THE DESIGN OF FLIGHT HARDWARE
Organizational and Technical Ideas From The MITRE/WPI Shuttle Program

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ABSTRACT

The MITRE Corporation of Bedford Massachusetts and Worcester Polytechnic Institute are developing several experiments for a future Shuttle flight. We have standardized upon several design practices for the development of the electrical equipment for our flight hardware. The purpose of this paper is to present some of our ideas, not as hard and fast rules, but rather in the interest of stimulating discussions for sharing such ideas.

ELECTRICITY
ELECTRIC BATTERIES
BATTERY CHARGERS
DATA STORAGE
HEAT TRANSMISSION

SPACE SHUTTLE MISSIONS
" " PAYLOADS
ELECTRONIC EQUIPMENT
COOLING
VIBRATION TESTING
SOFTWARE ENGINEERING

INTRODUCTION

Since late 1982, The MITRE Corporation and Worcester Polytechnic Institute [1] (WPI) have been working together to develop and build experiments for a future GASCAN payload [2] (G-408). Although the experiments have not been launched yet, in the course of developing the experiments many ideas have been implemented concerning the organization of the program and the design and implementation of the systems necessary for experiment control.

The purpose of this document is to present several of our ideas. We believe that this is particularly important for those who have either never attempted to develop space-flight hardware for the GAS program or for those who are in the early stages of experiment development.

PROGRAM ORGANIZATION AND DECISION PROCESSES

Upon initiation of our program, a Technical Steering Committee (TSC) composed of five WPI faculty and a MITRE engineer was appointed. The responsibilities of this Committee are to insure that: (a) the GAS canister is filled with experiments, (b) the experiments are chosen fairly from those developed, (c) the experiments comply with applicable safety, scheduling, budgetary and other logistic requirements, and (d) that all decisions relating to the program are made in an orderly manner.

The detailed concerns of the committee have included (a) soliciting project ideas, (b) selecting students to work on the projects, (c) committing WPI faculty to projects as advisors, (d) setting standards for reports, documentation and presentations, (e) acting as a liaison between MITRE, WPI and NASA, (f) controlling the disbursement of funds and other resources, (g) resolving technical issues involving all aspects of the program and of course, (h) setting deadlines for and evaluating the progress of the development of the experiments.

The presence of the MITRE engineer/scientist on the TSC has been of particular help to the program. In addition to providing an industrial perspective on the organization and development of the program, for WPI he functions as the point-of-contact with MITRE. For example, through him all visits, equipment requests, and requests for professional help are directed.

Industrial Interactions

The faculty and students at WPI interact regularly with local corporate engineers. For example, in an effort to develop a low friction mounting system for a custom accelerometer, the student project team members contacted a manufacturer of jeweled bearings and bearing assemblies. After an initial phone conversation, the students arranged for a plant visit to meet with an applications engineer. As a result of their efforts, the electrical and mechanical engineering students not only learned about the use of jeweled bearings, but also convinced the company to donate the necessary components.

In general, each project team has the responsibility of identifying the system design areas they are having problems with and, if they so choose, contacting a local company which they believe can help them solve their problems. The corporations, in turn, have generally been very receptive to the student requests and have committed many hours of staff time toward helping our students.

Design Reviews

In addition to the individual corporate engineering contacts to help with system designs and design reviews, we have had project group design reviews. Most recently, five MITRE scientist/engineers spent a full week at WPI. Each project team had to meet with the MITRE engineers for a full morning or afternoon. During that time the students presented their experimental equipment, calculations, theory and so forth for review. Prior to the meetings the student teams were, as expected, quite nervous about what the engineers might think of their efforts. After the meetings, the students felt that the expert comments from an outside source, the instructional information and suggestions and just as importantly, the praise they received for their work was well worth the three to four hours spent explaining details and operational aspects of their projects.

After the student meetings, the TSC met with the MITRE staff members to review their impressions of the projects. Comments ranged from minor suggestions concerning the strengthing of mounted components to discussions of major problems such as the trade-offs between expected battery power and anticipated canister weight. In short, the meetings served as a focal point where both the students, the WPI faculty and the MITRE staff could critically evaluate the experiments and as a result, improve the chances of an experiment working properly.

It has become apparant that regularly scheduled design reviews are crucial for any GASCAN project program. We have found that these reviews identify problems in designs, can help find flaws in basic system approaches to experiments, allow one to make changes to systems before they become difficult to change or a safety problem, help identify safety related issues and provide a good educational experience for the students. We intend to schedule these intense reviews for twice a year for our GAS II program.

SYSTEM DESIGN GOALS

All of the experiments the student groups are working on are based on the use of a microprocessor based system controller and the use of auxillary electronic and electro-mechanical equipment. As a result of this dependence we have spent considerable time selecting components and systems that we believe are suitable for the GASCAN environment.

