996 -0.1152  0.0844
GRID     94             -0.2726 -0.1574  0.2304
GRID     95             -0.2726 -0.1574  0.3991
GRID     96             -0.1996 -0.1152  0.5452
GRID     97             -0.0730 -0.0422  0.6296
GRID     98             -0.2293 -0.1324  0.4448
GRID     99             -0.2293 -0.1324  0.1848
GRID    100              0.0730  0.0422  0.0000
GRID    101              0.1363  0.0787  0.0422         123
GRID    102              0.1996  0.1152  0.0844
GRID    103              0.2726  0.1574  0.2304
GRID    104              0.2726  0.1574  0.3991
GRID    105              0.1996  0.1152  0.5452
GRID    106              0.0730  0.0422  0.6296
GRID    107              0.2293  0.1324  0.4448
GRID    108              0.2293  0.1324  0.1848
GRID    109              0.0000  0.0000  0.0000
GRID    110              0.0000  0.0000  0.6296
$
$1......2.......3.......4.......5.......6.......7.......8.......9.......10
$
LOAD    500     1.0     1.0     100     1.0     200
MAT1    25      70.0+9  26.316+90.33    2700.0  23.0-6
PBAR    10      25      4.0323-51.355-101.355-108.130-10
PBAR    20      25      1.613-4 8.671-9 5.420-106.121-9
PSHELL  30      25      .003    25      1.0     25      .833333
PSHELL  40      25      .003    25      1.0     25      .833333
PARAM   COUPMASS1
PARAM   GRDPNT  0
PARAM   USETPRT 1
SPC1    102
ENDDATA
```

NASTRAN Selected Static Output

```
                                                     MESSAGES FROM THE PLOT MODULE


P L O T T E R   D A T A

        THE FOLLOWING PLOTS ARE FOR A NASTPLT PLOTTER

        PAPER SIZE = 20.0 X 20.0,  PAPER TYPE = VELLUM

        PEN 1 - SIZE 1, BLACK
        PEN 2 - SIZE 1, BLACK
        PEN 3 - SIZE 1, BLACK
        PEN 4 - SIZE 1, BLACK


E N G I N E E R I N G   D A T A

        ORTHOGRAPHIC PROJECTION
        ROTATIONS (DEGREES) - GAMMA =   0.00, BETA =   0.00, ALPHA =   0.00,  AXES = -Y,+X,+Z, SYMMETRIC
        SCALE (OBJECT-TO-PLOT SIZE) = 2.947904E+01

        ORIGIN      1   -   X0 = -9.280000E+00, Y0 = -9.600000E-01     (INCHES)


L I S T   O F   P L O T S

        PLOT    1     UNDEFORMED SHAPE
1   BATSAT STRUCTURE                                                         MAY   5, 1993  MSC/NASTRAN  9/ 4/91   PAGE    15
     SIDE VIEW PANEL STRESSES (MOD14)
0
                       O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
0                                                 REFERENCE POINT =        0
                                                              M O
                 *  1.655534E+01  5.522655E-19  3.388132E-21 -2.562657E-19  5.095386E+00  2.510267E-17 *
                 *  5.217723E-19  1.655534E+01  0.000000E+00 -5.095386E+00  1.641892E-19  3.851628E-17 *
                 *  4.065758E-20  0.000000E+00  1.655534E+01 -1.660862E-17 -4.176889E-17 -1.090491E-19 *
                 * -2.517196E-19 -5.095386E+00 -2.043721E-17  2.685863E+00  9.622294E-19  9.741726E-18 *
                 *  5.095386E+00  1.643208E-19  1.626303E-18 -1.136718E-18  2.685863E+00  7.051549E-19 *
                 *  1.940722E-17  7.264155E-18 -1.111361E-19 -1.632910E-17  7.002421E-18  1.028373E+00 *
                                                               S
                                  *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                  *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                  *  0.000000E+00  0.000000E+00  1.000000E+00 *
                       DIRECTION
                  MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                          X             1.655534E+01      -1.547934E-20 -1.516289E-18  3.077791E-01
                          Y             1.655534E+01       2.326518E-18  9.917600E-21  3.077791E-01
                          Z             1.655534E+01       2.522986E-18 -1.003219E-18 -6.586943E-21
                                                             I(S)
                                  *  1.117610E+00 -9.622294E-19 -2.159623E-17 *
                                  * -9.622294E-19  1.117610E+00  7.020921E-18 *
                                  * -2.159623E-17  7.020921E-18  1.028373E+00 *
                                                             I(Q)
                                  *  1.117610E+00                             *
                                  *                1.117610E+00               *
                                  *                              1.028373E+00 *
                                                               Q
                                  *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                  *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                  *  0.000000E+00  0.000000E+00  1.000000E+00 *

