BIG SCIENCE ON A SMALL BUDGET:
A UNIVERSITY SOUNDING ROCKET

BY
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TABLE OF CONTENTS

Abstract .......................... Page 1
1. Introduction ...................... Page 2
2. Mission Overview ................. Page 2
  2.1 Mission Statement .......... Page 2
  2.2 Mission Profile .......... Page 2
3. Science ......................... Page 2
  3.1 Science Significance .......... Page 2
  3.2 Science Objectives .......... Page 2
  3.3 Science Payload ............... Page 2
    Spectrometer ................. Page 2
    Visible, Ultraviolet (UV), and Infrared (IR) photometers .... Page 3
  3.4 Science Results ............... Page 3
4. Technical Design ................ Page 3
  4.1 System Architecture .......... Page 3
  4.1.1 Attitude Determination System (ADS) .......... Page 3
  4.1.2 Command and Data Handling System (C&DH) ........ Page 3
  4.1.3 Telemetry System (TM) .... Page 3
  4.1.4 Electrical Power System (EPS) .......... Page 3
  4.1.5 Ground Support Equipment (GSE) .......... Page 3
  4.1.6 Payload Structure .......... Page 3
5. Mission Management .............. Page 3
  5.1 Team Organization and Communication ...... Page 3
  5.2 Schedule ...................... Page 3
  5.3 Budget ....................... Page 3
6. Lessons Learned ................. Page 3
7. Acknowledgements ................ Page 3
8. Conclusion ...................... Page 3
Endnotes .......................... Page 3

LIST OF FIGURES

Figure 1  HOMER Mission Profile .... Page 2
Figure 2  Science Instrumentation Summary .... Page 2
Figure 3  Spectrometer Electrical Interfaces .... Page 2
Figure 4  UV Airglow Spectra of the Earth's Limb .... Page 2
Figure 5  Ozone Slant Column .... Page 2
Figure 6  Atomic Oxygen and Ozone Density Profiles .... Page 2
Figure 7  The HOMER C&DH System .... Page 2

High-altitude Ozone Measuring and Educational Rocket
HOMER

07/03/97
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>HOMER Electrical Power System</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Payload structure, science instruments, and subsystem components</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Launch configuration</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>HOMER Team Leads</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>HOMER Project Milestones</td>
<td>9</td>
</tr>
<tr>
<td>13</td>
<td>HOMER Budget Summary</td>
<td>9</td>
</tr>
</tbody>
</table>
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Abstract: The High-altitude Ozone Measuring and Educational Rocket (HOMER), a pilot for the NASA Student Launch Program, was a suborbital rocket investigation conducted by the Colorado Space Grant Consortium (CSGC). The HOMER mission provided: a unique educational opportunity for hands-on involvement by students in colleges and universities throughout Colorado; measurements of ozone and atmospheric constituents which affect ozone in the Earth's atmosphere; a demonstration of advanced and low-cost technologies that enable these measurements; and an intercomparison of measurement techniques. HOMER was launched from Wallops Flight Facility in Wallops Island, Virginia on August 12, 1996. HOMER is a follow-on payload to two previous Colorado Space Grant missions; the Colorado Student Ozone Atmospheric Rocket (CSOAR), and the Cooperative Student High Altitude Research Payload (CSHARP) -- student-developed payloads successfully launched from Wallops Flight Facility in September of 1992, and August of 1994 respectively.

This paper will discuss the HOMER mission and its scientific achievements. The HOMER project was an outstanding success. With collaboration among colleges and universities throughout Colorado, HOMER was a multidisciplinary effort that provided an unparalleled educational experience for over 100 students. Working within the confines of a short schedule and small budget, students conceived, managed, designed, built, tested, and launched a payload that gathered significant science data. HOMER serves as a proven model for subsequent student-developed payloads.
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1. Introduction