Components And Logic

Almost universally, CMOS devices are the logic elements of choice for any design expected to survive the temperature extremes that can be encountered in the canister environment. While standard TTL devices can withstand a temperature range of 0 to 70 C, the 54xx series TTL family can work in an environment from -55 to +125 C. However, components in the 54xx logic family are not readily available, are expensive and have a high power consumption. Other MOS devices are generally restricted to a temperature range similar to that of standard TTL devices.

CMOS devices inherently have an advantage over other families for two major reasons; first, their operational temperature range and second, their tolerance to supply voltage fluctuations. The nominal operational temperature range for CMOS devices is -40 to +85 C for the 74Cxx family. The supply tolerance for these devices ranges from 2 to 6 volts for some high-speed families to approximately 4 to 15 volts for most of the 4xxx series of CMOS components. In short, the devices are ideal for harsh environments and have a minimal current draw.

The choice of analog devices is not as clearly defined for 'off-the-shelf' components. We have had considerable success using the Texas Instruments TL061 series of biFET operational amplifiers. These devices have the advantages of having low power supply requirements (+/-3V min), very low current draw (200uA, typ), relatively high slew rates (2-3 V/usec typ) and are available in several package arrangements.

Other components, such as analog multiplexers, converters, sensors and so forth are chosen first for their temperature range and low power consumption and second for the type or configuration available. In all cases, availability is of prime concern and to some extent, is more important than power draw.

Finally, we have provided our students with a list of components that we 'guarantee' that we will have available for their use. This list includes approximately twenty types of CMOS 74Cxx devices and approximately fifteen analog ICs such as operational amplifiers, multiplexers and analog-do-digital converters. Some system components such as 80C85's and associated support chips, and other items such as sensors, development hardware and connectors are also included in the list. The purpose of this list is to constrain our students to components we believe are reliable, easy to obtain, somewhat inexpensive and easy to replace if found to be defective. The result is that many of the controller designs are very simple and incorporate standard components.

Batteries And Powering

There are several interrelated problems associated with the choice of a battery power source. These problems include the following:

- The peak current draw required.
- The self-discharge of the battery over time.
- The available energy in a cell with temperature.
- The desirability of recharging a cell.
- The total energy capacity versus size/weight of a cell.

There is no single battery that is appropriate for all requirements. Generally, there are two basic types of cells that can be used, those that are rechargeable and those that are not.

Rechargeable cells have the obvious advantage that they can be reused. Two common types that are readily available include the standard nickle-cadmium (nicads) cell and the gelled lead-acid cells. The lead-acid cells generally have a high self-discharge rate, can be recycled to any discharge level without a memory effect, have exceptionally high peak-current capabilities, must be vented and are moderately affected by temperature. Our current canister is based on the use of GATES, sealed lead-acid (gelled) cells.

Nicads are rechargeable, have a low self-discharge rate, have good peak current capabilities, and are generally more energy dense than the gelled lead-acid cells. These cells have the problem, however, of having a memory for discharge cycles. Unless these cells are fully discharged and charged each time they are used, they will exhibit a memory effect and will either not deliver their full energy when discharged or will not accept a full charge.

There is some experience and test data indicating that 'heavy-duty' cells such as the Duracells and Eveready Alkaline cells are excellent for short duration space experiments [3]. Their features include exceptional energy density at low current draws and a relatively stable output voltage with time. In addition, they have a very long shelf life and do not need to be vented. The primary problem is that they cannot provide very high peak currents and their energy availability is strongly dependent on the average current draw, dropping as much as 40% in tests we have performed at 70ma (13.6wh at 1.2V) and 300ma (8wh at 1.1V). Finally, there is evidence that these cells are strongly affected by the ambient temperature, loosing much of their energy at low temperatures but regaining that capacity if warmed up [3].

Data Storage

Two reasonable approaches exist; storage on tape using a ruggedized data recorder or storage in memory using some form of non-volatile memory device. Tape storage is ideal for mass data storage. Because of the cost of such units (around $5000 minimum), however, other alternatives may be more appropriate for smaller amounts of data storage.

One attractive approach to storing data is the use of battery backed-up CMOS RAM or the use of an inherently stable PROM such as an EEROM or an EPROM. CMOS RAM is low power, available in relative dense configurations and is readily interfaced to any microprocessor system. In addition, many manufacturers have 32K and 64K standard bus CMOS boards available at reasonable prices. In addition, some of the commercial boards have a built-in battery back-up capability based on the use of a Lithium battery. Since NASA will not allow lithium cells to be used in a canister, the batteries must be removed or replaced with NASA acceptable units.

EEROM and EPROM need no such battery support but may require unusual programming timing and/or voltages. The latter requirement can often be mitigated through the appropriate choice of a device with a 5V-only programming mode. Although these devices are attractive from a storage viewpoint, they suffer from two primary problems; storage capacity and operational temperature range. EPROMS and EEROMS are generally available in 2, 4 and 8K sizes with byte-wide data paths and are, primarily, based on NMOS technology. CMOS devices, with their corresponding wider operational temperature range, are becoming more available however.