1   BATSAT STRUCTURE                                                         MAY   5, 1993  MSC/NASTRAN  9/ 4/91   PAGE    16
     SIDE VIEW PANEL STRESSES (MOD14)
0
1   BATSAT STRUCTURE                                                         MAY   5, 1993  MSC/NASTRAN  9/ 4/91   PAGE    17
     SIDE VIEW PANEL STRESSES (MOD14)
0
0                                                 OLOAD    RESULTANT
0            T1             T2             T3             R1             R2             R3
0      1  5.6784802E+02  1.8697655E-17 -1.7864865E+03  0.0000000E+00  1.7477174E+02  0.0000000E+00
1   BATSAT STRUCTURE                                                         MAY   5, 1993  MSC/NASTRAN  9/ 4/91   PAGE    18
     SIDE VIEW PANEL STRESSES (MOD14)
0
      U S E T   D E F I N I T I O N   T A B L E   ( I N T E R N A L   S E Q U E N C E ,   C O L U M N   S O R T )
```

INT DOF	INT GP.	EXT GP. DOF	SB	SG	L	A	F	N	G	R	O	S	M	E	INT DOF
1-	1 G	8 - 1			1	1	1	1	1					-	1
2-		- 2			2	2	2	2	2					-	2
3-		- 3			3	3	3	3	3					-	3
4-		- 4			4	4	4	4	4					-	4
5-		- 5			5	5	5	5	5					-	5
6-		- 6			6	6	6	6	6					-	6
7-	2 G	9 - 1			7	7	7	7	7					-	7
8-		- 2			8	8	8	8	8					-	8
9-		- 3			9	9	9	9	9					-	9
10-		- 4			10	10	10	10	10					-	10
11-		- 5			11	11	11	11	11					-	11
12-		- 6			12	12	12	12	12					-	12
13-	3 G	7 - 1			13	13	13	13	13					-	13
14-		- 2			14	14	14	14	14					-	14
15-		- 3			15	15	15	15	15					-	15
16-		- 4			16	16	16	16	16					-	16
17-		- 5			17	17	17	17	17					-	17
18-		- 6			18	18	18	18	18					-	18

FORCES IN BAR ELEMENTS (CBAR)

0 ELEMENT	BEND-MOMENT END-A		BEND-MOMENT END-B		- SHEAR -		AXIAL	
ID.	PLANE 1	PLANE 2	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
1	-3.590761E-13	2.144488E-02	1.106471E-13	-3.499864E-02	-5.565014E-12	6.687108E-01	1.084783E+01	2.971920E-13
2	9.351339E-14	-7.868370E-02	-5.512026E-14	6.357207E-02	1.762736E-12	-1.687097E+00	-4.457223E+01	2.931055E-14
3	1.595531E-15	1.171102E-02	6.130488E-17	4.705452E-03	9.097656E-15	4.154160E-02	-2.166726E+01	4.877645E-15
4	-1.228829E-15	-1.854249E-02	1.752490E-15	1.526943E-02	-1.767231E-14	-2.004263E-01	-9.374801E+00	5.545486E-15
5	1.426244E-14	-9.070121E-03	-2.129563E-14	6.221632E-03	2.107441E-13	-9.063052E-02	-4.976630E+00	1.440544E-14
6	-6.618376E-14	-1.165417E-03	1.811587E-13	-6.451873E-04	-1.465939E-12	-3.083276E-03	-3.507457E+00	1.006417E-13
7	1.328638E-13	-2.028330E-02	-3.653876E-14	3.386560E-02	6.557756E-13	-2.096162E-01	4.985665E-01	4.359654E-14
8	-2.132455E-15	-2.535553E-02	1.344051E-15	2.400393E-02	-1.337118E-14	-1.898441E-01	-1.100659E+00	4.275405E-14
9	4.161772E-14	-4.294580E-02	-1.513211E-13	3.454868E-02	7.468870E-13	-2.999895E-01	-4.480549E+01	7.227024E-14
10	-5.952623E-15	9.743042E-03	-5.127953E-14	-4.993476E-02	6.691468E-13	8.810045E-01	-1.761725E+00	1.418675E-14
11	1.322520E-14	3.175361E-02	6.467260E-14	-5.863283E-02	-7.602582E-13	1.335675E+00	-4.260091E+01	4.193039E-14
12	3.634989E-13	2.221957E-03	-1.072898E-13	-8.128450E-03	5.577639E-12	1.226258E-01	6.335533E+00	2.048117E-13
13	-1.081138E-13	-2.412591E-02	6.346715E-14	1.481274E-02	-2.034882E-12	-4.617968E-01	9.981408E-01	3.063550E-14
14	-1.728371E-15	6.843613E-03	1.359432E-16	-1.015999E-02	-1.105501E-14	1.008280E-01	-4.439110E+00	5.438592E-15
15	7.309290E-16	1.425886E-02	-8.789696E-16	-1.503234E-02	9.542967E-15	1.736289E-01	-3.945104E+00	6.197978E-15
16	-1.308880E-14	1.208695E-02	1.856686E-14	-7.169246E-03	-1.876154E-13	1.141268E-01	-2.755921E+00	1.234841E-14
17	7.212072E-14	-8.711179E-04	-1.935405E-13	3.412962E-03	1.574510E-12	-2.539071E-02	-2.956770E+00	1.633147E-13
18	-1.544750E-13	2.639141E-02	3.941676E-14	-4.402583E-02	-7.505758E-13	2.725927E-01	3.750731E+00	7.348701E-14
19	-1.642413E-17	3.349094E-02	-2.877231E-15	-3.546562E-02	1.100310E-14	2.652175E-01	-1.362224E+00	4.491782E-14
20	-4.162522E-14	4.714065E-02	1.422348E-13	-2.475102E-02	-7.117421E-13	2.783004E-01	-1.513659E+01	4.993161E-14
21	1.037460E-14	-4.232702E-02	6.196352E-14	9.099621E-02	-7.615908E-13	-1.968208E+00	3.329189E+00	4.081806E-14
22	-9.311121E-15	-3.312795E-02	-5.821990E-14	9.136084E-02	7.227440E-13	-1.839619E+00	-1.124533E+01	1.930331E-14
23	-7.486548E-13	2.777270E-02	8.036280E-13	-2.901038E-02	-1.841379E-11	6.735834E-01	2.196456E+00	-7.129661E-14
24	-8.993340E-13	-3.153107E-02	8.033114E-13	2.961048E-02	-2.019745E-11	-7.252854E-01	2.873801E+00	-6.588983E-13
25	-5.234889E-13	2.958771E-02	4.291914E-13	-2.834926E-02	-1.130107E-11	6.872713E-01	-2.271778E+00	2.509357E-14
26	-3.726431E-13	-3.133868E-02	4.259350E-13	2.865491E-02	-9.473051E-12	-7.116678E-01	-1.733441E+00	-7.542984E-13
27	1.216083E-02	1.574923E-02	-2.040341E-02	-2.481064E-02	3.859239E-01	4.806812E-01	1.055563E+01	7.077573E-04
28	-3.754690E-02	-6.229705E-02	3.001979E-02	5.104756E-02	-8.007433E-01	-1.343264E+00	-4.148076E+01	-5.417068E-03
29	9.989605E-03	3.814772E-03	2.994690E-03	4.665184E-03	4.148832E-02	-5.043976E-03	-2.052173E+01	-2.990394E-04
30	-1.550547E-02	-9.609520E-03	1.294831E-02	8.068538E-03	-1.686650E-01	-1.047899E-01	-9.010637E+00	-3.567546E-05
31	-7.973676E-03	-4.767393E-03	5.381461E-03	3.263598E-03	-7.917146E-02	-4.760905E-02	-4.826252E+00	2.786209E-04
32	-8.113426E-04	-6.572965E-04	-6.898224E-04	-5.011598E-04	-7.200772E-04	-9.252005E-04	-3.471506E+00	1.017989E-04
33	2.009037E-02	-8.003619E-03	-3.339978E-02	1.354119E-02	2.070886E-01	-8.341134E-02	7.196137E-01	2.162914E-03
34	2.302230E-02	-1.185355E-02	-2.066055E-02	1.369357E-02	1.680110E-01	-9.825817E-02	-1.122436E+00	-3.731592E-04
35	2.654099E-02	-3.586927E-02	-2.085124E-02	2.808128E-02	1.834804E-01	-2.475864E-01	-4.283487E+01	-3.329445E-03
36	-1.493154E-02	7.809504E-04	5.515825E-02	-1.633347E-02	-1.034726E+00	2.526578E-01	-1.414710E+00	-6.275317E-03
37	1.788837E-02	2.797319E-02	-3.137875E-02	-5.672431E-02	7.280481E-01	1.251623E+00	-4.051399E+01	5.876750E-03
38	-4.189087E-04	1.205415E-03	-2.824195E-03	-4.489919E-03	2.850542E-02	6.749628E-02	6.643507E+00	-6.995315E-04
39	-1.930806E-03	-2.111342E-02	-1.813357E-03	1.420500E-02	-1.391904E-03	-4.185641E-01	-2.095360E+00	5.384411E-03
40	5.976103E-03	1.138874E-03	-9.383663E-03	-3.587015E-03	9.110200E-02	2.803025E-02	-5.594239E+00	3.135261E-04
41	1.288231E-02	6.772039E-03	-1.328888E-02	-7.072475E-03	1.551345E-01	8.206587E-02	-4.310146E+00	4.140049E-05
42	9.643014E-03	6.968013E-03	-5.767337E-03	-4.167014E-03	9.135512E-02	6.601029E-02	-2.903188E+00	-2.746614E-04
43	-6.202278E-04	-4.336690E-04	1.966204E-03	2.565781E-03	-1.532610E-02	-1.777347E-02	-2.990755E+00	-1.026632E-04
44	-1.619169E-02	2.128040E-02	2.715116E-02	-3.533000E-02	-1.678031E-01	2.191688E-01	3.535139E+00	-2.160661E-03
45	-2.788747E-02	1.754001E-02	3.077885E-02	-1.603634E-02	-2.256397E-01	1.291398E-01	-1.346140E+00	4.118293E-04
46	-4.341981E-02	2.077136E-02	2.520260E-02	-9.200518E-03	-2.656736E-01	1.160370E-01	-1.714005E+01	3.317879E-03
47	2.453551E-02	-3.301664E-02	-5.172138E-02	7.516263E-02	1.125770E+00	-1.597035E+00	2.991270E+00	6.250551E-03
