Design Review:
Reduced Profile Electronics Packaging

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By

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In partial fulfillment of the requirements for course ME 486 C, Engineering Design,
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1. Executive Summary

Problem Statement
Orbital Sciences Corporation (OSC), Launch Systems Group (LSG) has requested a redesign for their avionics control housing. Particular vehicle designs require a housing that will have less head height to mount in smaller areas. We propose to design a new module assembly and new module housing as needed to fulfill the requirements.

Requirements
Two sets of requirements were received: hard requirements and optimization requirements. A summary of each is below (see Section 4 for more details).Hard requirements included utilizing existing printed wiring board (PWB) board layout, accommodating six modules with two PWB's each, and the maximum height of the entire unit must be less than five inches. The optimization requirements include optimizing properties such as footprint efficiency, Input/Output locations, resonant frequencies, safety factor, thermal resistance, unit weight, manufacturability, and cost.

Design Process (analysis)
Our design philosophy incorporates a proposal, brainstorming, decision matrices, simple hand calculations, in-depth analysis, computer modeling, and professional documentation in order to provide our customer (OSC) with a unique product that is free of the current paradigms, satisfies all the requirements, and optimizes as many other features as possible. Analysis of vibration, shock, thermal, stress/strain, and tolerancing will be included (see Section 5).

Expected Results
The expected results of the project as a whole include the analysis results and CAD drawings. The expected results of analysis are testable results. In the event that the design team does not construct a prototype, we will provide all information necessary for such construction.

Cost/Benefit
The budget for this project is on an objective dependent basis. If the objective changes to include prototyping or manufacturing, machining and materials costs will require reimbursement. Thus, the cost to Orbital is solely dependant upon their request for tasks requiring monetary support.

The benefits Orbital will receive from this project include: a robust design that will satisfy all hard requirements and optimize as many of the other requirements as possible, a fresh outlook on current housing design free from the current paradigms, and a team of hardworking dedicated students committed to producing accurate, professional, and functional results.

2. Objective

Orbital Sciences Corporation (OSC), Launch Systems Group (LSG) has requested a redesign for their avionics control housing. The current housing consists of numerous modules containing printed wiring boards (PWB's) performing different functions linked together to help fly a vehicle. Particular vehicle designs require a housing that will have less head height to mount in smaller areas. Our senior design team can provide a fresh look at the design. We will design a new module assembly and new module housing as needed to complete the task. We will meet all hard requirements for the design and optimize the parameters provided.

3. Background

The current design of the housing used by Orbital does not meet the parameters required for future vehicle projects. The current design is a module with dimensions of 6.0 inches x 3.0 inches x 1.25 inches. The current units are approximately 3.0 inches high, the remaining height being the mating connector, EMI backshell, and cable strain relief. The redesign needs to fit into an area with a 5.0 inch minimum head height. The new design must also accommodate 6 modules. We can provide a design that meets these requirements to be used on these future projects. We will perform analyses to determine if the new design will be able to survive flight environments encountered. These flight environments include random vibration, shock, sine vibration, thermal vacuum and thermal cycling.

4. Requirements

There are two classes of requirements specified by Orbital: Hard requirements, and optimization requirements. The highlights of both are listed below. For the complete requirements document, see Appendix 1.

Hard Requirements

1. Board outline and connector locations should be as shown in Figure 1 (see appendix 1). Perimeter changes to PWBs to augment mounting are allowed. Modules have two PWBs – one to provide the module function and another to provide the standard interface protocols. Some freedom will be allowed in re-thinking this approach.
2. The new design must accommodate 6 modules.
3. Maximum height of the finished unit (including mating connectors, backshells and cable strain relief) shall be less than 5 inches.

Optimization requirements

1. Unit footprint shall be optimized.
2. I/O connector locations (desirable to have all on one face)

3. Board and unit resonant frequencies. Board frequencies should be over 500 Hz. Board and unit frequencies should be separated by at least an octave.
4. Minimum safety factor of 1.4 using MIL-STD-1540 minimum qual vibration, and 2000 G shock.
5. Thermal conduction paths, thermal resistance shall be optimized.
6. Unit mass shall be optimized.
7. Design for manufacturability.
8. Minimize cost.

5. Methodology

Design Process: The College of Engineering and Natural Sciences at Northern Arizona University has a design intensive engineering program that focuses on the design process. As a result of this education, we have adopted a philosophy of design as follows.

The first step in design is the proposal. This requires finding a customer that has a need, contacting this customer, determining their requirements, and conducting initial research of the subject to determine if the project is feasible. Then a proposal document is written which states the details of the service that will be provided. Once the design team and the client reached mutual agreement, the next stage can begin.

The second state is brainstorming and decision matrices. After more in-depth research of the State-of-the-Art (SOTA) the team produces a list of all design possibilities, feasible or not, and groups them into subsystems. Then all possible combinations of subsystems are determined to produce system designs. Next, these system designs are evaluated with decision matrices to eliminate the designs that are not feasible, or inferior. Only the best designs will survive to the next stage.

After these five designs are obtained, simple hand calculations will be performed to get a better idea of the performance of each design. Also at this stage some simple physical models will be produced to give a physical representation to the designs. Some basic CAD models will also be developed to provide more exact physical representations. From the results of this step, a final design will be chosen.

Once the final design has been chosen, more in depth hand calculations and computer modeling will take place. At customer requests, testing, prototyping, or additional requirements, they may be performed upon evaluation and approval of the design team. All throughout the process, documentation will be compiled by the design team including time reports updating the amount of time devoted to the project, frequent status reports updating the customer on project progress, a design report outlining the final design and intermediate analysis results, a final report giving detailed information about the final design, all analysis results, detailed drawings of the design, and any prototypes constructed during the course of the project.