The High-altitude Ozone Measuring Educational Rocket (HOMER) was a sounding rocket project involving over 100 students in the Colorado Space Grant Consortium (CSGC). CSGC is a group of sixteen Colorado colleges and universities supported by NASA for the express purpose of educating students of all ages in the science and engineering aspects of space related activities. The programs sponsored by CSGC range from introductory space education for K-12 students, to the design and development of actual space payloads by undergraduate and graduate students. Since its formation in 1989, CSGC has acquired a rich heritage in student payloads -- with three successful rocket launches, two shuttle payloads, and a small satellite proposal. CSGC is extending this heritage with a shuttle payload (to be launched onboard STS-85) and a small satellite currently under development. These projects provide unparalleled opportunities for students to obtain hands-on experience in designing, building, launching, operating, and analyzing real space payloads. From project management to detailed performance analysis, the students go beyond textbooks and classroom learning, and in the process develop valuable technical skills and techniques for working in a team environment.

To address one of today’s most significant environmental issues, HOMER measured ozone and constituents which affect ozone in the Earth’s atmosphere. Satellite measurements have revealed that the concentrations of stratospheric ozone have dropped to record low levels during the past decade over the middle latitudes and polar regions of the Earth. In fact, recent global averages of total ozone concentration are two to three percent lower than the lowest values observed in earlier years. An increase of ozone-hostile constituents in the stratosphere has played a significant role in the increasing rate of ozone destruction. Therefore, it is extremely important to have accurate measurements of ozone, and of the atmospheric constituents that can alter the destruction rate of ozone. Specific constituents, such as oxides of nitrogen, are believed to catalytically destroy ozone through various chemical processes. Specifically, HOMER measured ozone (O₃), atomic oxygen (O), molecular oxygen (O₂), nitric oxide (NO), and air density in the upper stratosphere and lower mesosphere. The project provided valuable insight into middle atmospheric photochemistry and related energetics by investigating the relationship between atmospheric composition, the absorption of ultraviolet (UV) flux, and emission characteristics in the UV and near infrared (IR) regions. These measurements are being compared to data received from two previous CSGC rocket projects, CSOAR and CSHARP, to study trends in ozone concentration. O₃, NO, O, and O₂ were measured by a student-built, low-cost, high-performance, ultraviolet imaging Charge-Coupled-Device (CCD) Spectrometer. The spectrometer measured light above the Earth’s limb in UV wavelengths (215 nm - 265 nm), while flight-demonstrating a state-of-the-art, back-side-thinned, delta-doped CCD detector. The re-flight of two photometers flown on the 1992 and 1994 CSGC rocket missions, a UV photometer (270 nm) and a visible photometer (450 nm), were used to obtain the density profile of ozone over the rocket range. These photometers provided a continuity of CSGC ozone measurements. Finally, an IR photodiode photometer (1270 nm) was flown to provide a second and indirect observation of the concentrations of ozone and atomic oxygen higher in the atmosphere.
The data analysis phase of the HOMER mission is ongoing, with expected completion in the next few months. The imaging spectrometer data has thus far provided insight into the radiometric intricacies of limb observations in the UV region. From this data, emission features can be identified, and vertical distribution of source molecules can be extracted. In the longer wavelengths (245 nm – 265 nm), a unique data analysis technique, Differential Optical Absorption Spectroscopy (DOAS), has been employed to determine ozone distribution in the lower mesosphere and upper stratosphere. By using the DOAS approach, spectral calibration was not imperative because systematic errors cancel during the data reduction process.

2. Mission Overview

HOMER launched on August 12, 1996 from Wallops Flight Facility in Wallops Island, VA. Over a span of two years, the HOMER payload was designed, prototyped, manufactured, tested, and flown. Students controlled all experiment phases from initial concept through data analysis and publication. Student researchers, with a small budget and short schedule, demonstrated their ability to meet significant scientific objectives. Five of the sixteen colleges and universities in CSGC were involved in the project, each with duties ranging from subsystem construction to mission analysis. This diverse team made the HOMER mission an unqualified success; all mission success criteria were achieved.

2.1 Mission Statement

HOMER was a student-developed, NASA sounding rocket mission to:

- Provide local measurements of ozone and constituents which affect ozone in the Earth’s atmosphere;
- Demonstrate advanced and low-cost technologies that enable these measurements;
- Provide an intercomparison of measurement techniques; and
- Provide a unique educational opportunity for hands-on involvement of students in colleges and universities throughout Colorado.