48	-3.119554E-02	-1.430750E-02	8.216929E-02	4.102083E-02	-1.675256E+00	-8.176181E-01	-1.336062E+01	-5.886101E-03
49	4.257632E-04	2.801530E-02	-3.075795E-04	-2.903874E-02	8.697152E-03	6.766381E-01	2.239632E+00	1.665154E-04
50	4.222245E-04	-3.126584E-02	-3.058539E-04	2.955695E-02	8.634720E-03	-7.213342E-01	2.826720E+00	-1.673221E-04

FORCES IN BAR ELEMENTS (CBAR)

0 ELEMENT	BEND-MOMENT END-A		BEND-MOMENT END-B		- SHEAR -		AXIAL	
ID.	PLANE 1	PLANE 2	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
51	4.815668E-04	2.969050E-02	-2.992716E-04	-2.835599E-02	9.260433E-03	6.884083E-01	-2.236255E+00	1.300307E-04
52	4.816061E-04	-3.120659E-02	-2.992316E-04	2.862079E-02	9.260423E-03	-7.095288E-01	-1.770165E+00	-1.320234E-04
53	1.161587E-02	-1.049281E-02	-1.690304E-02	1.740152E-02	3.379820E-01	-3.305800E-01	9.734171E+00	1.198611E-03
54	-5.079036E-02	2.598196E-02	4.270640E-02	-2.112120E-02	-1.108044E+00	5.582267E-01	-3.318760E+01	-9.317691E-03
55	3.582076E-03	-7.319125E-03	7.187615E-03	-1.720148E-04	-2.138521E-02	-4.239102E-02	-1.735949E+01	-5.475537E-04
56	-1.561429E-02	7.863455E-03	1.361659E-02	-6.824913E-03	-1.732713E-01	8.706798E-02	-8.017959E+00	-7.531007E-05
57	-7.746551E-03	6.101894E-03	5.117561E-03	-3.973575E-03	-7.626059E-02	5.972905E-02	-4.420108E+00	4.723465E-04
58	-1.841763E-04	7.080293E-04	-6.230299E-04	1.228768E-03	2.600461E-03	-3.085678E-03	-3.367541E+00	1.784743E-04
59	9.999488E-03	2.228367E-02	-1.693849E-02	-3.689345E-02	1.042912E-01	2.291059E-01	1.305749E+00	3.738995E-03
60	2.260979E-02	1.554239E-02	-2.453909E-02	-1.116628E-02	1.813418E-01	1.027256E-01	-1.171019E+00	-7.149538E-04
61	4.626993E-02	1.264653E-02	-3.437777E-02	-8.465639E-03	3.122299E-01	8.173636E-02	-3.742892E+01	-5.748353E-03
62	-3.257121E-03	-2.359012E-02	1.919570E-02	6.991457E-02	-3.314678E-01	-1.380397E+00	-4.915852E-01	-1.082779E-02
63	3.493507E-02	-8.456687E-03	-7.577238E-02	1.408836E-02	1.635987E+00	-3.331609E-01	-3.479886E+01	1.019692E-02
64	-9.638674E-04	4.051004E-03	6.761833E-04	-2.919202E-03	-1.943649E-02	8.260497E-02	7.464971E+00	-1.206837E-03
65	-1.517426E-02	-1.520166E-02	1.087325E-02	1.572136E-02	-3.086930E-01	-3.664735E-01	-1.038853E+01	9.350347E-03
66	-4.314262E-04	-4.643227E-03	-5.190738E-03	8.080184E-03	2.822848E-02	-7.546524E-02	-8.756479E+00	5.330670E-04
67	1.277350E-02	-8.518103E-03	-1.262059E-02	8.316101E-03	1.505281E-01	-9.978780E-02	-5.302825E+00	6.958505E-05
68	9.870138E-03	-5.633512E-03	-6.031237E-03	3.457037E-03	9.426599E-02	-5.389028E-02	-3.309331E+00	-4.763060E-04
69	6.938424E-06	4.844018E-04	2.032996E-03	-1.838173E-03	-1.200556E-02	1.376259E-02	-3.094721E+00	-1.776100E-04
70	-2.628257E-02	-7.000344E-03	4.361244E-02	1.197774E-02	-2.706006E-01	-7.347420E-02	2.949004E+00	-3.741247E-03
71	-2.829999E-02	-1.385117E-02	2.690031E-02	1.856363E-02	-2.123088E-01	-1.246723E-01	-1.297558E+00	6.762836E-04
72	-2.369087E-02	-4.399411E-02	1.167607E-02	2.881615E-02	-1.369241E-01	-2.818870E-01	-2.254599E+01	5.759919E-03
73	3.620993E-02	1.020747E-02	-8.768392E-02	-2.158153E-02	1.829027E+00	4.692965E-01	2.068146E+00	1.085255E-02
74	-1.414884E-02	3.382400E-02	3.777566E-02	-8.365679E-02	-7.673178E-01	1.736080E+00	-1.907575E+01	-1.018757E-02
75	-7.307676E-04	-2.870341E-02	5.292339E-04	2.914898E-02	-1.494312E-02	-6.861063E-01	2.363853E+00	2.875661E-04
76	-7.343062E-04	3.057773E-02	5.309596E-04	-2.944672E-02	-1.500555E-02	7.118660E-01	2.702499E+00	-2.867593E-04
77	-8.374247E-04	-3.001085E-02	5.198264E-04	2.841203E-02	-1.609646E-02	-6.928721E-01	-2.138038E+00	2.271382E-04
78	-8.373854E-04	3.088623E-02	5.198665E-04	-2.856475E-02	-1.609647E-02	7.050650E-01	-1.868382E+00	-2.251455E-04
79	2.218983E-03	-9.611459E-03	-1.614133E-03	1.343509E-02	4.541259E-02	-2.730425E-01	8.591681E+00	1.393502E-03
80	-2.475919E-02	2.727889E-02	2.138408E-02	-2.437967E-02	-5.472408E-01	6.126499E-01	-2.178704E+01	-1.079295E-02
81	-4.736858E-03	-2.433702E-03	4.441009E-03	-7.432719E-03	-5.442293E-02	2.964318E-02	-1.305319E+01	-6.213687E-04
82	-1.147575E-03	1.640067E-02	1.033259E-03	-1.515089E-02	-1.292729E-02	1.870276E-01	-6.659952E+00	-8.151900E-05
83	9.061488E-04	1.057854E-02	-5.384588E-04	-6.695439E-03	8.561840E-03	1.023787E-01	-3.866276E+00	5.530859E-04
84	3.666873E-04	1.471495E-04	3.886380E-04	2.029075E-03	-1.300967E-04	-1.115371E-02	-3.232114E+00	2.042179E-04
85	-1.277510E-02	2.333735E-02	2.087355E-02	-3.894572E-02	-1.302576E-01	2.411045E-01	2.124649E+00	4.319953E-03
86	-2.490008E-03	2.942323E-02	-3.021410E-03	-2.973478E-02	2.043857E-03	2.275308E-01	-1.231441E+00	-7.983861E-04
87	2.229456E-02	4.504322E-02	-1.738811E-02	-2.964985E-02	1.536159E-01	2.891449E-01	-2.997104E+01	-6.645053E-03
88	1.824134E-02	-2.603503E-02	-4.692085E-02	7.046549E-02	9.619687E-01	-1.424606E+00	7.837318E-01	-1.252023E-02
89	1.895599E-02	-3.244078E-02	-4.482878E-02	7.499683E-02	9.425724E-01	-1.587647E+00	-2.692312E+01	1.176799E-02

266	5.840750E+02	-2.340509E+03	-2.622489E+03	-4.725084E-02	-6.591293E-02	4.349691E-02	-7.667595E+00	-1.758206E+01
267	1.145086E+03	-7.123824E+02	-7.507527E+02	3.790018E-02	1.053804E-01	5.426811E-03	4.208248E-01	-2.385860E-01
268	3.440515E+02	-4.324756E+02	-2.731831E+02	-3.679375E-03	-1.526136E-02	8.543625E-05	-6.687283E-01	-3.425724E+00
269	9.214516E+01	-2.944826E+02	-1.239226E+02	-1.827132E-02	-3.533856E-02	-6.650033E-04	-9.339312E-01	-1.847940E+00
270	-5.784969E+01	-2.901468E+02	-7.358328E+01	-7.397202E-03	-1.956263E-02	-1.072379E-03	-4.089126E-01	1.513366E-01
271	3.014476E+02	7.384348E+02	-1.235699E+02	-1.069292E-02	-1.516873E-02	-6.864618E-03	-6.372569E+00	3.452614E+00
272	4.704423E+02	-1.362935E+03	2.625096E+03	-9.306367E-03	-3.171459E-04	-4.362293E-02	7.674496E+00	-6.718120E+00
273	8.230325E+02	-5.186360E+02	7.503003E+02	2.915794E-02	7.622188E-02	-5.410534E-03	-4.284848E-01	-8.672036E-01
274	2.550189E+02	-3.608545E+02	2.731595E+02	-3.661976E-03	-7.138585E-03	-5.767200E-05	6.704285E-01	-3.297414E+00
275	3.022311E+01	-2.688803E+02	1.238849E+02	-2.260741E-02	-4.097283E-02	6.670963E-04	9.365753E-01	-1.961423E+00
276	-9.339983E+01	-2.887101E+02	7.364703E+01	-7.707814E-03	-2.123360E-02	1.069567E-03	4.093098E-01	2.930611E-01
277	3.014476E+02	7.384348E+02	1.235699E+02	-1.069292E-02	-1.516873E-02	6.864618E-03	6.372569E+00	3.452614E+00
278	4.704423E+02	-1.362935E+03	-2.625096E+03	-9.306367E-03	-3.171459E-04	4.362293E-02	-7.674496E+00	-6.718120E+00
279	8.230325E+02	-5.186360E+02	-7.503003E+02	2.915794E-02	7.622188E-02	5.410534E-03	4.284848E-01	-8.672036E-01
280	2.550189E+02	-3.608545E+02	-2.731595E+02	-3.661976E-03	-7.138585E-03	5.767200E-05	-6.704285E-01	-3.297414E+00
281	3.022311E+01	-2.688803E+02	-1.238849E+02	-2.260741E-02	-4.097283E-02	-6.670963E-04	-9.365753E-01	-1.961423E+00
282	-9.339983E+01	-2.887101E+02	-7.364703E+01	-7.707814E-03	-2.123360E-02	-1.069567E-03	-4.093098E-01	2.930611E-01