Vibration Analysis: Hand calculations will estimate a natural frequency for the housing(s) and a natural frequency for the PWB(s) mounted in the housing. Mass, size, material, and mounting information will be used to perform a Steinberg analysis finding the natural frequency of the PWB(s). Common single degree of freedom methods will be used to find the fundamental natural frequency of the housing

For the computer modeling COSMOS/M Geostar will be used to find the natural frequencies and confirm the hand calculations. The packaging and PWB's can be modeled in COSMOS, and a mesh created with the known material properties and calculated damping. The A_Frequency and R_Frequency commands will perform and run the frequency analysis, outputting multiple natural frequencies. Simulations of random vibration testing are in consideration and are subject to the ability of the available software and quality of the current data.

Shock Analysis: Hand calculations will be used to find the natural frequency as mentioned for the vibration analysis. This shock level at the natural frequency will be used to determine the force acting on certain critical design elements. A subsequent stress analysis will be performed.

Thermal Analysis: Hand calculations will be performed using known properties of the material and geometry for each particular design to determine the thermal resistance. This value will be used to analyze how well the design dissipates/retains heat, and to make sure that the temperatures of the electrical components, and the expansion/contraction of the structure itself will not cause failure or malfunction of the components. An approximation of the expected thermal environment will consist of temperatures from –34˚ C to 71˚ C. All three modes of heat transfer (conduction, convection, and radiation) will be considered.

Stress/Strain Analysis: The accelerations due to natural frequencies determined from the vibration and shock analyses will be used to find the forces for the stress analyses. For determining deflections of the PWB(s), the total mass of each board will be evenly distributed and a flat plate analysis will be used based on Roark's formulas for stress and strain analysis. The total mass of the PWB(s) and housing will then be used to analyze the stresses at the mounting fasteners. A hand calculation according to Roark's method will also be used to approximate deflections and stresses on the PWB(s) and housing components. Computer modeling in Unigraphics will be used for a Finite Element Analysis to verify maximum deflections and stress concentrations over the PWB(s) and housing components.

Tolerance Stackups: Tolerance stackup analysis will be performed in all critical locations where clearance could be a problem. This includes, but is not limited to, fastener locations, connecting part interfaces, connector interfaces, housing interfaces, and low board clearance locations. Tolerances of the components involved in the stackup shall be obtained for stackup analysis. For only two components, the tolerances will be added and the range of possible values measured in that way. For three or more components a root-sum-square (RSS) method will be implemented to statistically account for individual errors. This will be the analysis used most often in design, and iteratively as concerns arise.

Modeling: A prototype will be built in order to have a physical model. Obtaining a physical model will help us to better understand how things go together. This model will be scaled so changes can accurately be made to the model. Solid Edge will be used to generate computer models and drawings. Solid Edge files are easily imported into either I-deas or UniGraphics for finite element analysis. As for the format of the printed drawings, a template will be developed by us in order to minimize the difficulty of machining.

6. Project Plan/Tasks

The timeframe for this design project is September 2004 thru May 2005. In this nine month time period a considerable number of tasks need to be accomplished. In order to deliver a useful design to our client we have formulated a project plan that includes all major and minor tasks throughout the design process. This project plan can be seen in Figure 6.1 below. A brief description of the components of each task is included below the figure.

ID		Task Name	Duration	Start	Finish
1	✓	Project Memo	14 days	Mon 9/13/0	Sun 9/26/0
2	✓	Project Plan	8 days	Mon 9/27/0	Mon 10/4/0
12		Research	113 days	Mon 9/27/0	Mon 1/17/0
17		Web Page Template	50 days	Mon 9/27/0	Mon 11/15/0
3	✓	Requirements Gathering	12 days	Thu 9/30/0	Mon 10/11/0
7	✓	Time Report 1	1 day	Fri 10/1/0	Fri 10/1/0
4	✓	1st Sponsor Meeting	1 day	Thu 10/7/0	Thu 10/7/0
5	✓	Status Report 1	5 days	Mon 10/11/0	Fri 10/15/0
10	✓	Initial Proposal Presentati	22 days	Mon 10/11/0	Mon 11/1/0
13	✓	Initial Proposal Compilatic	22 days	Mon 10/11/0	Mon 11/1/0
15		Brainstorming	15 days	Mon 10/11/0	Mon 10/25/0
14		Design	47 days	Mon 10/25/0	Fri 12/10/0
8	✓	Time Report 2	1 day	Fri 10/29/0	Fri 10/29/0
16		Final Proposal	15 days	Mon 11/1/0	Mon 11/15/0
6	✓	Status Report 2	5 days	Mon 11/8/0	Fri 11/12/0
11		Final Proposal Presentatic	15 days	Mon 11/8/0	Mon 11/22/0
9		Time Report 3	1 day	Fri 12/3/0	Fri 12/3/0
32		Initial Downsizing	1 day	Fri 1/14/0	Fri 1/14/0
18		Hand Vibration Analysis	26 days	Mon 1/17/0	Fri 2/11/0
19		Hand Thermal Analysis	26 days	Mon 1/17/0	Fri 2/11/0
20		Hand Shock Analysis	26 days	Mon 1/17/0	Fri 2/11/0
25		Modeling (CAD)	33 days	Mon 1/17/0	Fri 2/18/0
26		Design Document	33 days	Mon 1/17/0	Fri 2/18/0
27		Status Report 3	4 days	Fri 1/21/0	Mon 1/24/0
33		Final Downsizing	1 day	Fri 2/11/0	Fri 2/11/0
28		Status Report 4	4 days	Fri 2/18/0	Mon 2/21/0
21		Modeling Vibration Analys	26 days	Mon 2/21/0	Fri 3/18/0
22		Modeling Thermal Analysi	26 days	Mon 2/21/0	Fri 3/18/0
23		Modeling Shock Analysis	26 days	Mon 2/21/0	Fri 3/18/0
29		Status Report 5	5 days	Tue 3/1/0	Sat 3/5/0
24		Fabrication	26 days	Mon 3/28/0	Fri 4/22/0
30		Design Presentation	23 days	Mon 3/28/0	Tue 4/19/0
31		Final Report	36 days	Mon 3/28/0	Mon 5/2/0