2.2 Mission Profile

The HOMER payload was flown atop a Nike-Orion rocket motor. The rocket was despun to under 0.25 Hz just after motor burn so the science instruments could produce atmospheric images as the rocket approached apogee. All instruments were canted to look at the Earth’s limb through quartz window apertures in the side of the rocket skin, allowing atmospheric observations from 40 km to 100 km. To help stabilize the rocket, the second stage motor was not deployed until after apogee. The instruments continued to take data until splashdown. Figure 1 illustrates the HOMER mission profile.

![Figure 1: HOMER Mission Profile](image)

3. Science

During the initial concept phase of the HOMER mission, the team was tasked with the responsibility of conceiving a mission that would provide useful information for the scientific community. In light of growing public concern about the wellness of our planet, the HOMER team chose to concentrate on ozone, an atmospheric constituent crucial to life on Earth.

3.1 Science Significance

Stratospheric ozone is responsible for preventing much of the Sun’s biologically harmful radiation from reaching the Earth’s surface. Ozone is a relatively unstable molecule, created when oxygen molecules (O₂) photodissociate into extremely reactive oxygen atoms (O). The oxygen atoms then bond with other oxygen molecules, forming the ozone molecule (O₃). Simultaneously, ozone is being destroyed as a result of other aeronomic reactions, creating a precarious balance. An upset in this balance can have significant adverse effects including...
an increase in the risk of skin cancer and cataracts, impairment of immune systems, and damage to food crops, plants, and animals.

During the past decade, the lowest levels of ozone in recent history have been measured due to an increase of ozone-hostile constituents in the stratosphere. Recent measurements have shown significant decreases in Arctic ozone levels from previous years. This fact, combined with the possibility that ozone concentrations will reach critical levels within the next decade, makes it essential that this protective shield be accurately monitored. Currently, total column and vertical distribution measurements of ozone are obtained by satellite-based instruments including the Total Ozone Mapping Spectrometer (TOMS) and Stratospheric Aerosol and Gas Experiment (SAGE), the ground-based Dobson network and Umkehr instruments, and balloon-borne ozonesondes. Verification of these ozone measurements through comparative measurements is vital. Comparison between satellite and ground-based instruments, however, is complicated due to the fact that ground-based instruments look through the lower atmosphere (troposphere) to collect data. Discrepancies of ozone measurements are even greater in the northern hemisphere where tropospheric ozone is increasing.

The HOMER science payload, by incorporating improved techniques for measuring ozone, was designed to complement and extend current ozone measurements and further the understanding of anthropogenic changes in the northern hemisphere. In addition to total column and vertical distribution measurements of ozone, HOMER measured primary oxygen species related to ozone chemistry, mainly atomic oxygen (O), nitric oxide (NO), and molecular oxygen (O2). Measurements of these species and UV flux yield an understanding of the production rates of ozone, as a function of altitude.

3.2 Science Objectives

In accordance with rising concerns about the Earth’s ozone layer, the main objectives of the HOMER science payload were to:

- provide both column and vertical distribution measurements of ozone and atmospheric constituents affecting ozone, including O2, NO, and O in the upper stratosphere (40 km) and lower mesosphere (100 km);
- demonstrate low-cost, high-performance, ultra-violet imaging CCD technology in the measurements of these atmospheric constituents; and
- acquire comparison data to complement current ozone data and data retrieved by the two previous CSGC rocket missions, CSOAR and CSHARP.

3.3 Science Payload

The HOMER science payload, consisting of three individual science experiments, was unique because it provided a direct intercomparison of three different ozone measurement techniques. These techniques used separate instrumentation, separate scientific rationale, and completely separate algorithms for data analysis. This intercomparison was especially important for the CCD spectrometer which had never been flown.

A video camera was optically aligned with science instruments to aid in post-flight analysis and attitude determination. The video camera also provided a memorable audio/visual record of the flight.