283	3.534035E+02	8.471934E+02	-1.234523E+02	-3.777957E-02	-6.372009E-02	-6.865422E-03	-6.361629E+00	7.393185E+00
284	5.840750E+02	-2.340509E+03	2.622489E+03	-4.725084E-02	-6.591293E-02	-4.349691E-02	7.667595E+00	-1.758206E+01
285	1.145086E+03	-7.123824E+02	7.507527E+02	3.790018E-02	1.053804E-01	-5.426811E-03	-4.208248E-01	-2.385860E-01
286	3.440515E+02	-4.324756E+02	2.731831E+02	-3.679375E-03	-1.526136E-02	-8.543625E-05	6.687283E-01	-3.425724E+00
287	9.214516E+01	-2.944826E+02	1.239226E+02	-1.827132E-02	-3.533856E-02	6.650033E-04	9.339312E-01	-1.847940E+00
288	-5.784969E+01	-2.901468E+02	7.358328E+01	-7.397202E-03	-1.956263E-02	1.072379E-03	4.089126E-01	1.513366E-01
289	2.565121E+02	6.450062E+02	9.034018E+01	1.278056E-02	2.691199E-02	5.030826E-03	4.682122E+00	3.221761E-02
290	3.725855E+02	-5.191925E+02	-1.919869E+03	2.362441E-02	5.660649E-02	3.189762E-02	-5.636991E+00	2.673728E+00

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 47

SIDE VIEW PANEL STRESSES (MOD14)

0 SUBCASE 1

F O R C E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   (Q U A D 4)

ELEMENT	- MEMBRANE	FORCES -		- BENDING	MOMENTS -		- TRANSVERSE SHEAR	FORCES -
ID	FX	FY	FXY	MX	MY	MXY	QX	QY
291	5.440270E+02	-3.508220E+02	-5.494080E+02	2.155004E-02	5.090450E-02	3.964988E-03	3.080928E-01	-1.413865E+00
292	1.779070E+02	-2.988895E+02	-1.999196E+02	-3.601516E-03	-6.561957E-05	4.963365E-05	-4.906484E-01	-3.185804E+00
293	-2.333251E+01	-2.465347E+02	-9.074060E+01	-2.639591E-02	-4.586403E-02	-4.875443E-04	-6.834825E-01	-2.061070E+00
294	-1.241116E+02	-2.873134E+02	-5.388642E+01	-8.053681E-03	-2.270973E-02	-7.830276E-04	-3.029959E-01	4.160261E-01
295	3.984750E+02	9.417280E+02	-9.034018E+01	-6.117753E-02	-1.057644E-01	-5.030826E-03	-4.682122E+00	1.082029E+01
296	6.808348E+02	-3.188227E+03	1.919869E+03	-8.031138E-02	-1.226618E-01	-3.189762E-02	5.636991E+00	-2.695327E+01
297	1.424169E+03	-8.805180E+02	5.494080E+02	4.504438E-02	1.303880E-01	-3.964988E-03	-3.080928E-01	3.051223E-01
298	4.212050E+02	-4.944595E+02	1.999196E+02	-3.886455E-03	-2.231827E-02	-4.963365E-05	4.906484E-01	-3.535986E+00
299	1.456992E+02	-3.165609E+02	9.074060E+01	-1.453263E-02	-3.048427E-02	4.875443E-04	6.834825E-01	-1.749176E+00
300	-2.685900E+01	-2.916120E+02	5.388642E+01	-7.097768E-03	-1.809774E-02	7.830276E-04	3.029959E-01	2.856101E-02
301	2.305433E+02	5.906006E+02	3.302573E+01	2.629867E-02	5.117396E-02	1.830485E-03	1.705994E+00	-1.940346E+00
302	3.164997E+02	-3.004304E+01	-7.029039E+02	4.270343E-02	8.946729E-02	1.166887E-02	-2.052203E+00	8.095702E+00
303	3.829587E+02	-2.535450E+02	-2.012976E+02	1.730427E-02	3.636815E-02	1.457379E-03	1.138642E-01	-1.728503E+00
304	1.333423E+02	-2.630892E+02	-7.316280E+01	-3.537118E-03	4.009573E-03	2.040058E-05	-1.791735E-01	-3.121838E+00
305	-5.424064E+01	-2.338188E+02	-3.328263E+01	-2.855325E-02	-4.867032E-02	-1.765705E-04	-2.498072E-01	-2.117826E+00
306	-1.420886E+02	-2.864876E+02	-1.961604E+01	-8.197386E-03	-2.354261E-02	-2.907645E-04	-1.079436E-01	4.868928E-01
307	4.243077E+02	9.950275E+02	-3.314326E+01	-7.477117E-02	-1.300628E-01	-1.829681E-03	-1.716934E+00	1.278614E+01
308	7.380176E+02	-3.673401E+03	7.055115E+02	-9.926064E-02	-1.556974E-01	-1.179488E-02	2.059104E+00	-3.239589E+01
309	1.585160E+03	-9.774734E+02	2.008452E+02	4.975385E-02	1.452342E-01	-1.441102E-03	-1.215242E-01	6.227138E-01
310	4.657281E+02	-5.302409E+02	7.313913E+01	-3.804233E-03	-2.640952E-02	7.363667E-06	1.808737E-01	-3.601300E+00
311	1.766089E+02	-3.295441E+02	3.324495E+01	-1.232549E-02	-2.764107E-02	1.786635E-04	2.524513E-01	-1.691536E+00
312	-9.160946E+00	-2.923692E+02	1.967980E+01	-6.907630E-03	-1.725362E-02	2.879529E-04	1.083408E-01	-4.249511E-02

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 48

SIDE VIEW PANEL STRESSES (MOD14)

0 SUBCASE 1

F O R C E S   I N   T R I A N G U L A R   E L E M E N T S   (T R I A 3)

ELEMENT	- MEMBRANE	FORCES -		- BENDING	MOMENTS -		- TRANSVERSE SHEAR	FORCES -
ID	FX	FY	FXY	MX	MY	MXY	QX	QY
313	2.828431E+02	3.619044E+02	-2.006487E+01	-1.389326E-02	-1.096154E-02	6.959004E-04	-1.341242E+01	-3.629241E+00
314	2.797918E+02	3.429239E+02	-1.014448E+01	-1.033262E-02	-5.561737E-03	2.797052E-03	-1.349378E+01	-3.788272E+00
315	2.773234E+02	3.074381E+02	2.351855E+00	-2.896355E-03	2.433355E-03	4.128995E-03	-1.370117E+01	-3.955634E+00
316	2.759903E+02	2.647839E+02	1.404323E+01	6.449910E-03	1.095433E-02	4.385742E-03	-1.397548E+01	-3.956221E+00
317	2.758804E+02	2.267170E+02	2.219034E+01	1.522677E-02	1.768626E-02	3.462604E-03	-1.419375E+01	-3.975418E+00
318	2.774180E+02	2.033702E+02	2.444205E+01	2.103826E-02	2.075778E-02	1.606153E-03	-1.435229E+01	-3.954347E+00
319	2.800517E+02	2.007365E+02	1.988613E+01	2.235985E-02	1.943618E-02	-6.800230E-04	-1.440456E+01	-3.759483E+00
320	2.828293E+02	2.197682E+02	1.012404E+01	1.883420E-02	1.407883E-02	-2.801517E-03	-1.428386E+01	-3.638389E+00
321	2.853529E+02	2.554214E+02	-2.152674E+00	1.137873E-02	6.025515E-03	-4.140407E-03	-1.407927E+01	-3.569278E+00
322	2.869044E+02	2.978571E+02	-1.422198E+01	2.016685E-03	-2.479685E-03	-4.369865E-03	-1.384150E+01	-3.432503E+00
323	2.867406E+02	3.359750E+02	-2.221077E+01	-6.725188E-03	-9.169168E-03	-3.467069E-03	-1.358389E+01	-3.451242E+00
324	2.852584E+02	3.594892E+02	-2.424286E+01	-1.255589E-02	-1.229891E-02	-1.617565E-03	-1.342816E+01	-3.570565E+00
325	-2.279715E+02	-1.786455E+02	-1.196417E+01	1.625538E-02	1.810005E-02	1.587912E-04	-1.364186E+01	-3.785041E+00
326	-2.285584E+02	-1.884325E+02	-5.201788E+00	1.780953E-02	2.039281E-02	1.163792E-03	-1.361117E+01	-4.087207E+00
327	-2.274201E+02	-2.071265E+02	2.876509E+00	2.108722E-02	2.367536E-02	1.861753E-03	-1.367714E+01	-4.315587E+00
328	-2.249190E+02	-2.300799E+02	1.015638E+01	2.523974E-02	2.714378E-02	2.045684E-03	-1.381701E+01	-4.277997E+00
329	-2.218711E+02	-2.511057E+02	1.477013E+01	2.913949E-02	2.989443E-02	1.690253E-03	-1.394214E+01	-4.175695E+00
330	-2.188461E+02	-2.640823E+02	1.544573E+01	3.172157E-02	3.106909E-02	8.943732E-04	-1.407550E+01	-3.976472E+00
331	-2.167918E+02	-2.661366E+02	1.189208E+01	3.233318E-02	3.045748E-02	-1.636225E-04	-1.417600E+01	-3.601804E+00
332	-2.163769E+02	-2.565999E+02	5.229742E+00	3.078945E-02	2.824447E-02	-1.174821E-03	-1.416577E+01	-3.339266E+00
333	-2.174104E+02	-2.375885E+02	-2.832367E+00	2.748939E-02	2.489413E-02	-1.845892E-03	-1.410312E+01	-3.211393E+00
334	-2.198443E+02	-2.147022E+02	-1.022848E+01	2.334883E-02	2.141375E-02	-2.050515E-03	-1.400084E+01	-3.108848E+00
335	-2.230642E+02	-1.939267E+02	-1.474218E+01	1.945949E-02	1.874285E-02	-1.701282E-03	-1.383480E+01	-3.250778E+00
336	-2.259844E+02	-1.806326E+02	-1.540159E+01	1.685503E-02	1.750040E-02	-8.785126E-04	-1.370477E+01	-3.550507E+00

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 49

SIDE VIEW PANEL STRESSES (MOD14)

0

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 50

SIDE VIEW PANEL STRESSES (MOD14)

0 SUBCASE 1

S T R E S S E S   I N   B A R   E L E M E N T S   (C B A R)