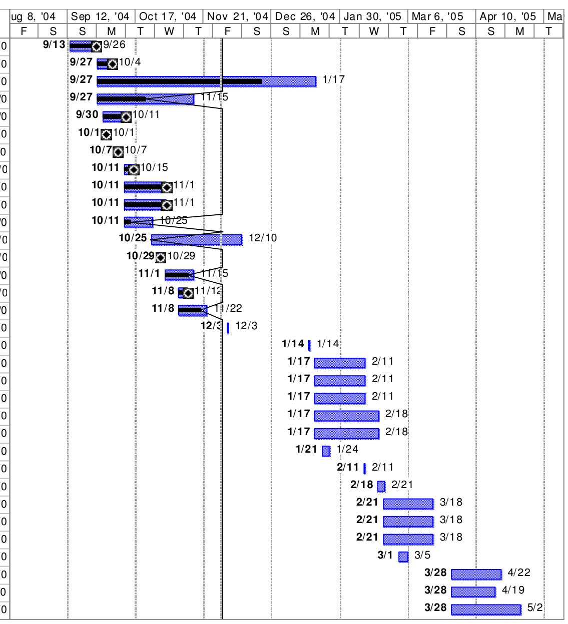

Figure 6.1: Project Plan through end of Spring 2005 semester

Note: Black bars indicate task progress, vertical line represents current project progress.

Project Memo – Memo outlining basic project and team structure

Research – State of the Art (SOTA) search (see Appendix 3) encompassing the Internet, journals, patents, manufacturers, standards, experts, etc. to determine means and methods for the design of the project.

Web Page Template – Basic structure of project webpage including color scheme, format, and HTML/CSS coding.

Requirements Gathering – Communication with client about specific requirements for the project, including confirmation of requirements.

Time Reports – Periodic updates on amount of time dedicated to project.

Status Reports – Periodic updates on type and scope of work achieved on project.

Brainstorming – Taking initial SOTA search results and applying them to the requirements document to produce viable design alternatives

Initial Proposal – Document stating initial terms of project. Must be discussed and revised with client.

Design – General task encompassing brainstorming, modeling, and narrowing options toward a final design. This process is iterative, and a large quantity of ideas is ideal.

Final Proposal/Presentation – Final proposal document agreed upon by team and customer detailing methods and expected results of the design project through May 2005. A copy of the proposal presentation has been included in Appendix 2.

Initial Downsizing – Brainstorming design possibilities will be reduced to five viable design concepts initial analysis.

Design Document - Document containing detailed description of design chosen by team. This includes a description of all functions, and anticipated outcomes of analysis, along with either detailed conceptual sketches or CAD drawings.

Hand/Modeling Analysis – These tasks are fully described in Section 3 of this document.

Final Downsizing – The final design concept will be chosen based on the results of the initial hand analysis.

Fabrication – Any machining/fabrication required of the team in order to obtain a prototype of the design, and get a tangible model to aid design modification and visualization.

Design Presentation – Formal presentation of results of design process to clients, faculty, students, and the public, scheduled for April 29, 2005.

Webpage Finalization – Publication of webpage on the World Wide Web outlining project and results.

Final Report – Final document fully describing chosen design, implementation and results of analysis, detailed CAD drawings suitable for delivery to a machining/fabrication facility, and recommendations to client for further

7. Design Concepts

As a result of the brainstorming process, a variety of possible designs, orientations, connector locations, and attachment methods were discussed. Five of the resulting design concepts are discussed below.

Slanted Unit – The slanted unit design concept shown below in Figure 7.1 consists of a single housing that can accommodate up to six function boards and six controller boards.

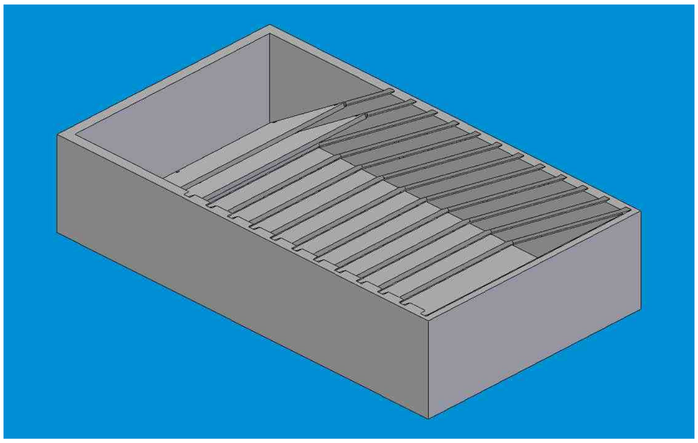

Figure 7.1: Slanted Unit design concept.
Note: Two boards have been placed in housing

This design accomplishes the reduced heat height requirement by orienting the boards at an angle. To meet the requirement of overall head height under five inches, this angle of the boards with respect to the bulkhead would have to be about 30 degrees. This would result in greater horizontal spacing between boards to ensure there would be no interference. There would also be a significant amount of wasted space on the ends of the housing. Another issue is cable strain. All of the cables and backshells would have to come out of the top of the housing, creating more head height, and the angle at which the boards are oriented may create issues with connector placement and spacing.

Slanted Module – The slanted module design retains the modularity of the current housing design, only orienting the modules at an angle to reduce the head height. A rough representation of this is shown in Figure 7.2 below.