The scientific instrumentation is summarized in the following table:

<table>
<thead>
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<th>Instrument</th>
<th>Wavelength</th>
<th>Observation</th>
<th>Method</th>
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</thead>
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<td>Spectrometer</td>
<td>215-265nm</td>
<td>O, NO, O3</td>
<td>CCD</td>
</tr>
<tr>
<td>UV photometer</td>
<td>270nm</td>
<td>O3</td>
<td>PMT</td>
</tr>
<tr>
<td>Visible photometer</td>
<td>450nm</td>
<td>stratospheric and lower mesospheric air density</td>
<td>Diode</td>
</tr>
<tr>
<td>IR photometer</td>
<td>1270nm</td>
<td>O, O3</td>
<td>Diode</td>
</tr>
</tbody>
</table>

Figure 2: Science Instrumentation Summary

**Spectrometer** The HOMER spectrometer was designed to address two of the main science objectives. The first was to determine both column and vertical distribution of O3, O, O2 and NO. The second was to demonstrate that measurements in the far ultraviolet are possible using a delta-doped CCD. Difficulties with using CCDs in the past have been due to low efficiencies at wavelengths shorter than about 400 nm, and the contamination of signal from much brighter visible light. NASA’s Jet Propulsion Laboratories (JPL) provided CSGC with the use of a delta-doped CCD for flight-testing and validation. These CCDs show enhanced responsivity in the UV, making them an attractive detection device for ozone monitoring.
The optical design of the spectrometer consisted of the fore-optics (telescope) and the aft-optics (spectrograph). The telescope is an F/12 off-axis Gregorian design using a 50 µm entrance slit. The spectrograph was an Ebert-Fastie design with a primary spherical mirror, allowing for high throughput while maintaining excellent image quality. The spectrometer electrical design (Figure 3) had two main parts, the IBM model XT (or 'XT') box and the Camera Control Unit (CCU). The XT box contained three boards (microcontroller, framegrabber, and dual-port RAM memory) connected by a passive backplane. The XT had onboard dynamic RAM and flash RAM where the flight program was contained. The CCU, consisting of a mother and daughter board from EG&G Reticon, provided all the timing and video processing necessary for the CCD. The video output from the motherboard traveled to the XT box which then transferred the signal to the C&DH system in a digital format.

Figure 3: Spectrometer electrical interfaces.

The CCD spectrometer was controlled with a dedicated microprocessor contained in the XT box. This microprocessor allowed the spectrometer to image periodically. This instrument computer packaged data into IRIG format for downlink to the Wallops Flight Facility ground station, where it was recorded for post-flight data analysis.

Visible, Ultraviolet (UV), and Infrared (IR) photometers The HOMER visible and UV photometers, centered at 450 nm and 270 nm respectively, provided a density profile of ozone. The visible photometer measured scattering, while the UV photometer determined the amount of ultraviolet light absorbed as the solar irradiance is attenuated through the atmosphere. These photometers flew on CSOAR and CSHARP and were refurbished for the HOMER mission to improve performance and reduce noise. They provided a continuity of measurements between the three CSRC sounding rocket projects.

The HOMER IR photometer was flown to provide a second and indirect observation of the concentration of ozone. This photometer provided measurements of the density profile of high-energy molecular oxygen formed through ozone photolysis in the stratosphere and mesosphere. The rate of formation of stratospheric excited-state atomic oxygen, which is essential in interacting with methane and water vapor to naturally decompose the ozone molecule, can be determined from this measurement. In addition, this photometer aided in obtaining a more accurate ozone profile higher in the atmosphere. The IR photometer is based upon the concept used by the Solar Mesosphere Explorer’s Infrared Airglow photometer.

All three photometers required counting electronics, high-speed channels for digital data, and data output handling. The structural optic designs were based on a Poker Flats photometer flown by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, Boulder.

3.4 Scientific Results

The data analysis phase of the HOMER mission is underway. The imaging spectrometer data is providing a wealth of information on the radiometric intricacies of limb observations in the UV region. Emission features are being identified and vertical distribution of source molecules is being extracted from the data (see Figure 4).