	ELEMENT	SA1	SA2	SA3	SA4	AXIAL	SA-MAX	SA-MIN	M.S.-T
	ID.	SB1	SB2	SB3	SB4	STRESS	SB-MAX	SB-MIN	M.S.-C
0	1	0.0	0.0	0.0	0.0	2.690234E+05	2.690234E+05	2.690234E+05	
		0.0	0.0	0.0	0.0		2.690234E+05	2.690234E+05	
0	2	0.0	0.0	0.0	0.0	-1.105380E+06	-1.105380E+06	-1.105380E+06	
		0.0	0.0	0.0	0.0		-1.105380E+06	-1.105380E+06	
0	3	0.0	0.0	0.0	0.0	-5.373424E+05	-5.373424E+05	-5.373424E+05	

		0.0	0.0	0.0	0.0		-5.373424E+05	-5.373424E+05	
0	4	0.0	0.0	0.0	0.0	-2.324926E+05	-2.324926E+05	-2.324926E+05	
		0.0	0.0	0.0	0.0		-2.324926E+05	-2.324926E+05	
0	5	0.0	0.0	0.0	0.0	-1.234191E+05	-1.234191E+05	-1.234191E+05	
		0.0	0.0	0.0	0.0		-1.234191E+05	-1.234191E+05	
0	6	0.0	0.0	0.0	0.0	-8.698404E+04	-8.698404E+04	-8.698404E+04	
		0.0	0.0	0.0	0.0		-8.698404E+04	-8.698404E+04	
0	7	0.0	0.0	0.0	0.0	1.236432E+04	1.236432E+04	1.236432E+04	
		0.0	0.0	0.0	0.0		1.236432E+04	1.236432E+04	
0	8	0.0	0.0	0.0	0.0	-2.729605E+04	-2.729605E+04	-2.729605E+04	
		0.0	0.0	0.0	0.0		-2.729605E+04	-2.729605E+04	
0	9	0.0	0.0	0.0	0.0	-1.111165E+06	-1.111165E+06	-1.111165E+06	
		0.0	0.0	0.0	0.0		-1.111165E+06	-1.111165E+06	
0	10	0.0	0.0	0.0	0.0	-4.369033E+04	-4.369033E+04	-4.369033E+04	
		0.0	0.0	0.0	0.0		-4.369033E+04	-4.369033E+04	
0	11	0.0	0.0	0.0	0.0	-1.056492E+06	-1.056492E+06	-1.056492E+06	
		0.0	0.0	0.0	0.0		-1.056492E+06	-1.056492E+06	
0	12	0.0	0.0	0.0	0.0	1.571196E+05	1.571196E+05	1.571196E+05	
		0.0	0.0	0.0	0.0		1.571196E+05	1.571196E+05	
0	13	0.0	0.0	0.0	0.0	2.475363E+04	2.475363E+04	2.475363E+04	
		0.0	0.0	0.0	0.0		2.475363E+04	2.475363E+04	
0	14	0.0	0.0	0.0	0.0	-1.100888E+05	-1.100888E+05	-1.100888E+05	
		0.0	0.0	0.0	0.0		-1.100888E+05	-1.100888E+05	
0	15	0.0	0.0	0.0	0.0	-9.783756E+04	-9.783756E+04	-9.783756E+04	
		0.0	0.0	0.0	0.0		-9.783756E+04	-9.783756E+04	
0	16	0.0	0.0	0.0	0.0	-6.834614E+04	-6.834614E+04	-6.834614E+04	
		0.0	0.0	0.0	0.0		-6.834614E+04	-6.834614E+04	

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 51

SIDE VIEW PANEL STRESSES (MOD14)

0 SUBCASE 1

S T R E S S E S   I N   B A R   E L E M E N T S   (C B A R)

	ELEMENT ID.	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
0	17	0.0	0.0	0.0	0.0	-7.332713E+04	-7.332713E+04	-7.332713E+04	
		0.0	0.0	0.0	0.0		-7.332713E+04	-7.332713E+04	
0	18	0.0	0.0	0.0	0.0	9.301716E+04	9.301716E+04	9.301716E+04	
		0.0	0.0	0.0	0.0		9.301716E+04	9.301716E+04	
0	19	0.0	0.0	0.0	0.0	-3.378280E+04	-3.378280E+04	-3.378280E+04	
		0.0	0.0	0.0	0.0		-3.378280E+04	-3.378280E+04	
0	20	0.0	0.0	0.0	0.0	-3.753836E+05	-3.753836E+05	-3.753836E+05	
		0.0	0.0	0.0	0.0		-3.753836E+05	-3.753836E+05	
0	21	0.0	0.0	0.0	0.0	8.256302E+04	8.256302E+04	8.256302E+04	
		0.0	0.0	0.0	0.0		8.256302E+04	8.256302E+04	
0	22	0.0	0.0	0.0	0.0	-2.788812E+05	-2.788812E+05	-2.788812E+05	
		0.0	0.0	0.0	0.0		-2.788812E+05	-2.788812E+05	
0	23	0.0	0.0	0.0	0.0	5.447155E+04	5.447155E+04	5.447155E+04	
		0.0	0.0	0.0	0.0		5.447155E+04	5.447155E+04	
0	24	0.0	0.0	0.0	0.0	7.126953E+04	7.126953E+04	7.126953E+04	
		0.0	0.0	0.0	0.0		7.126953E+04	7.126953E+04	
0	25	0.0	0.0	0.0	0.0	-5.633950E+04	-5.633950E+04	-5.633950E+04	
		0.0	0.0	0.0	0.0		-5.633950E+04	-5.633950E+04	
0	26	0.0	0.0	0.0	0.0	-4.298890E+04	-4.298890E+04	-4.298890E+04	
		0.0	0.0	0.0	0.0		-4.298890E+04	-4.298890E+04	
0	27	0.0	0.0	0.0	0.0	2.617770E+05	2.617770E+05	2.617770E+05	
		0.0	0.0	0.0	0.0		2.617770E+05	2.617770E+05	
0	28	0.0	0.0	0.0	0.0	-1.028712E+06	-1.028712E+06	-1.028712E+06	
		0.0	0.0	0.0	0.0		-1.028712E+06	-1.028712E+06	
0	29	0.0	0.0	0.0	0.0	-5.089336E+05	-5.089336E+05	-5.089336E+05	
		0.0	0.0	0.0	0.0		-5.089336E+05	-5.089336E+05	
0	30	0.0	0.0	0.0	0.0	-2.234615E+05	-2.234615E+05	-2.234615E+05	
		0.0	0.0	0.0	0.0		-2.234615E+05	-2.234615E+05	
0	31	0.0	0.0	0.0	0.0	-1.196898E+05	-1.196898E+05	-1.196898E+05	
		0.0	0.0	0.0	0.0		-1.196898E+05	-1.196898E+05	
0	32	0.0	0.0	0.0	0.0	-8.609246E+04	-8.609246E+04	-8.609246E+04	
		0.0	0.0	0.0	0.0		-8.609246E+04	-8.609246E+04	

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 52

SIDE VIEW PANEL STRESSES (MOD14)

0 SUBCASE 1

S T R E S S E S   I N   B A R   E L E M E N T S   (C B A R)

	ELEMENT ID.	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
0	33	0.0	0.0	0.0	0.0	1.784623E+04	1.784623E+04	1.784623E+04	
		0.0	0.0	0.0	0.0		1.784623E+04	1.784623E+04	
0	34	0.0	0.0	0.0	0.0	-2.783613E+04	-2.783613E+04	-2.783613E+04	
		0.0	0.0	0.0	0.0		-2.783613E+04	-2.783613E+04	
0	35	0.0	0.0	0.0	0.0	-1.062294E+06	-1.062294E+06	-1.062294E+06	
		0.0	0.0	0.0	0.0		-1.062294E+06	-1.062294E+06	
0	36	0.0	0.0	0.0	0.0	-3.508443E+04	-3.508443E+04	-3.508443E+04	
		0.0	0.0	0.0	0.0		-3.508443E+04	-3.508443E+04	
0	37	0.0	0.0	0.0	0.0	-1.004737E+06	-1.004737E+06	-1.004737E+06	
		0.0	0.0	0.0	0.0		-1.004737E+06	-1.004737E+06	
0	38	0.0	0.0	0.0	0.0	1.647573E+05	1.647573E+05	1.647573E+05	
		0.0	0.0	0.0	0.0		1.647573E+05	1.647573E+05	
0	39	0.0	0.0	0.0	0.0	-5.196439E+04	-5.196439E+04	-5.196439E+04	
		0.0	0.0	0.0	0.0		-5.196439E+04	-5.196439E+04	
0	40	0.0	0.0	0.0	0.0	-1.387357E+05	-1.387357E+05	-1.387357E+05	
		0.0	0.0	0.0	0.0		-1.387357E+05	-1.387357E+05	
0	41	0.0	0.0	0.0	0.0	-1.068905E+05	-1.068905E+05	-1.068905E+05	
		0.0	0.0	0.0	0.0		-1.068905E+05	-1.068905E+05	
0	42	0.0	0.0	0.0	0.0	-7.199831E+04	-7.199831E+04	-7.199831E+04	
		0.0	0.0	0.0	0.0		-7.199831E+04	-7.199831E+04	
0	43	0.0	0.0	0.0	0.0	-7.416995E+04	-7.416995E+04	-7.416995E+04	
		0.0	0.0	0.0	0.0		-7.416995E+04	-7.416995E+04	
0	44	0.0	0.0	0.0	0.0	8.767053E+04	8.767053E+04	8.767053E+04	
		0.0	0.0	0.0	0.0		8.767053E+04	8.767053E+04	
0	45	0.0	0.0	0.0	0.0	-3.338393E+04	-3.338393E+04	-3.338393E+04	
		0.0	0.0	0.0	0.0		-3.338393E+04	-3.338393E+04	
0	46	0.0	0.0	0.0	0.0	-4.250688E+05	-4.250688E+05	-4.250688E+05	
		0.0	0.0	0.0	0.0		-4.250688E+05	-4.250688E+05	
0	47	0.0	0.0	0.0	0.0	7.418273E+04	7.418273E+04	7.418273E+04	
		0.0	0.0	0.0	0.0		7.418273E+04	7.418273E+04	

P L O T T E R   D A T A

THE FOLLOWING PLOTS ARE FOR A NASTPLT PLOTTER

PAPER SIZE = 20.0 X 20.0, PAPER TYPE = VELLUM

PEN 1 - SIZE 1, BLACK
PEN 2 - SIZE 1, BLACK
PEN 3 - SIZE 1, BLACK
PEN 4 - SIZE 1, BLACK

E N G I N E E R I N G   D A T A

ORTHOGRAPHIC PROJECTION
ROTATIONS (DEGREES) - GAMMA = 0.00, BETA = 0.00, ALPHA = 0.00, AXES = -Y,+X,+Z, SYMMETRIC
SCALE (OBJECT-TO-PLOT SIZE) = 2.512692E+01

ORIGIN   1 - X0 = -9.280000E+00, Y0 = -2.330045E+00   (INCHES)

L I S T O F P L O T S

PLOT 2 STATIC STRESS   1 - SUBCASE   500 - LOAD

C O N T O U R   P L O T T I N G   D A T A

ABOVE PLOT IS A CONTOUR PLOT OF STRESS, MAJOR-PR   MIN = -5.361738E+04   MAX = 8.097764E+05
THE CONTOUR VALUES ARE CALCULATED AT FIBER DISTANCE MAX - Z1,Z2

TABLE OF PLOTTING SYMBOLS

SYMBOL	VALUE	SYMBOL	VALUE	SYMBOL	VALUE	SYMBOL	VALUE	SYMBOL	VALUE
1	-5.361738E+04								
2	1.190614E+05								
3	2.917401E+05								
4	4.644189E+05								
5	6.370976E+05								
6	8.097764E+05								

1   * * * END OF JOB * * *

Appendix A, cont.

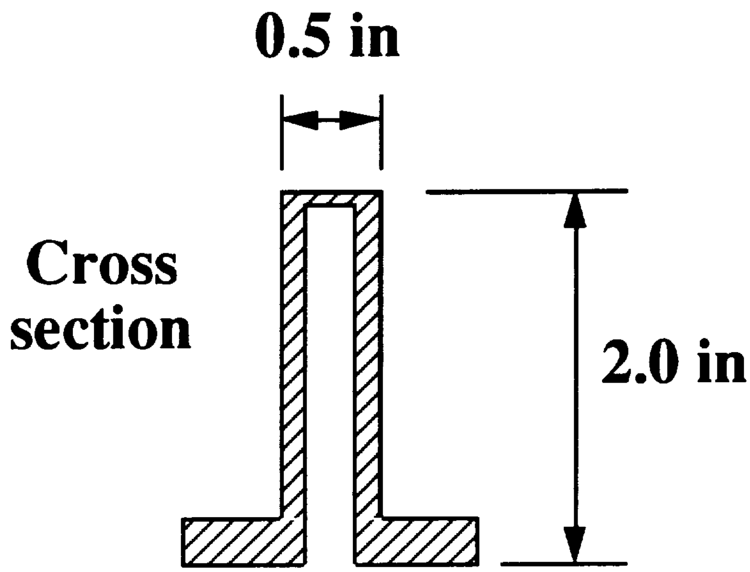
NASTRAN Frequency Analysis