One form of data storage that should not be overlooked is the use of a 35mm camera with a close-up lens and an autowinder. Such an arrangement has been used before and reported on during the first GAS User's Symposium [4]. The film is used to record numerical data via BCD displays in the field of view of the camera. The advantage of such an approach is primarily that film is a simple and permanent form of data storage. To enhance the amount of data storage required, the user need only add a larger film pack.

Two other forms of data storage include the use of a movie camera and a video camera and recorder. Several portable video camera units are now available that are exceptionally small and are completely self-contained. All necessary power requirements are provided through the use of the battery pack included with the camera. The user need only find a way to mount the unit and either pad the unit or ruggedize it against vibrational damages. The movie (film) camera, like a 35mm camera, is easy to use and generally only requires a close-up lens. Such a camera has the advantage that it can take single frame pictures. Based on a three minute roll of film at 24 frames-per-second, a movie camera could be used to take more than 4000 individual frames of picture data. This is, obviously, many more than a 35mm camera can handle.

Heat Dissipation

It is imperative that GAS experimenters recognize that heat dissipation in an environment where there is no air convection presents a serious problem for heat dissipation from electronic components. Although one could add a low power fan, a more direct approach and certainly a more reliable and lower power approach is to properly heat sink the target devices. Prime candidates are power transistors for driving control motors, voltage regulators and possibly special analog signal processing IC's.

The solution to the heat sink problem is simply to mount the devices on a solid metal wall such as the side of the electronic housing. A less attractive alternative, but acceptible if the heat generation problem is less severe, is to securely mount a device to a wide copper ground plane on the host printed circuit board. If there is sufficient metal in the ground plane, the device may be kept in a reasonable temperature range.

Proper attention to this problem with also solve a second, equally important design problem, that of mounting components so that they do not vibrate and fail during launch. As an example of problem consider the typical 3-pin flat pack voltage regulator. Proper mounting for heat dissipation of this device will also provide a secure mounting mechanism.

DEVELOPMENT SUPPORT

With any program such as a GAS experiment development effort, the host organization should endeavor to provide the design teams with the proper development tools. In an educational environment, except for general laboratory equipment, design and evaluation tools are often not readily available. However, we have found that there are a number of aids that are useful for developing quality experimental equipment. Some of these items will be discussed below.

Vibrational Testing

Although not strictly a design tool, we have found that a shaker table crucial to insure that a system will survive the launch environment. In particular, we have calibrated our table by adding accelerometers and have developed a special, white-noise, spectrally shaped signal generator to drive the table controller. Based on preliminary shaker tests, we have already found problems with some of our designs and have found vibrational effects that, although not considered a structural problem, have forced us to modify our design approach for a given experiment. An example of this is a situation where we have used a stepper motor to activate a piston in a pressure vessel. The shaker tests showed that the motor would move from its 'home' position to an unknown position. To counteract this action, our software routines now include an initialization procedure to force the motor to a `home` position, regardless of whether it was there originally.

Software

Software support items include uP based development aids, word processing, drafting aids, printed circuit board layout tools and analytical modeling aids. Although some of the tools were not available for our first canister, we have found that a significant amount of time is wasted in tasks that could be better handled with the help of a design tool. Since there are a number of inexpensive tools available for an IBM PC or equivalent system, we have purchased a number of these tools for student use.

A word processor is available to the project students. This system allows the students to generate professional looking reports. This is an asset to the individual who must interpret those reports and generate the PAR, PSDP and so forth.

Drafting aids are provided in the form of general PC based picture drawing tools. These tools can be used to generate figures, mechanical drawings, schematics, system drawings and other types of graphical pictures. The software also finds use as an aid for developing overheads for presentations and discussion sessions. In particular, like the word processor, the aids are invaluable in the generation of graphics for NASA documents.

The Wintek (tm) printed circuit board design software is available for student use. For GAS I, all of our PCB designs were done manually. For GAS II and new GAS I boards, we will use the Wintek software to design boards. This software, while not providing true auto-design capabilites, does handle auto-routing and double sided boards. In addition, the output is a 2X layout that is camera ready.

Finally, several analytical modeling aids are available to the students. These aids range from P-SPICE for general circuit analysis, to specialized (non-PC based) CAD packages for thermal and mechanical modeling.

SUMMARY

An organization considering the development of a GAS experiment should closely examine the support required to properly carry out such a development. We were rather niave when we started with our GAS I program. As a result, it is likely that of the original experiments we developed for our first canister, only a few of them will actually fly.

For our GAS II program, we believe that we are much better prepared to develop experiments that will almost certainly function properly in the canister environment. In part, this is a result of the development and evaluation mechanisms we have outlined above.

ACKNOWLEDGEMENTS

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