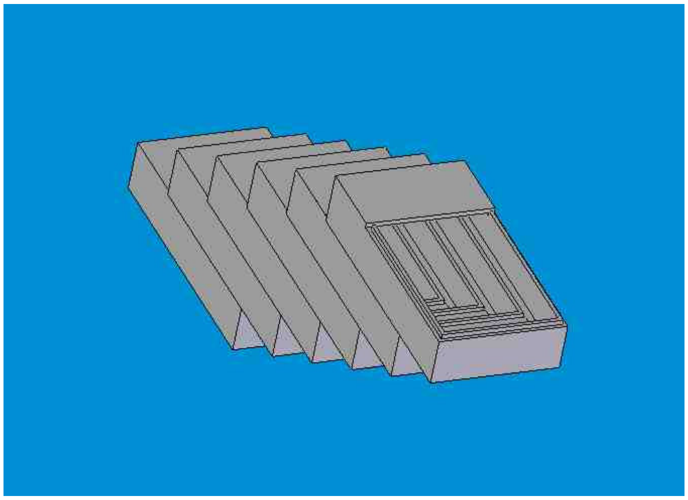

Figure 7.2: Slanted Module design concept
Note: Two boards would be mounted inside each module

In this design, the boards would be attached to each other with standoffs and one would be attached to each module using bolts. This design would require a significant amount of machining, and the geometry would be complex with all the required lips and intermodular connections. Another difficulty would be mounting each module to the bulkhead due to the angled ends.

Motherboard – The motherboard design concept would utilize a single motherboard in place of the six controller boards. This concept is shown if Figure 7.3.

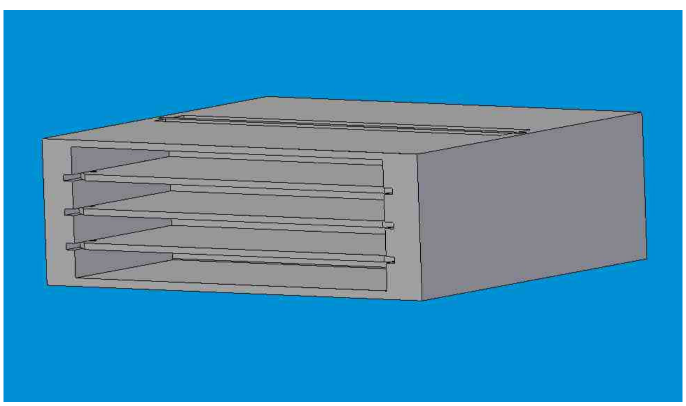

Figure 7.3: Motherboard design concept
Note: Function boards are connected to both sides of the motherboard

The motherboard design provides the simplest geometry and requires that only six boards be accommodated instead of twelve. The function boards would be attached to both sides of the motherboard, and attached to the housing with wedgelocks. This design would require that a motherboard be designed which would take a significant amount of work and add to the overall cost. Another disadvantage of this design is the relatively large footprint required due to the need for connectors, cables, and backshells on both sides of the module.

Back to Back – The Back-to-Back design concept features two modules, each capable of holding three function boards and controller boards. Each function board and its corresponding controller board lie in the same plane. This concept is shown in Figure 7.4 below.

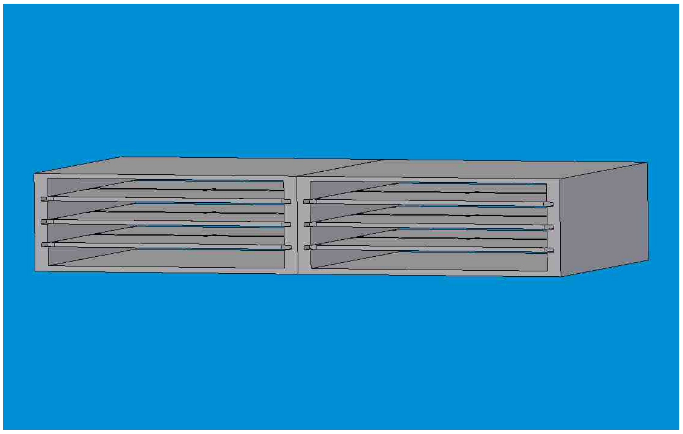

Figure 7.4: Back to back design concept
Note: The boards would be connected to each other on their mating edge

While the head height could be reduced significantly with this concept, cables, connectors, and backshells would again be required on the front and back faces of the modules making the overall footprint the largest of all of the designs.

Two-Stacks – The three stacks design shown in Figure 7.5. This design consists of modular housings each containing two complete function and controller PWB pairs. The modules would be connected mechanically and electrically.

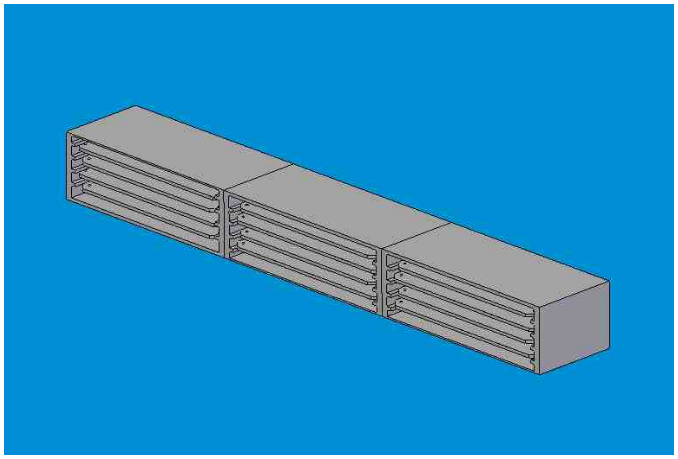

Figure 7.5: Three-Stacks design concept
Note: Each stack of two function and control boards would be contained in a modular housing

The original brainstorming concept was called Two-Stacks, and each module contained two pairs of boards, but after calculating the amount of space available by moving all the cables from the top face to the sides, it was determined that three pairs of boards could be put in each module. This design also features a more efficient footprint due to the possibility of attaching all cables, connectors, and backshells to one side of the housing.

8. Analysis Performed on Design Concepts

Vib B

Thermal B

Manufacturability – A qualitative analysis of the relative manufacturability of each design was conducted with five main categories: Quantity of machined pieces (part count), assembly requirements, tolerance limitations and requirements, geometric complexity, and inter-modular connection. Other factors unique to each design were also considered. Below is a description of the characteristics of each design concept and a manufacturability summary table (Table 8.1).