```
NASTRAN
ASSIGN MASTER='MOD14.MASTER'
RESTART, VERSION=1
ID NORMAL MODES
SOL 103
TIME 3
CEND
TITLE=ASE274 - MODEL 1
SUBTITLE=MODEL 1 STATIC
DISP=ALL
LABEL = NORMAL MODES ANALYSIS
METHOD=4
LOAD=500
OLOAD=ALL
SUBCASE 1
SPC=102
OUTPUT(PLOT)
PLOTTER NAST
SET 1=QUAD4,TRIA3
AXES MY,X,Z
VIEW 0.,0.,0.
FIND SCALE,ORIGIN 1,SET 1
PLOT SET 1,ORIGIN 1,LABEL BOTH
PLOT STATIC DEFORMATION 0, SET 1, ORIGIN 1, LABELBOTH
BEGIN BULK
$L= .1687       r= .26  d= .05 radius =0.01
$1......2.......3.......4.......5.......6.......7.......8.......9.......10
$
EIGRL   4       -0.1            4       0
ENDDATA
```

```
E N G I N E E R I N G   D A T A


        ORTHOGRAPHIC PROJECTION
        ROTATIONS (DEGREES) - GAMMA =   0.00, BETA =   0.00, ALPHA =   0.00,  AXES = -Y,+X,+Z, SYMMETRIC
        SCALE (OBJECT-TO-PLOT SIZE) = 2.947904E+01

        ORIGIN       1  -  X0 = -9.280000E+00, Y0 = -9.600000E-01     (INCHES)


L I S T   O F   P L O T S


        PLOT    1     UNDEFORMED SHAPE
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    15
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS
0*** USER INFORMATION MESSAGE 5010, STURM SEQUENCE DATA FOR EIGENVALUE EXTRACTION.
    TRIAL EIGENVALUE =  1.194408D+04, CYCLES =  1.739388D+01 NUMBER OF EIGENVALUES BELOW THIS VALUE =       0
0*** USER INFORMATION MESSAGE 4158---STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK SCRATCH  FOLLOW
         NUMBER OF NEGATIVE TERMS ON FACTOR DIAGONAL =      3
0*** USER INFORMATION MESSAGE 5010, STURM SEQUENCE DATA FOR EIGENVALUE EXTRACTION.
    TRIAL EIGENVALUE =  4.702861D+06, CYCLES =  3.451447D+02 NUMBER OF EIGENVALUES BELOW THIS VALUE =       3
0*** USER INFORMATION MESSAGE 4158---STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK SCRATCH  FOLLOW
         NUMBER OF NEGATIVE TERMS ON FACTOR DIAGONAL =     41
0*** USER INFORMATION MESSAGE 5010, STURM SEQUENCE DATA FOR EIGENVALUE EXTRACTION.
    TRIAL EIGENVALUE =  1.410858D+07, CYCLES =  5.978081D+02 NUMBER OF EIGENVALUES BELOW THIS VALUE =      41
0*** USER INFORMATION MESSAGE 4158---STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK SCRATCH  FOLLOW
         NUMBER OF NEGATIVE TERMS ON FACTOR DIAGONAL =      7
0*** USER INFORMATION MESSAGE 5010, STURM SEQUENCE DATA FOR EIGENVALUE EXTRACTION.
    TRIAL EIGENVALUE =  4.950380D+06, CYCLES =  3.541110D+02 NUMBER OF EIGENVALUES BELOW THIS VALUE =       7
0*** USER WARNING MESSAGE 3034, ORTHOGONALITY TEST FAILED. LARGEST TERM =   2.93E-10 ,NUMBER FAILED =         2
                                                          PAIR =    4,    2  , EPSILON =      1.00E-10
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    16
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS
0


                         E I G E N V A L U E   A N A L Y S I S   S U M M A R Y   (LANCZOS ITERATION)


                                BLOCK SIZE USED ......................     7

                                NUMBER OF DECOMPOSITIONS .............     4

                                NUMBER OF ROOTS FOUND ................     4

                                NUMBER OF SOLVES REQUIRED ............    23

                                TERMINATION MESSAGE :  REQUIRED NUMBER OF EIGENVALUES FOUND.
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    17
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS

                                              R E A L   E I G E N V A L U E S
   MODE    EXTRACTION      EIGENVALUE            RADIANS             CYCLES            GENERALIZED         GENERALIZED
    NO.       ORDER                                                                        MASS              STIFFNESS
        1         1        1.293321E+06        1.137243E+03        1.809978E+02        1.000000E+00        1.293321E+06
        2         2        1.293321E+06        1.137243E+03        1.809978E+02        1.000000E+00        1.293321E+06
        3         3        4.638585E+06        2.153738E+03        3.427780E+02        1.000000E+00        4.638585E+06
        4         4        4.767133E+06        2.183376E+03        3.474951E+02        1.000000E+00        4.767133E+06
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    18
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    19
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    20
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS
0                                                      MAXIMUM  DISPLACEMENTS
0                T1              T2              T3              R1              R2              R3
0        1  1.0255939E-01  3.7702328E-01  1.8000318E-01  1.3383291E+00  4.8583096E-01  1.3963877E+00
0        2  3.7702328E-01  1.0255939E-01  1.8000318E-01  4.8583096E-01  1.3383291E+00  1.3963877E+00
0        3  1.0437756E+00  1.0437756E+00  1.6939754E-05  7.8765683E+00  7.8765683E+00  1.7531828E+01
0        4  1.2437719E+00  1.2264830E+00  7.2158093E-04  9.9412727E+00  1.0082914E+01  2.4128210E+01
1  ASE274 - MODEL 1                                                       MAY   4, 1993  MSC/NASTRAN  9/ 4/91    PAGE    21
    MODEL 1 STATIC
0    NORMAL MODES ANALYSIS                                                                                   SUBCASE 1
    EIGENVALUE =  1.293321E+06
       CYCLES =  1.809978E+02         R E A L   E I G E N V E C T O R   N O .          1

    POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           1      G      -1.375345E-04  -3.822579E-04   6.983513E-04   4.351418E-02   8.910947E-03  -4.113543E-04
           2      G       0.0            0.0            0.0           -1.857303E-02  -1.139710E-01  -2.540105E-02
           3      G      -1.347286E-02  -4.054736E-02   2.713132E-02   5.123412E-01  -2.503318E-01   6.710506E-02
           4      G      -3.113424E-02  -1.362344E-01   3.910747E-02   5.748325E-01  -9.268253E-02   7.251531E-02
           5      G      -5.329991E-02  -2.387710E-01   3.962892E-02   5.831530E-01  -1.411709E-01   1.009546E-01
           6      G      -7.204834E-02  -3.262686E-01   2.905677E-02   5.743058E-01  -1.228908E-01   5.195493E-02
           7      G      -8.298090E-02  -3.766795E-01   1.026438E-02   5.502121E-01  -1.167734E-01  -2.659249E-02
           8      G      -6.342372E-02  -3.535394E-01   2.878754E-02   1.338329E+00  -1.944400E-01   1.396388E+00
           9      G      -2.305672E-02  -1.392333E-01   2.870909E-02   5.748501E-01  -2.470573E-01   5.637153E-01
          10      G      -1.375345E-04  -3.822579E-04  -6.983513E-04   4.351418E-02   8.910947E-03   4.113543E-04
          11      G       0.0            0.0            0.0           -1.857303E-02  -1.139710E-01   2.540105E-02
          12      G      -1.347286E-02  -4.054736E-02  -2.713132E-02   5.123412E-01  -2.503318E-01  -6.710506E-02
          13      G      -3.113424E-02  -1.362344E-01  -3.910747E-02   5.748325E-01  -9.268253E-02  -7.251531E-02
          14      G      -5.329991E-02  -2.387710E-01  -3.962892E-02   5.831530E-01  -1.411709E-01  -1.009546E-01
          15      G      -7.204834E-02  -3.262686E-01  -2.905677E-02   5.743058E-01  -1.228908E-01  -5.195493E-02
```

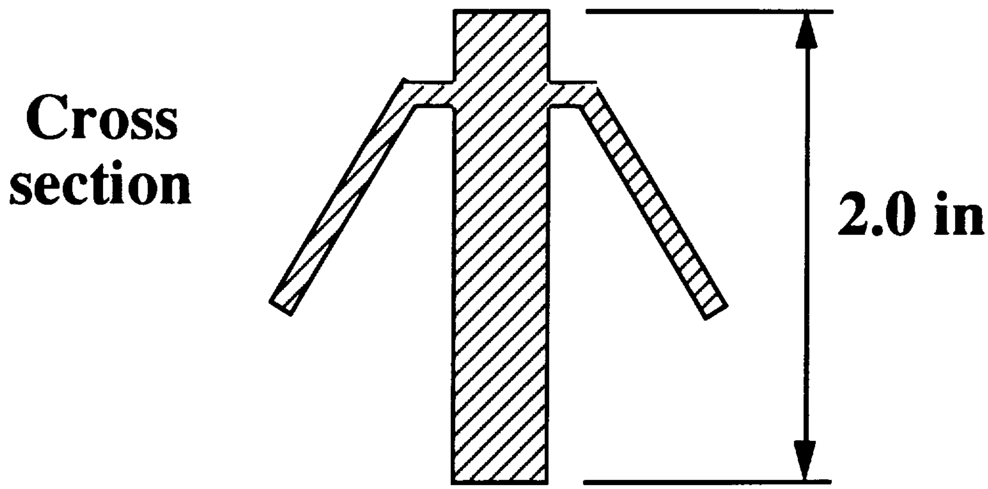
Appendix B

BATSAT Antennae



Ka Band Antenna

BATSAT Antennae (Cont.)



S Band Antenna

Appendix C

BATSAT Power Sizing

	Instrument in Use	
	Equpment	Power Req.
on	Ka Transmitter	1.5 W
on	X Transmitter	1.5 W
off	Ku Transmitter	5.1 W
off	S Transmitter	1.5 W
on	Heaters	2.0 W
on	Command	2.1 W
	Total Power=	8.6 W

	Solar Cell Info	
Si	Si	GaAs
Po	190.0 W/m2	244.0 W/r
Id	0.77	0.
LdegFact	3.75%	2.75
Mass/m^2	2.800 kg/m2	1.600 kg/r
Cost/m^2	$83.19	$415.

Power Design Parameters	
Life= 10.0 yrs	Satellite Lifetime