Ultraviolet Airglow Spectra from Limb Viewing Spectrograph
August 12, 1996

![Ultraviolet Airglow Spectra of the Earth’s Limb](image)

Figure 4: UV Airglow Spectra of the Earth’s Limb
Figure 4 shows the ultraviolet airglow spectra of the Earth's limb obtained by the HOMER spectrometer. The plotted lines are from measurements taken progressively higher above the limb. The distinct variation in the intensity of the nitrogen and nitric oxide emission peaks as a function of height above the limb is observed because the nitric oxide emission is predominately created near 100 km, while nitrogen emission is created near 250 km. In the longer wavelengths (245 nm - 265 nm), Differential Optical Absorption Spectroscopy (DOAS) is being employed to determine ozone distribution in the mesosphere and upper stratosphere. Figure 5 shows the calculated ozone slant column over Wallops Island on August 12, 1996. This data was calculated from the ratio of two ozone absorption lines at 258.6 and 260.1 nm as measured by the HOMER spectrometer.

Calculated ozone column using line ratios from image 53

![Figure 5: Ozone Slant Column](image)

HOMER spectrometer data will be compared and verified with the IR photometer observations.

Figure 6 shows the atomic oxygen and ozone density profiles from observations of the Atmospheric Infrared Band. This preliminary plot does not yet include correction to the photolysis rate of ozone below 50 km, but when the analysis is complete, these observations will be a valuable data set to correlate with the spectrometer observations.

4. Technical Design

The HOMER sounding rocket payload was designed to be simple to facilitate completion within the project schedule, robust to survive in a harsh environment, modular to adapt well to future payloads, and low-cost to accommodate the modest budget. All requirements were carefully tracked, the design went through extensive review and evaluation, and extensive subsystem and system level tests were performed to ensure flight readiness. The payload is currently being used as a testbed for future CSGC rocket and balloon projects, and many components will be reused for follow-on investigations.

4.1 System Architecture

The system architecture took full advantage of the heritage that students and faculty of the Colorado Space Grant Consortium have accumulated in ozone instrumentation and rocket system design. This architecture emphasized a modular, adaptable rocket design to accommodate design changes, problem solving, and reuse on future flights.

4.1.1 Attitude Determination System (ADS):

HOMER's ADS system featured a magnetometer and two Sun sensors. The magnetometer provided knowledge of the rocket's orientation with respect to the Earth's magnetic field. The two Sun sensors, mounted on opposite sides of the rocket (to ensure one always detects the Sun), provided measurements of HOMER's position with respect to the Sun during the rocket flight. This data is important for data analysis and science data interpretation.

4.1.2 Command and Data Handling (C&DH):

The C&DH flight system for HOMER was a small computer responsible for event sequencing during the flight; collection and packaging of science data for transmission to the ground; and health and status monitoring of the various onboard systems. Before launch, the C&DH system communicated with the Ground Support Equipment (GSE) through the payload umbilical. After launch, the system functioned autonomously. There was no command...
uplink capability. The HOMER flight computer was a 68HC16 computer ruggedized for the flight environment. By using off-the-shelf technology, this computer was inexpensive and powerful. Due to the standardized PC architecture, software and hardware development were simplified. The computer featured direct digital and analog I/O (for monitoring and controlling various onboard systems), a serial link to the GSE, and high-speed interfaces to the imaging experiments and telemetry system. Figure 7 shows a functional block diagram of the C&DH system for HOMER.

This testing was done with external power until steady state, followed by EPS testing via internal power. See figure 8 for a functional block diagram of the HOMER Electrical Power System.

**Figure 7: The HOMER C&DH System**

**4.1.3 Telemetry System (TM):**

The HOMER TM system used two transmitters to downlink science and engineering data. The output of the transmitters was coupled via diplexor into one signal, and sent to a S-band band antenna. A ranging beacon, using two C-band ramshorn antennas, was used to maintain an accurate fix on the rocket’s location. Science data volume largely dictated the HOMER data budget. Digital science, and analog health and status data were time-stamped by C&DH and stored in RAM prior to transmission to the Wallops Ground Station.