- **Slanted Unit**
  - **Part count** – Requires at least six face plates with slots or flanges for circuit board connection
  - **Assembly** – Each side would have to be fastened to each other side and either wedge-locks, bolts, or another form of connector would have to be used to secure each board.
  - **Tolerance** – Slots would have to follow close tolerances in order to maintain proper clearances. Also, the angle of the

slots would directly affect the clearance between boards and must be maintained constant.
    - **Complexity –** Moderate complexity of machining the slots and proper lips to prevent EMI interference would be encountered.
    - **Connections – N**o inter-modular connectors would be necessary, only connection points for each board and to the spacecraft.
- **Slanted Modules**
    - **Part count –** Each module could be made from a single piece, so part count would be limited to number of modules.
    - **Assembly** – Easy assembly and no post machining assembly required.
    - **Tolerance –** Bolted connections for all boards would require less strict tolerancing.
    - **Complexity –** Complex geometry would require CNC coding and would have to be turned over to finish part geometry.
    - **Connections –** Inter-modular connections would be required as well as a method for fastening slanted modules to the spacecraft.
- **Motherboard**
    - **Part count –** Fewer parts than modular options, but still more than non-modular concepts.
    - **Assembly** – Fewer boards than other concepts would require less assembly time.
    - **Tolerance –** Tolerance on slots would be critical, yet more room clearance would be available due to reduced number of boards.
    - **Complexity –** Geometry is not complex.
    - **Connections –** No inter-modular connections required. Wedge-locks or fasteners required for boards.
- **Back to back**
    - **Part count –** The modular nature of this design results in more parts.
    - **Assembly** – Post-machining assembly would be required for each module.
    - **Tolerance –** Tight tolerances on slots.
    - **Complexity –** Simple part geometry would result in ease of machining.
    - **Connections –** Connections between modules and to spacecraft would be required.
- **Two-stacks**
    - **Part count** – This design would result in the most machined pieces. Each side of each module would have to be fabricated separately.
    - **Assembly** – Post-machining assembly would be required for each module.
    - **Tolerance –** Tight tolerances on slots.

- **Complexity –** Simple geometry would result in ease of machining.
- **Connections -** Connections between modules and to spacecraft would be required.

Table 8.1: Summary or relative manufacturability of each design concept

Category	Design				
	Slant. Unit	Slant. Mod.	Motherboard	Back-2-Back	Two-Stack
Part count	(–)	(+)	(–)	(–)	(– –)
Material	(–)	(–)	(+)	(–)	(–)
Tolerance	(–)	(+)	(–)	(–)	(–)
Complexity	(–)	(–)	(+)	(+)	(+)
Connections	(+)	(–)	(+)	(–)	(–)
Total	**-3**	**-1**	**1**	**-3**	**-4**

Connector trade study B

Cable strain analysis R

Attachment search/development – Methods and devices for securing the circuit boards to the housings were researched and a list of alternatives is given below.

- **Wedgelocks –** These mechanisms produced by _____________ and ______________ are basically two, three or five wedges attached to a screw that when tightened forces the wedges together decreasing the length between each wedge and forcing them apart against the housing and the board. An example of a wedgelock is shown below in Figure 8.1.

lfhlsdkfhsldkfhlsdkf

- **Bolts –** By far the simplest method of attachment, bolts provide a force to a concentrated area of the board equal to the area under the head of the bolt. Using a washer or as a bar spanning two bolts can increase this area and provide greater stability.
- **Cylinder-Lock –**Our design team conceived this idea while considering fastening options. The design comprises of a cylindrical piece of material with a tapering slot that constricts on the PWB as the cylinder is turned on its axis. A transverse groove will be cut along the axis of the cylinder to allow for the board to slide down to the groove, and a lip on the bottom side of the slot will assure that the board will be in the correct position. These cylinders could be stacked in order to accommodate more than one board. Figure 8.2 below shows a model of the cylinder lock.

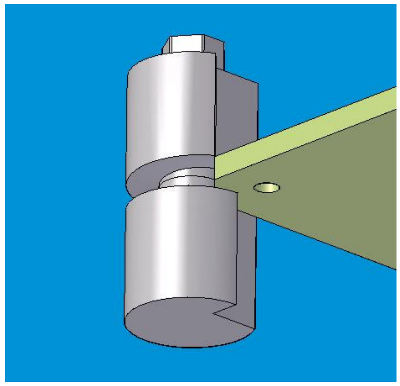

Figure 8.2: Cylinder-lock device used to secure PWB's
Note: Tapered slot constricts PWB as cylinder rotates

9. Final Design Choice

10. Expected Results

With the final design chosen, the detailed analysis can begin. A detailed computer model will be assembled using Solid Edge. This model will be a representation of the housing, PWB's, and connectors, as it would be manufactured. With this model, COSMOS will be used to perform a finite element analysis (FEA) to find critical stress locations, stresses throughout the housing with different load conditions, vibrations analysis including natural frequency determinations and displacements as a result of vibration.

Thermal: ____

These results will be testable results. The natural frequencies of the board and the housing are critical and are easily tested on a vibration table. The results of the thermal analysis are also testable by subjecting a prototype to the known environmental conditions. As such, the desired outcome of analysis is to have similarly testable parameters defined by all analyses, so that Orbital may build and/or test the design.

The expected results of the project as a whole include the analysis results and CAD drawings. A design that meets the requirements and assembles easily is also desired. As such, ease of manufacturing, drawing standards, and tolerance stackup assurances are necessary goals.

10. Budget

The budget for this project is on an objective dependent basis. If the objective changes to include prototyping or manufacturing, machining and materials costs will require reimbursement. Further trips to Orbital in Chandler are subject to Orbital's approval, and will also require reimbursement as shown in Table 1 below. An agreement on these items by Orbital is necessary for determining the scope of each expense. Also included in Table 10.1 is a summary of the time dedicated to the project thus far, and the projected time in each task.

