G-399 AND G-178: LESSONS LEARNED

Michael Dobeck
Sierra College

ABSTRACT

This paper outlines the lessons learned implementing GAS payloads G-399 and G-178 with regard to power systems, computer/data logger, structure and working with undergraduates[1].

INTRODUCTION

Sierra College has successfully flown two GAS payloads. The first of these payloads, G-399, flew in June of 1993 aboard the Shuttle Endeavour and the second payload, G-178, flew in September of 1994 aboard the Discovery. The experience gained on these two flights is being applied to a third GAS payload, G-744, that will fly in April of 1996.

Sierra's "space program" now spans more than five years. During this time over 200 students have been involved in the design, analysis, manufacturing and test of GAS payloads. We are currently working with students to create a small remote sensing satellite that is scheduled for launch in late 1997.

The high-points of the cumulative knowledge gathered in building two GAS payloads is presented in the following paragraphs.

POWER SYSTEM

One of the major failure modes in GAS payloads is the power system. More than one payload has gone into orbit with a depleted battery pack. Power issues can be easily overcome with proper planning, design, and battery choice. The key in planing is to calculate realistic rates of energy consumption and run tests on the payload to determine the accuracy of the calculations. If energy is a critical issue, careful attention must be paid to low-power design techniques. The battery pack must be able to deliver the required power at worst-case payload thermal conditions.

The power source in GAS payloads is limited by safety considerations and cost factors to batteries. The battery of choice for both G-399 and G-178 was an alkaline F cell. Although one could argue for more exotic power sources, the time and effort required for flight approval is, in most cases, prohibitive. The F cell is a standard

---

[1] The work described in this paper is supported by an ARPA/TRP grant. The grant is managed through the NASA management office at the Jet Propulsion Laboratory in Pasadena, California. The grant number is NAG7-1.

commercial product, manufactured by a number of vendors, for use in 'lantern' batteries and a variety of other products. Each 1.5 V F cell delivers 20 amp-hours with a 0.5 amp load. This type of cell is available pre-packaged from several distributors in custom configurations. In both of our GAS payloads, the F cell batteries performed as expected.

Batteries

There are a wide variety of battery types on the market, but all batteries fit into two basic categories-- primary cells and secondary cells. Primary cells are designed for a single discharge only-- i.e. primary cells cannot be recharged. Secondary cells (e.g. NiCd) are designed to be recharged several hundred times. (1)

The major considerations in choosing batteries are as follows:

- Safety concerns must be addressed-- i.e., explosion hazard.
- The batteries must provide sufficient energy at flight temperatures.
- The voltage and current availability must match your experiment.
- The batteries must have a shelf life of at least 3 months-- 6 months is more reasonable.

<u>Primary Cells and Secondary Cells</u>

The standard dry-cell battery is made up of a central carbon rod surrounded by a cathode mixture of manganese dioxide, carbon, ammonium chloride and zinc chloride electrolytes. The cathode is separated from the zinc anode outer can by an insulating layer. The can is sealed with a wax and asphalt seal. If this sounds primitive, that's because it is primitive! This type of cell has low power density, a sloping discharge curve and its impedance rises as the cell is discharged. (2) The heavy duty dry cells offer improved delivery of their rated energy capacity, but still have a number of the standard cell drawbacks. The one advantage of these batteries is their low cost (see Table 1).

Alkaline dry-cell batteries offer far better performance than the standard and heavy duty dry-cell batteries. Alkalines have a shelf life of several years and perform well at temperatures ordinarily experienced in the GAS environment. The F type cells have a higher energy density than consumer D cells. Type F alkaline dry cells are also widely available at low cost.

Mercury and sliver oxide cells perform better than alkaline cells, but they are expensive. Because of mercury's willingness to combine with other metals, mercury batteries are considered a severe safety hazard (2). If your program can afford silver oxide cells, they are worthy of further investigation.

Lithium batteries are nearly perfect for GAS payloads when using the categories listed in table one as the determining factors. Unfortunately, they constitute a major safety hazard because they have exploded on several occasions causing severe damage to equipment and personnel. The small button type lithium batteries embedded in real-time clocks generally do not pose a hazard (2).

Secondary batteries (rechargeable) have lower energy density than primary batteries and the secondary cells self discharge. A NiCd battery will lose 50% of its charge in four months, and a lead-acid battery will lose one-third of its charge in eight months. The major feature of secondary batteries is that they can be recharged, but is this an important characteristic for a one-shot payload? On the positive side, both lead-acid and NiCd cells have low internal resistance, so current can be drawn from the cells at a high rate.

Battery Type	Energy Density (Wh/in^3)	Discharge Curve	Performance at 5 Degrees C	Shelf Life	Safety Hazard	Cost
Zinc-carbon (standard cell)	1-2	sloping	poor	?	minimal	low
Zinc-carbon (heavy duty)	2-2.5	sloping	poor	?	minimal	low
Alkaline	3.5	sloping	good	very good	flown	low
Mercury	7	flat	good	good	high	high
Silver oxide	6	flat	very good	excellent	?	high
Lithium	8	flat	excellent	excellent	high	high
NiCd	1	flat	good	poor (50% of charge lost in 4 months)	flown	low
Lead Acid	1	flat	good	acceptable (33% of charge lost in 8 months)	flown	low

Table 1: Battery characteristics.