**4.1.4 Electrical Power System (EPS):**

The power system for HOMER was divided into three sections: batteries, relays, and a Power Distribution Unit (PDU). Two NiCd battery stacks provided internal power to the payload. A relay driver board toggled power to subsystems requiring switching during environmental testing or flight. Electrical power was distributed throughout the payload by the PDU, which housed DC/DC converters and regulators, and critical current and voltage monitors. The HOMER EPS was calibrated prior to, and following, integration. The power system was designed with healthy safety factors, and tested beyond payload temperature requirements.

**Figure 8: HOMER Electrical Power System**

**4.1.5 Ground Support Equipment (GSE):**

The HOMER GSE had two sections: a suitcase for battery charging and external power, and a laptop computer with an RS-422 link to the flight computer. Both sections housed vital monitors used for integration and testing procedures, as well as go/no-go launch decisions. The GSE provided the ability to turn on and off instruments, and showed all payload health information in a concise format.

**4.1.6 Payload Structure:**

The payload structure can be broken down into six sections (see Figures 9 & 10). Each section was designed to perform a particular task or house specific equipment. These sections were recovered after splashdown, and will be reused on future payloads.

All structural elements were composed of 6061-T6 aluminum unless otherwise noted. Radix joints were used to maximize bending moment resistance. A sectional description of the payload structure follows:

- The *nosecone* was a 19° straight taper nosecone with a base diameter of 17.26 inches.
- The *pressurized section* contained all of the hardware necessary for data collection and transmission. The internal support structure consisted of four circular deck plates supported by three cylindrical longerons. This modular design allowed for interacting components to be placed close together, thereby minimizing wire lengths. This structural design withstood lateral and axial accelerations of 25 G’s and 50 G’s.
respectively. All subsystem components were mounted to the decks using a rail system that allowed easy access and component removal. The section was pressurized to two atmospheres prior to launch, and sealed with a bulkhead at each end.

Figure 9: Payload structure, science instruments, and subsystem components.
- The unpressurized section housed sun sensors used for attitude determination. Two ramshorn antennas, a band antenna, and two lanyards were mounted external to this section.
- The transition section provided a smooth transition from a diameter of 17.26 inches (driven by the pressurized section) to 14 inches (driven by the Nike-Orion motor), and housed the despins equipment.
- The recovery section, provided by Wallops Flight Facility, housed the rocket’s parachute.
- The skin had apertures for the viewing instruments. It also provided a watertight interface between the bulkheads, which created the buoyancy necessary for post splashdown recovery.

5. Mission Management

One of the major challenges in designing and building an actual space payload at a University, using primarily student labor, is meeting the budget and schedule constraints of the project. While the university setting lends itself to education, the mission success cannot be achieved without
performing significant science and/or technology investigations. Faced with student inexperience, high student turnover rates, and minimal budgets, careful consideration must go into the management philosophies embraced by these projects. The HOMER project established a management approach incorporating traditional techniques with sensible new ideas. Key aspects of this approach were:

- A dedicated core student team, with overall project responsibility, advised by skilled and professional mentors from academia, government, and industry;
- Consistent and effective communication between team members;
- Generous margins in the project schedule, and emphasis on planning for major project milestones;
- Particular attention to the number and usefulness of meetings and reviews held; and
- An emphasis on producing only pertinent documentation.

5.1 Team Organization and Communication:

CSGC, with its 16 member schools and affiliates, provided the overall network organization for HOMER; enabled student and faculty involvement by participating Colorado schools; and enabled the use of facilities and resources on each campus. The HOMER team organization was similar to a "traditional" project – with project management, subsystem leads, and subsystem teams. The development responsibility was divided into ten separate subsystems: Attitude Determination, Command and Data Handling, Electrical Power, Ground Support Equipment, Integration and Testing, Mission Analysis, Science, Structures, Telemetry, and Data Analysis. A select group of undergraduate and graduate students from the University of Colorado at Boulder, Fort Lewis College, Colorado State University, the University of Colorado Springs, and Mesa State College supported HOMER's development. Figure 11 shows the project organization with team leads for each of the subsystems. The team leads were responsible for ensuring that their subsystem team, comprised of additional undergraduate and graduate students, met all functional, performance, and programmatic requirements. The rocket team worked throughout the project to design, develop, and test HOMER, and evaluate its science data.