Table 10.1: Budget Overview, Time and Funding

Present Hours Spent

Task	Man Hours
Travel	24
Project Plan	4
Meetings	37
Research	15
Initial Proposal	10
Web Page	4
Total	**94**

Subject/Task	Price
Traveling to Orbit (4 trips @ $40/trip)	$160
Materials	$4/lb
Machining	$75/hour

Projected Hours (through May 2005)

Travel	72
Meetings	150
Brainstorming	48
Web Page	12
Research	160
Final Proposal	8
Developing and Choosing a Design	16
Design Document	20
Shock/Vibration Analysis	32
Thermal Analysis	40
Stress/Strain Analysis	24
Tolerance Stackups	24
Modeling	20
Final Report	16
Total	**642**

Appendix 1 – Requirements Document

Comment [r1]:

Orbital uses a proprietary electronics unit for control of various functions. Stacks have been qualified with module counts ranging from 3 to 10. The basic building block is a module with dimensions of 6.0 inches x 3.0 inches x 1.25 inches. I/O connectors (Right angle 'D' subminiature) come out the top face. Interconnects between modules are accomplished by flex cables on the bottom edge of the boards (Samtec connectors)

This box configuration has fit in most locations on our vehicles. There is a desire to mount units in areas with significantly less head height on future programs. The goal is to fit these units into a space that is 5.0 inches high. Note that the units themselves are just over 3 inches high. However, the mating connector, EMI backshell and cable strain relief will put the required height well over 5 inches.

We would like the NAU team to come up with an alternate packaging approach that fits into areas with a 5" minimum head height. A list of requirements is shown below.

1. Board outline and connector locations should be as shown in figure 1. Perimeter changes to PWBs to augment mounting are allowed. Modules have two PWBs – one to provide the module function and another to provide the standard interface protocols. Some freedom will be allowed in re-thinking this approach.
2. The new design must accommodate 6 modules.
3. Maximum height of the finished unit (including mating connectors, backshells and cable strain relief) shall be less than 5 inches.

In addition to meeting the above hard requirements the following parameters should be optimized.

1. Unit footprint should be optimized. If the unit's volume stays the same (it won't), a decrease in height must be accompanied by an increase in footprint. We can judge the efficiency of the new design by comparing the new footprint to the reduction in height.
2. I/O connector locations. Placement of I/O connectors is a critical parameter. It is desirable to have all I/O connectors on one face of the unit. At most, connectors could be on two faces of the unit.
3. Board and unit resonant frequencies. Low resonant frequencies that have accompanying high deflections will usually fail vibration testing. Board frequencies should be over 500 Hz. Resonant frequencies and deflections in vibration and shock should be calculated. Orbital will work with the team to specify minimum deflections. Overlap of unit and board natural frequencies can cause coupling and inflate transmissibility leading to failures in vibration or shock testing. Board and unit natural frequencies should be separated by an octave at least

4. Safety factors should be calculated for critical parts assuming Mil-STD-1540 minimum qual vibration and a 2000 G shock. Minimum safety factor shall be 1.4
5. Thermal conduction paths should be understood. Temperature rise from unit power dissipation in the center of the board shall be optimized.
6. Unit's mass shall be optimized. The goal is to keep the mass similar to the current unit while still meeting all performance parameters.
7. Design for manufacturability. There are many texts and references on designing for manufacturability. Some thought should be put into this topic. Issues to address are as follows:
a. Reduce hardware (screw, nuts and washers) count and hardware types. Different length screw of the same size counts as a different type.
b. Top down design – ask me
c. Reduce number of piece parts.
8. Minimize Cost. Simplify parts to reduce machining costs.

The above criteria should be used as a starting point for the NAU team's design effort. The team should explore different approaches to packaging the PWBs. The key to having a volume efficient, easily manufacturable, robust design is the configuration of the PWBs and the interconnection scheme. Design variations and tradeoffs should be discussed with the Orbital team.