LOW POWER DESIGN

Low power design is a philosophy that must be embraced for most GAS payloads. Because of battery power limitations, mission success generally depends upon the designer's skill in minimizing power usage. The basic low-power design philosophy can be summed up as follows:

- Don't build in more computing power than you need (CPU speed, memory size).
- Use low power (i.e. CMOS) electronics whenever possible.
- If a device is not required during a certain time period, *turn it off*.

Computer and Data Logging

The computer on most GAS payloads does not have to be very powerful in terms of processor speed and memory size. Typically the processor is used as an event sequencer and data logger. Although numerous 80x86 single board computers are available off-the-shelf, most are quite power hungry. There are numerous microcontroller boards (not based on the 80x86 architecture) available that use very little electrical energy and can be programmed using PC based tools. Microcontrollers are ideal for most GAS experiments.

On our first GAS payload, G-399, the students and staff built a custom 80C552 based microcontroller card. The major drawbacks to this approach were the long development time and the lack of a high-level language for programming. On our second GAS payload, G-178, we used an off the shelf 80x86 based single board computer. The major advantage of this approach was ease of programming using the 'C' language in a PC environment. The disadvantage of the single board computer was its high power consumption (>100 mA at 5 VDC).

Our current approach is to use an ultra low-power RISC microcontroller. The Microchip PIC™ consumes less than 1 mA at a clock speed of 4 Mhz (3). The PIC has between 12 and 20 general purpose I/O lines and it executes almost all of its 33 instructions in one clock cycle. By placing PICs in each instrument in the payload, and using an RS-485 bus in a simple network configuration, the wiring harness is cut to four wires daisy-chained between devices. This approach distributes the intelligence to the various devices in the payload and requires very little electrical power.

Another approach to saving energy is to power cycle the entire experiment. By using a real-time hardware clock with a time-out output, coupled to a solid-state power switching relay, the payload can be powered-up at appropriate time intervals. We have run a number of successful laboratory experiments on this approach. When using power cycling you must be careful to correctly program the time-out interval. A mistake in programming the clock can shut down the experiment for several years!

Recording experiment data is essential to most payloads. It is also useful to collect information on the operation of the experiment for later analysis. On our GAS payloads we collected primarily temperature data, but a number of other useful parameters such as valve status, current draw and battery pack voltage, can also be gathered. This data can be stored in battery backed SRAM, EEPROM, Flash memory or hard disk. On G-399 we used 8 kb of battery backed SRAM, but on G-178 the digital images required 50 kb each, so we flew a pair of laptop grade hard disks. The hard disks we flew could withstand a 100 G operating shock. The complete data set was recovered from both disks without error. Our next GAS payload will use Flash memory for data recording. Flash memory consumes less than 1 mA in stand-by mode and it can be power cycled.

STRUCTURE

A number of different GAS structures have been designed and flown by a variety of educational users. Our advice is to use someone else's design and focus your attention on your experiment. Unless your requirements are very unique, it is easier to build a previously flown structure. We have designed and flown a standard 2.5 cubic foot GAS structure. The drawings and notes are available to all GAS users.

WORKING WITH UNDERGRADUATES

Building Space Shuttle experiments can be a very effective learning experience for students who choose to participate in the process. GAS experiments require students to apply the knowledge acquired in physics, engineering and computer science. Students must analyze, design and manufacture the experiments. The following are a few guidelines for building GAS payloads with freshman and sophomore college students:

- Clearly define the objectives of the experiment you are building. What data do you hope to recover from the completed experiment?
- Divide the class into design teams for the various subsystems. Write a "contract" with each group so they know exactly what they are expected to produce during the quarter or semester. Limit the size of each group to four people.
- Design the group projects so the groups must interact with one another. This builds excellent communication and work skills.
- Have each team report its progress during weekly meetings.
- Have the students in each group grade one another's performance and use that grade as a portion of the students final grade.
- Have each team present formal midterm and final reports. The final report should include a demonstration of the product built by each team.
- Focus the teams on building the flight article. Most undergraduates do not understand the difference between analysis and design problems. Many students believe there is only one solution to a design problem-- theirs. Care must be taken to arrive at the best solution given the manufacturing environment available.

CONCLUSION

Building GAS payloads with an experienced engineering team is a difficult task. Careful selection of batteries and use of low-power design techniques help to ensure mission success. Use of existing structures can dramatically reduce the work load.

Building GAS payloads with freshman and sophomore students is complicated by the need to help students to implement an appropriate solution to a given problem. The head of such a project must act as teacher, coach, mentor and cheerleader. The students who participate in a GAS project come away with deep knowledge of product design, analysis and manufacturing.

References

1. Horowitz, P.; Hill, W.: The Art of Electronics, 2nd edition, Cambridge University Press, 1989.
2. ________: Manned Space Vehicle Battery Safety Handbook, NASA JSC-20793, 1985.
3. ________: Embedded Control Handbook 1994/1995, Microchip Technology Inc., 1994.