The student project team had the overall responsibility of conceptualizing and detailing the design, performing relevant analysis, fabricating most subsystem components, integrating subsystems, testing system components, and preparing for a sequence of environmental tests for the HOMER sounding rocket. This core student team was mentored by a group of dedicated experts from industry, the university, and government who provided insights and assistance to the team by reviewing their work, providing guidance, and making suggestions for further investigations. This student/mentor philosophy proved to be very successful. Students gained confidence in design choices, were allowed to have primary responsibilities, and made mission critical decisions. In addition, students gained an understanding of the sounding rocket as one integrated system. These experiences created a strong feeling of "ownership" and pride within the student team.

5.2 Schedule

An important step in the success of HOMER was the foresight put into the overall project schedule. At the beginning of the project, subsystem teams were charged to produce a schedule of weekly and monthly tasks. Care was taken to ensure project milestones were realistic, and to include margin at each project phase. Progress was tracked so potential
schedule delays were highlighted as soon as they occurred. Figure 12 is a chart showing major milestones in the HOMER project schedule. HOMER was designed, fabricated, tested, and flown within two years. Development, prototyping, and build-up of payload components was accomplished in the first year. The following year encompassed subsystem integration, payload testing, and instrument calibration. Launch was late in the second year (August 12, 1996), followed by data analysis and publication.

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Figure 12: HOMER Project Milestones

5.3 Budget

Meeting the overall project budget was one of the greatest challenges for the HOMER team. Throughout the project schedule, trades were made between the level of mission success and cost. While the HOMER team continually tried to ensure a high level of mission success, there were times when the budget wouldn’t allow it. In these cases, the HOMER team depended heavily on donations of time, expertise, equipment, and labor. Industry partners and government labs were instrumental in the success of the HOMER payload. The following table shows a breakdown of cost for the HOMER project.

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<th>Budget Item</th>
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<td>HOMER Payload</td>
<td>$20,000</td>
<td>CSGC</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Donations (CCD chip)</td>
<td>$50,000</td>
<td>JPL</td>
</tr>
<tr>
<td>Donations (skin, nosecone, etc.)</td>
<td>$20,000</td>
<td>NASA</td>
</tr>
<tr>
<td>Person Hours</td>
<td>60,000 hrs</td>
<td>Students</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$90,000 + labor</td>
<td></td>
</tr>
</tbody>
</table>

Figure 13: HOMER Budget Summary

6. Lessons Learned

Upon completion of each student project at CSGC, the team conducts a “lessons learned” meeting to discuss possible areas of improvement, problems encountered during the project, and ideas or design strategies that were successful. This meeting is one of the most valuable tools for future teams, as they incorporate lessons learned on previous projects, thereby reducing the learning curve, and increasing the reliability of future designs. The HOMER team collaborated near the end of the project to identify, diagnose, and solve major system problems. The following list of lessons learned is a product of two years of space research and engineering.

- **Schedule Management** – The HOMER team found that meeting schedule deadlines, or planning schedule changes in advance, would have lessened time pressures and increased payload reliability. Integrated payload testing could have been better emphasized. An accelerated science payload schedule could have increased data accuracy by allowing time for pre-launch characterization and calibration.

- **Budget Management** – A single point of contact carefully monitored all purchases and updated the budget on a weekly basis, thereby preventing budget overrun.

- **Extended Team Management** – Better communication between extended teams could have eased timing and interface problems that occurred during integration.
• Personnel/CU Team Management – Good inter-team communication, productive meetings, and emphasis on incorporation of heritage and student experience led to the overall success of the HOMER project. More Computer Science and Electrical Engineering students, with experience in electrical and digital systems, could have eased the load on Aerospace students by facilitating design development of electrical systems.

• Documentation – The HOMER Interface Agreement and Design documents are invaluable in facilitating communication between team members.