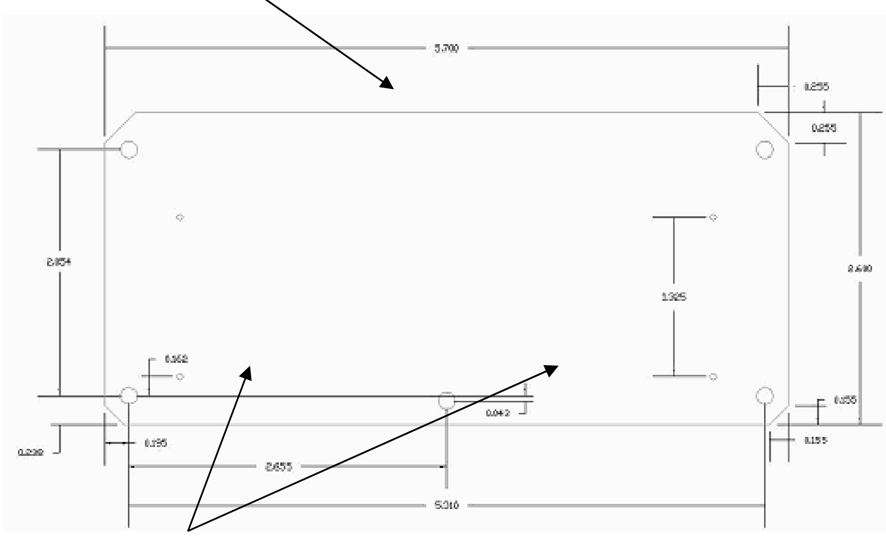

Figure 1

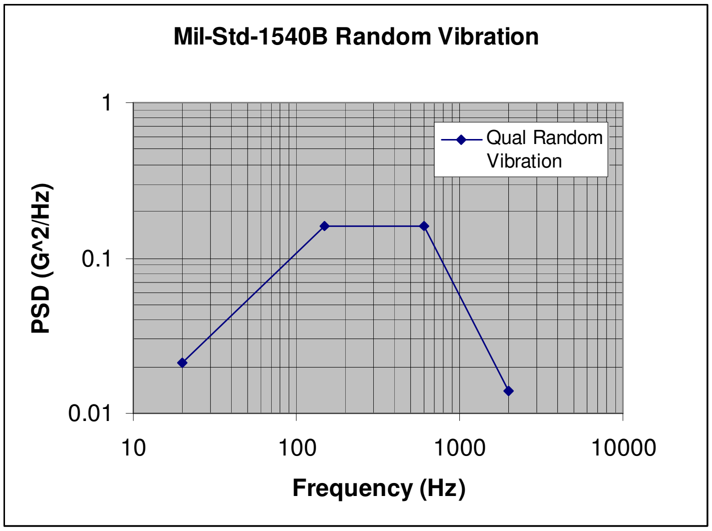

Figure 2

Req'd Qual Levels	
Hz	PSD
20	0.021
150	0.16
600	0.16
2000	0.014
12.2 Grms	
3 min/axis	

Table 1

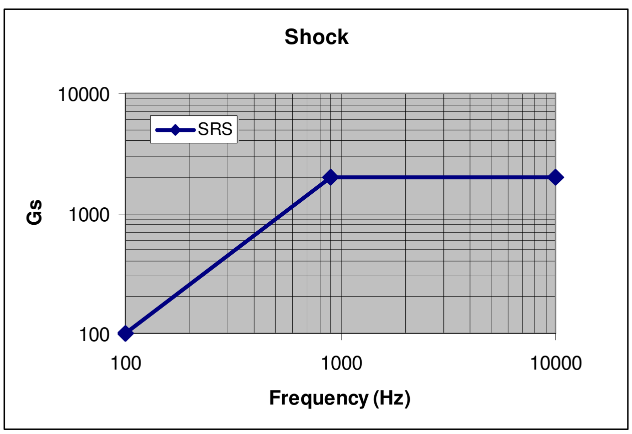

Figure 3

Shock Response Spectrum	
Hz	Gs
100	100
900	2000
10000	2000
3 hits/axis	

Table 2

Appendix 2 – SOTA Research Results

State of the Art Search: Standards

1. A-A-55563, "Holders, Electrical Card, Metal Card Guide, General Requirements for," Defense Supply Center Columbus.

   This standard talks about requirements for a specific type of metal card guide. In the search for new mounting configurations/methods, requirements for new card guide designs are important to look at.

2. A-A-59590, "Holder, Electrical Card, Wedge Retainers, 3 Piece, Screw Actuated Drive, General Requirements for," Defense Supply Center Columbus.

   This standard sets out requirements for a line of wedge retainers. This is another possibility for board mounting, which could be looked into.

3. ASTM E1530-04, "Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique," ASTM International.

   In our thermal analysis, the thermal resistance values from the center of the board will be used as a measure of the thermal properties of the design. Knowledge of this test method may give insight into important thermal relationships and calculations to be used in analysis.

4. MIL-HDBK-1861, "Selection and Use of Electrical and Electronic Assemblies, Boards, Cards, and Associated Har," Defense Supply Center Columbus.

   This handbook examines some possible considerations in the design of PWB and PWB mounting. As such, it could provide some valuable information relating to design of PWB mounting systems.

5. MIL-STD-275, "Printed Wiring for Electronic Equipment," Defense Supply Center Columbus.

   This MIL standard gives a general overview of requirements related to PWB construction, parts mounting, and other important aspects. It could be useful in understanding stresses, deflections, and vibration response of the PWB.

State of the Art Search: Website Results

1. http://www.enre.umd.edu/stein.htm

   This is a table of contents for a book on vibration analysis for electronics equipment.

2. http://www.extron.com/product/listbytype.asp?subtype=11

Here, there are many different designs of mounting plates for electronics. By looking at these designs, we can get an idea of the best types of designs.

3. http://www.nasatech.com/Briefs/Jan99/NPO19972.html

This web site provides a briefing on the Multi-Board Module (MBM) scheme and also provides link for detailed technical support for the briefing.

4. http://www.tomshardware.com/howto/20010810/

This web-site provides a variety of information on printed circuit boards, including different types of PCB's, technologies for component packaging, design and manufacturing processes, and issues to pay attention to in order to save money.

5. http://www.winonics.com/about.html

Winonics is a pre-manufacturing company for printed wiring boards. The majority of their manufactured products are for the telecommunications and instrumentation segments, but they also manufacture boards for the aerospace industry as well as industrial and computer controls.

6. http://www.samtec.com/flex_circuitry/standard_products.asp

Here are flex cables similar to those that Orbital uses. This will be helpful for getting some dimensions and specifications for the required size and type of connectors.

7. http://www.regalusa.com/d-subs_-_right_angle_.html

Here are some subminiature right angle 'D' connectors. It would be helpful to know the number of pins that Orbital requires, but this site should be good for general specifications.

8. http://www.squ1.com/index.php?http://www.squ1.com/thermal/resistance.html

A simple description of thermal resistance as it pertains to insulation and buildings.

9. http://www.coolingzone.com/Content/Library/Tutorials/Tutorial%204/Thermal%20Resistance.html

A detailed description of thermal resistance theory with practical examples. Also contains good links to other valuable references.

10. http://www.infineon.com/cmc_upload/documents/039/975/Appli077.pdf

    Thermal resistance calculations for a chip mounted on a substrate.

State of the Art Search: Patents

1. Patent # 6083032

   This patent outlines a mounting method using "combs" that provides multiple mounting locations for the PWB's. The combs attach to the output/inputs of the PWB and facilitate mounting and conduction. This may not be feasible for our design. But it is still an option. The connectors could be integrated into the mount instead of running around them.