Theta = 0.0 °	Array incidence angle
Period = 110.51 min	Orbital Period
Pe= 8.6 W/m2	Eclipse Power (from equipment choice)
te= 35.80 min	Eclipse Duration
xe= 0.65	Array-Batt.-Load efficiency
Pd= 8.6 W/m2	Daylight Power
td= 74.71 min	Day duration
xd= 0.9	Source-Load efficiency
Cd= 0.1	Battery Depth of Discharge
Vd= 27.5	Battery discharge voltage
N= 1	Number of batteries
Po = 190.0 W/m2	From Array Choice
Id = 0.77	From Array Choice
LdegFact= 3.75%	From Array Choice

Computed Solar Paramters	
Psa= 15.8 W/m2	Total daylight collected power
Pbol= 146.3 W/m2	Power beginning of life
Peol= 99.8 W/m2	Power ending of life

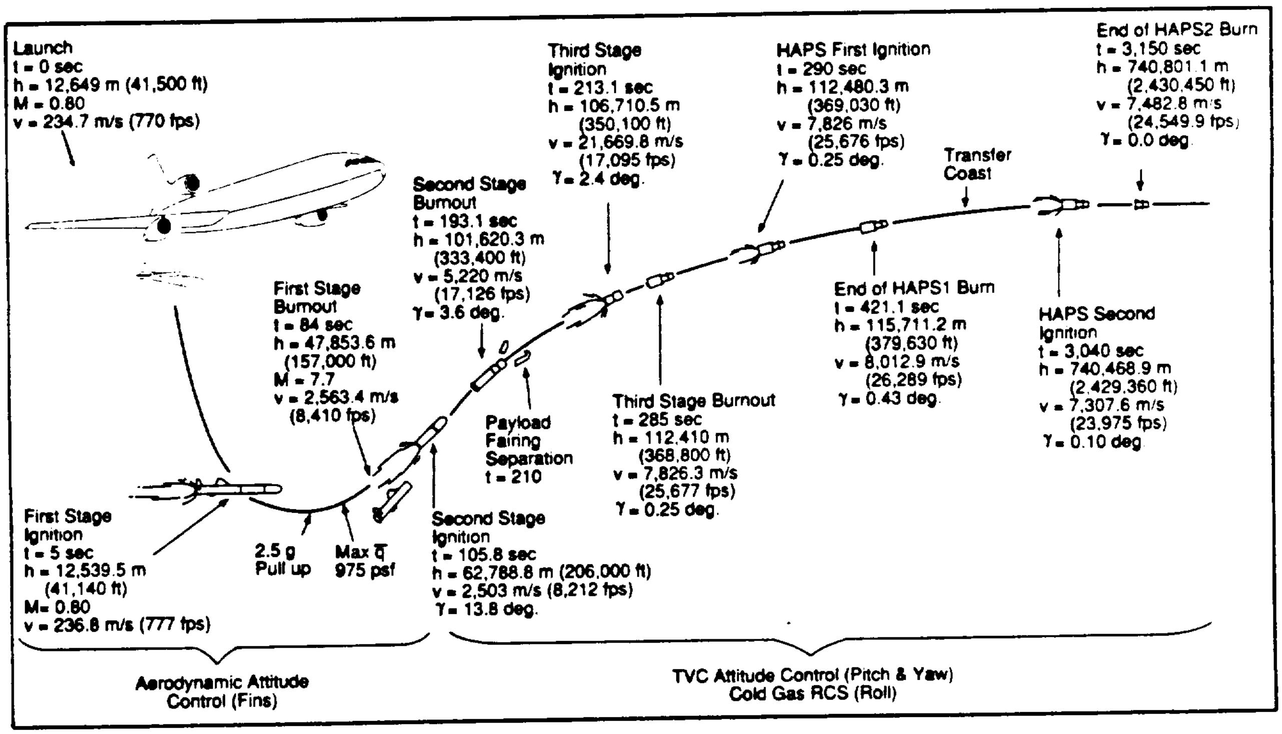
Asa= 0.174 m^2	Total Estimated array Area + 10%,unadjusted for sha
Est Mass = 1.952 kg	Adjusted for shape
Est Cost = $57.99	Total Estimated Cost in thousands, adjusted for shape
Cr= 2.06 A-hrs	Battery Capacity in A-hrs

Spacecraft Sizing		
Shape:	Grav-Gradient	Spherical
Min Area:	0.547 m^2	0.697 m^2
Radius:	0.25 m	0.24 m
Height:	0.35 m	n/a

Appendix D

Pegasus Mission Timeline With HAPS Booster

[Source: Pegasus User's Guide]



Pegasus Launch Environment

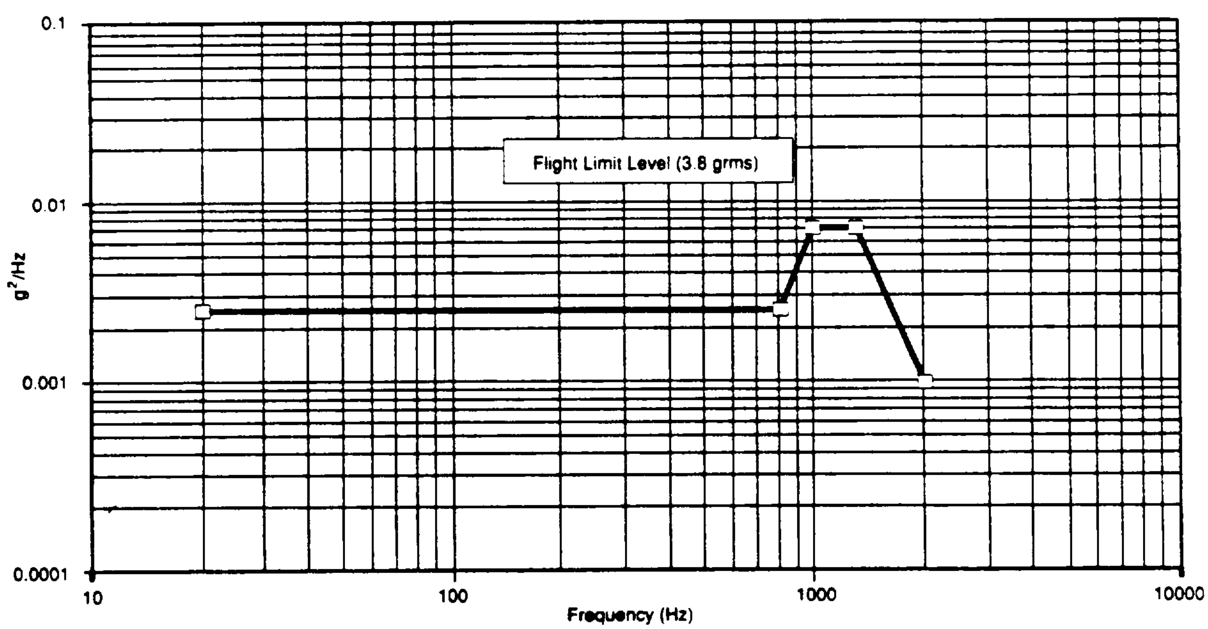
[Source: Pegasus User's Guide]

Acceleration Environment

Type		Linear Acceleration (g's)		
		x	y	z
Ground Operations		+/-0.5	+/-0.5	+ 1.5
Captive Carry Flight/Taxi [1]	Case 1	+/-1.0	0	+ 2.2/-1.0
	Case 2	0	+/-0.3	+ 2.2
	Case 3	0	+/-0.4	+ 1.0
Abort Landing		+/-0.6	+/-0.6	+ 2.7/-0.1
Launch/Drop		0	0	Payload Dependent
Aerodynamic Pull-up		-4.0	+/-0.5	+2.85
First Stage Burnout		-7.5	+/-0.2	+/-0.2
Second and Third Stage Burnout		Payload Dependent (See Figure 4.1)		

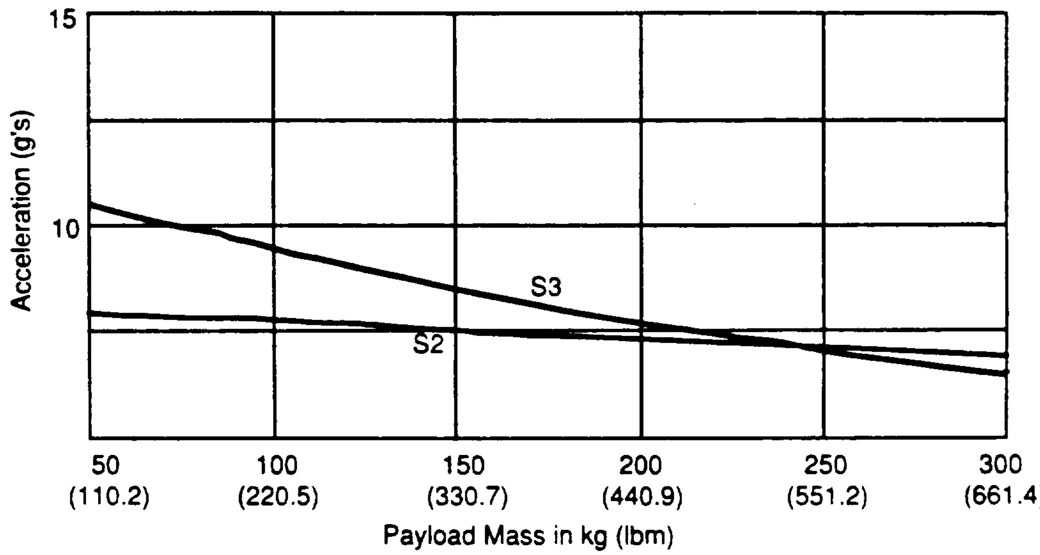
Note 1: Payload must meet each of these case requirements individually to satisfy NASA-Dryden B-52 utilization constraints

Payload Vibration Environment

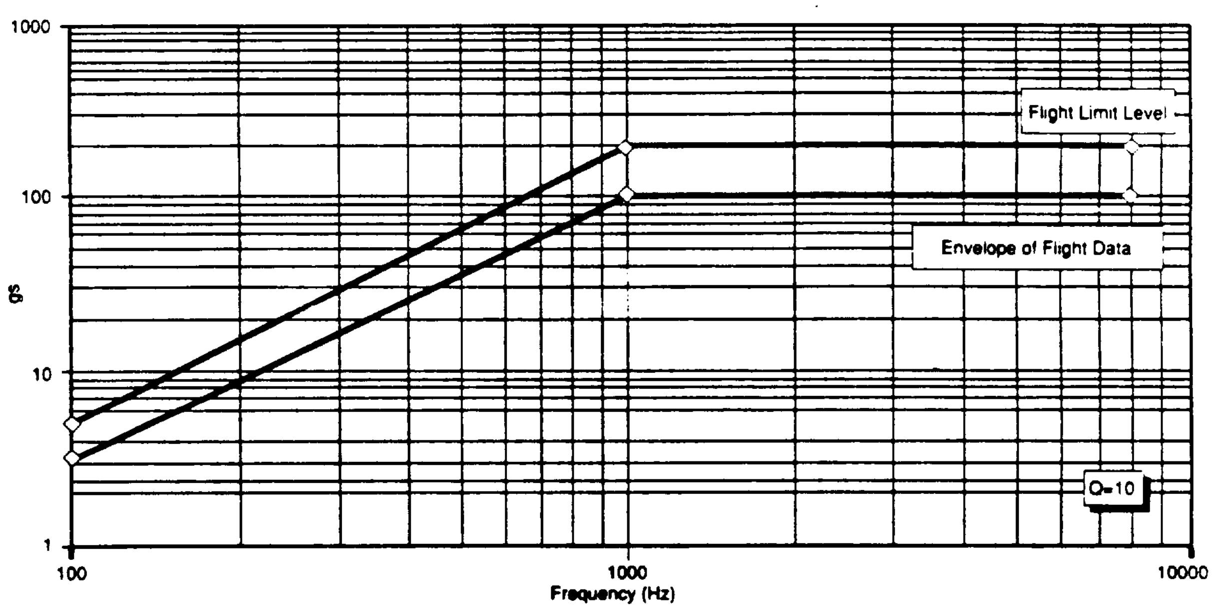


Pegasus Launch Environment cont.

Payload Maximum Axial Acceleration

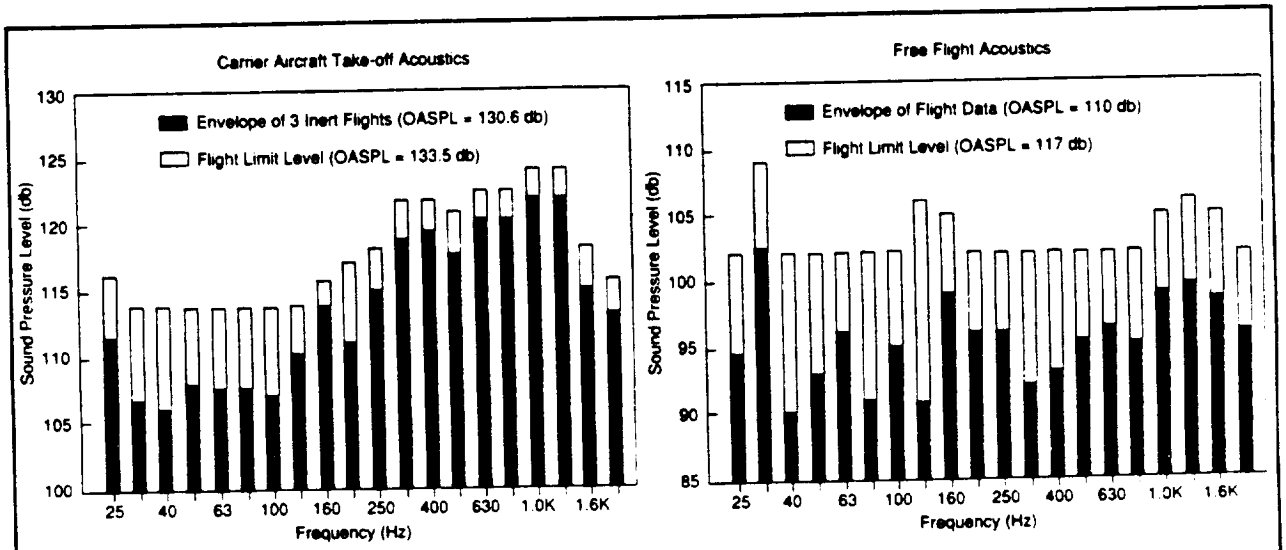


Payload Shock Environment



Pegasus Launch Environment cont.

Payload Acoustic Environment



OASPL = Overall Sound Pressure Level

McWilliams • Tedesco • Araiza • Wortman • Jones • Lett • Opiela • Clavenna • Norman • Slatton

DSN Ka Band
Satellite Design
Team

Goldstone • Madrid
Canberra

Mockingbird Designs

Excellence in Engineering