• Contingency – Pre-planned budget and schedule margins allowed more money to be spent at critical schedule phases. In addition, time and money were saved early on by a willingness to descope when necessary.

• Integration and Testing Design – The whole team had a systems-level understanding of the rocket, enabling team members to fill in where and when needed.

• Integration Implementation – Most connectors were crimped, cutting down on time spent for wiring harness development. Implementation of specific problem-solving techniques allowed for quick diagnosis of problems.

• Spacecraft Hardware Design – HOMER’s modular design allowed ease of integration and assembly, enabled simultaneous work on separate subsystems, and facilitated trouble-shooting.

• Spacecraft Software Design and Development – Tiered software design was beneficial. More emphasis on software milestones could have alleviated schedule stress during final flight software development.

• Mission Objectives and Success Criteria – Tiered success criteria and heritage allowed the HOMER team to set, and later achieve, realistic mission goals.

7. Acknowledgements

On the cover of this paper, there is a picture of eight exceptional student engineers who are the “core team” largely responsible for the success of the HOMER mission. Their dedication to the HOMER project, patience in times of stress, long hours in the labs, and “five weeks and one day” at Wallops Flight Facility made the mission unforgettable. We are in the debt of Sean Dougherty -- Co-Project Manager and Structures Team Lead, Mike Grusin -- C&DH Team Lead, electrical guru, video expert, and Systems Engineer, Tony Colaprete -- Principal Scientist, Patrick Adam -- Structures Team Member and procurement expert, Linda Cuplin -- Structures Team Member and AutoCAD Goddess, and Brian Stuebe -- C&DH Team Member and XT Savior. We couldn’t have asked for a better team.

In addition to this core team, the success of the HOMER project would not have been possible without the dedicated efforts of many other students, faculty, and mentors. Donations of time, equipment, and expertise were made by many people at the university, in government, and in industry. We would like to thank the many students who comprised the HOMER team; faculty advisors and staff from participating Colorado colleges and universities; industry advisors; our dedicated and exceptional team of NASA engineers and technicians from Wallops Flight Facility; Director Elaine Hansen and the Colorado Space Grant College and Fellowship Program; and NASA.

The NASA Student Launch Program supported the work done on the High-altitude Ozone Measuring Educational Rocket.

8. Conclusion

The HOMER project was an outstanding success. With collaboration among colleges and universities throughout Colorado, the HOMER team was a multidisciplinary effort that provided an unparalleled educational experience for over 100 students. Data obtained from the flight provided local measurements of ozone, and constituents which affect ozone in the Earth’s atmosphere. HOMER demonstrated advanced and low-cost technologies that enabled these measurements. The HOMER student team demonstrated their capabilities of designing, building, and operating a complex rocket payload within a constrained budget and schedule. The new technology contributed to HOMER’s large data set, and provided an intercomparison of measurement techniques. Subsystem design gave students a unique educational opportunity for hands-on involvement in a real-world engineering setting. The ability to design and manufacture key subsystem components (such as software, circuit boards, and structural components) ‘in-house’ provided this
excellent learning opportunity and reduced the costs of production. Limited by a short schedule and small budget, students conceived, managed, designed, built, tested, and launched a payload that gathered significant science data. This pilot for the NASA Student Launch Program serves as a solid framework for subsequent student-developed payloads.

ENDNOTES


3 The Solar Mesosphere Explorer (SME) was a satellite mission conducted by NASA, Ball Aerospace, and CU-LASP. This satellite (operational from 1981-1989) gathered scientific data on mesospheric ozone, and reduced and analyzed these data. Many University of Colorado students were involved in the real-time mission operations of SME.

4 The Laboratory for Atmospheric and Space Physics (LASP) is a research organization located at the University of Colorado in Boulder. LASP has been an active participant in the U.S. space program since the early 1950's. Members of LASP conduct fundamental research in the atmospheric and planetary sciences, develop space instrumentation, and create computer information systems for space operations.


6 Background information for this section was obtained from: Riddle, Ellen and Sean Dougherty, et al. HOMER Mission Readiness Review (MRR) Document. 1996. Colorado Space Grant College, Boulder, Colorado.