State of the Art Search: Journals

1. Assadian, N., Pourtakdoust, S.H. "Investigation *of thrust effect on the vibrational characteristics of flexible guided missiles*". Journal of Sound and Vibration: Volume 272, Issues 1-2 , 22 April 2004, Pages 287-299.

   In this paper the effect of thrust on the bending behavior of flexible missiles is investigated. For this purpose, the governing equations of motion of a flexible guided missile are derived following the Lagrangian approach. The missile is idealized as a non-uniform beam where the bending elastic deflections are modeled using the method of modal substitution. The vehicle (time varying) bending mode shapes and natural frequencies are determined by modeling variable mass and stiffness distributions with thrust and mass burning effects accounted for. To solve this problem the missile is divided into several segments of uniform stiffness, density and axial force distribution. This approach produces a non-linear transcendental equation, which requires an iterative scheme to numerically determine the magnitude of the eigenvalues. Since inertial measuring units (IMU) also sense the local body vibrations, the mass and stiffness non-uniformities plus the thrust action on elastic missiles can potentially influence their measurements and thus must be properly accounted for in an aero elastic simulation. It is noted that the thrust force reduces the vehicle natural frequency while mass consumption increases it. Thus the modal natural frequencies can either decrease or increase in time. Also the critical buckling thrust, which dynamically causes a zero natural frequency, is obtained and therefore the thrust instability limitations are determined through simulation. With proper modeling of the IMU vibrations effects and engine/thrust fluctuations, the influence of body vibrations on the missile dynamics and controls are investigated with axial thrust effect.

2. De Baetselier E., Goedertier, W. and De Mey, G. "*A survey of the thermal stability of an active heat sink*". Microelectronics and Reliability: Volume 37, Issue 12, December 1997, Pages 1805-1812.

In cases where forced convective cooling alone is inadequate, or where the size of the housing limits the heat sink's dimensions, ICs can be cooled using an active heat sink. Compared to a classical finned heat sink, it can benefit from a substantial size reduction or from an important enhancement of the heat transport from the IC to its surroundings. The active heat sink's function is based upon a Peltier-effect cooling system. The active heat sink controls the IC's thermal resistance to its surroundings. The Peltier-effect heat pump is a non-linear system. Therefore, surveys of the system's stability are far from evident. Thermo-electric models for both the Peltier-effect heat pump and a NTCR (Negative Temperature Coefficient Resistance) temperature sensor are presented. These are linked to thermal models for the IC packaging and a finned heat sink on one hand and to electronic models for the controlling circuit on the other hand. Simulation show non-linear thermal behavior and system instabilities according to the power load on the IC, to the forward amplification of the circuit, but also to the ambient temperature change. The latter phenomenon occurs after power-on of the whole device of which the IC is a part. The theoretical results were confirmed by infrared thermo graphic measurements on a self-constructed active heat sink.

3. Brönnimann, R. and Hack, E. "*Electronic speckle pattern interferometry deformation measurement on lightweight structures under thermal load*". Optics and Lasers in Engineering: Volume 31, Issue 3 , March 1999, Pages 213-222.

We report on the application of ESPI to measure deformations induced by thermal load on lightweight honeycomb panels for space applications. The panel was mounted isostatically onto a **vibration** isolated table. A **housing** for temperature stabilization was constructed enclosing the panel, heating elements, fans and the ESPI-head made of Invar. Emphasis is put on the quantitative analysis of the deformation of this large object ($0.8\times0.8\ m^2$) viewed from a relatively short distance of 1.1 m and illuminated sequentially from three non-orthogonal directions. Influences of laser stability, rigid body displacements, temperature in homogeneities as well as possible deformations of the measurement head are discussed in order to derive the measurement uncertainty and to estimate corrections. Beside the sensitivity vector analysis it is important to take into account the optical light path changes due to temperature changes. Out-of-plane deformation fields of the panel are presented.

4. Moon, Y., Kim, B., Ko, M., Lee, I. "*Modified modal methods for calculating eigenpair sensitivity of asymmetric damped system*". International Journal for Numerical Methods in Engineering: Volume 60, Issue 11 , Pages 1847 – 1860.

Many real systems such as moving vehicles on roads, missiles following trajectories and ships in sea water have asymmetric mass, damping and stiffness matrices. Eigen-sensitivity analysis methods for the symmetric damped system cannot be used in the asymmetric damped case. Therefore, a method for calculating eigenpair sensitivity of the asymmetric damped system is needed. To do this, a modal method employing a modal superposition idea was recently developed. Since the accuracy of the modal method is dependent on the number of modes used in calculation, the modal method needs higher eigenvectors to guarantee the accuracy. In large-scale systems, however, only a few lower modes are generally considered for the dynamic analysis. Hence, if the modal method is used to obtain the eigen-sensitivity of the large-scale system, the significant errors could not be avoided due to the lack of the information of higher modes. In this paper, the modified modal methods for computing the sensitivities of the eigenpairs of asymmetric damped system using a few lowest sets of modes are proposed. Numerical example shows that the proposed methods achieve better calculating efficiency than the previous modal method.

5. Lee, S., Song, S., Moran, K. P., Yavanovich, M. M. *"Analytical Modeling of Thermal Resistance in Bolted Joints"*. Enhanced Cooling Techniques for Electronics Applications; Vol 263. ASME 1993, Pages 115-122.

   An analytical approximate solution is developed for predicting the thermal resistance of bolted joints between two square plates of the same material, but different thicknesses. The plates are assumed to have perfectly flat and smooth surfaces, and they are joined by a bolted connection at the center of the square, forming a concentric annular contact region at the interface. The entire surface area of the plates are insulated, except for the surfaces where the source/sink is applied and where the interracial contact is formed. The heat flows from one edge of a plate to the opposite edge of the other plate through the contact area. The results are presented over a wide range of variables commonly found in most electronic packaging applications. Comparisons with published numerical results show excellent agreement, and satisfactory to good agreement is obtained between the analytical predictions and experimental data.