A SMALL STUDENT-DESIGNED DESCENT PROBE

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ABSTRACT

The student-designed Venus descent probe team (V-Team) comprises two mechanical and three electrical engineering students. The team designed an aerodynamically stable instrumented descent probe that maintains structural, aerodynamic, and thermal integrity through release, descent, and landing. The probe is designed to freefall for a predetermined period of time before autonomously deploying a parachute for a survivable landing. The goal of the project is to demonstrate that a small, light weight, low cost instrumented descent probe designed to collect useful atmospheric data can be built with off the shelf components.

1.0 INTRODUCTION

1.1 Background

The Venus Instrumented Descent Probe is a University of Idaho senior design project sponsored by the NASA Ames Research Center in collaboration with the Idaho RISE (Research Involving Student Engineers and Educators) program. NASA Ames is one of the nation's premiere research centers. Its purpose is to conduct the fundamental research and technology development that make NASA missions possible. The client representing NASA Ames is Dr. Tony Colaprete. The Idaho RISE program is funded by the Idaho Space Grant Consortium (ISGC). The goal of Idaho RISE is to develop the capability to design, build, test, fly, and recover high altitude science and engineering instrumentation. The faculty advisor for this project is Dr. David H. Atkinson. NASA Ames and the Idaho Space Grant Consortium sponsored the NASA V-Team senior design group to design and implement the instrumented descent probe.

1.2 Objective

The NASA V-Team proposed to design a balanced and aerodynamically stable instrumented descent probe that would maintain structural, aerodynamic, and thermal integrity and survive impact upon landing. The NASA V-Team designed, built, tested, and implemented a data acquisition and data storage system. The acceleration data collected was used to illustrate the ability to derive temperature and pressure profiles.

1.3 Flight Procedure

The probe was designed to follow a pre-determined flight path. The flight begins with the launch of the balloon which carries the probe to 85,000 ft. At this altitude a microcontroller triggers a release mechanism to detach the probe from the balloon. Once the release mechanism is triggered data acquisition begins. All data is stored onboard and transmitted to ground in real time. The probe then free-falls for a specified period of time (≈ 120 seconds) before the microcontroller triggers parachute deployment. After parachute deployment, the probe continues data acquisition while descending to ground. The flight procedure is illustrated in Fig. 1.

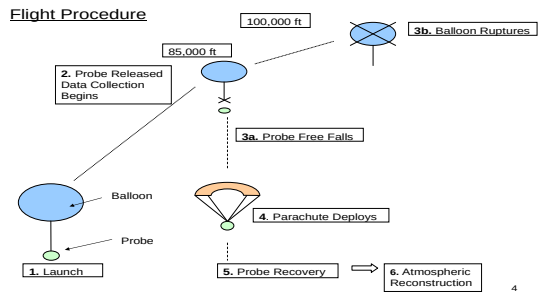

Fig. 1: Flight Procedure

2.0 PROBLEM DEFINITION

2.1 Client Needs

The client needs are highlighted in the list below:

- Perform atmospheric reconstruction using the acceleration data to obtain pressure and temperature profiles of the atmosphere.
- Use pressure and temperature sensors to compare and validate the pressure and temperature profiles derived from the acceleration data results.
- Include a telemetry system that transmits data from the probe to the ground.
- Write a detailed report containing an evaluation of the final product as well as results from the data reconstruction.
- Work within a budget of $2000.

2.2 Specifications
Tables 1 and 2 portray the project specifications for the NASA V-Team.

Table 1: Summary of Mechanical Specifications

Mechanical Specifications
Survive expected impact (velocity approximately 5m/s)
Aerodynamically stable (Pitch\Roll < 10º) for free fall descent
Reliable parachute deployment system (95% reliability)
Operate in low pressure (est. 21.3 mb at 26 km)
Operate in low temperature (-55ºC)
Position pressure and temp. sensors outside boundary layer
Minimize mass and size
Maximize free fall-time (≈ 120 sec minimum)

Table 2: Summary of Electrical Specifications

Electrical Specifications
Record 3-axis acceleration, probe orientation, temperature and pressure
Store sensor data onboard
Transmit sensor and GPS data to ground in real-time
Minimum sampling rate of 10Hz
Report position during flight derived from GPS (for tracking and recovery)
Detach probe from balloon at predetermined altitude (85,000ft)
Deploy parachute after free-fall

3.0 PRODUCT DESCRIPTION

3.1 Electrical

The electrical system features a single microcontroller. Fifteen of the ADC inputs of the microcontroller were used to input data from the instruments. The sensors package consisted of four accelerometers (1-3 axis, 1-2 axis, and 2-1 axis which yields seven measurements), three temperature sensors, two pressure sensors, and three gyroscopes. The microcontroller initiates analog-to-digital conversion of the sensor inputs every tenth of a second (10Hz). When analog-to-digital conversion is performed once for each of the 16 analog channels, a data packet of 32 bytes is formed. The first ADC channel is not used, so one data packet contains 30 bytes of useful sensor data. This data packet is transmitted through telemetry at 10Hz. The GPS data string received by the microcontroller is parsed to transmit altitude, latitude and longitude through the telemetry system at 1Hz. The data packet resulting from the analog-to-digital conversion is combined with the current altitude received from the GPS and saved in the external memory at 10Hz.

An additional GPS tracking unit was included in the final design to decrease the risk of losing the probe. The additional tracking unit is independent of the rest of the electrical system.

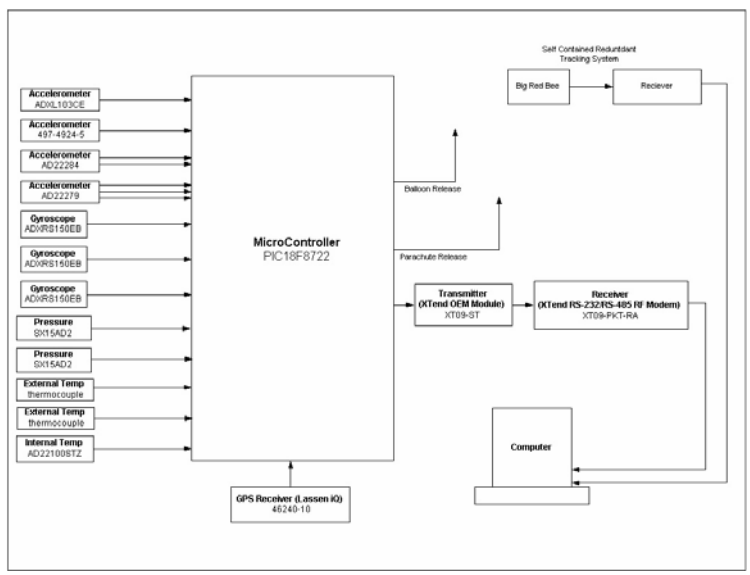

Fig. 2: Final Electrical Design

3.2 Mechanical

Following a prioritization and tradeoff study, the selected mechanical design comprises a spherical

geometry made from a plastic shell. The release mechanism consists of a nichrome wire heating element that burned through the cord(s) suspending the probe underneath the balloon. The parachute deployment mechanism consists of a mortar tube that upon triggering uses a controlled explosion to eject the parachute from the probe. The parachute design has a parachute with stability hole in the center for increased stability during descent. The pressure and temperature sensor arms are oriented in a cross pattern.

During the ordering and fabrication of the mechanical design, several problems and challenges with the selected design surfaced. These problems included the selection of a specific plastic material, the capability to machine the sphere shape, the mortar design, the parachute design, the orientation of the sensor arms, and the stability of the probe. These challenges are further outlined below.

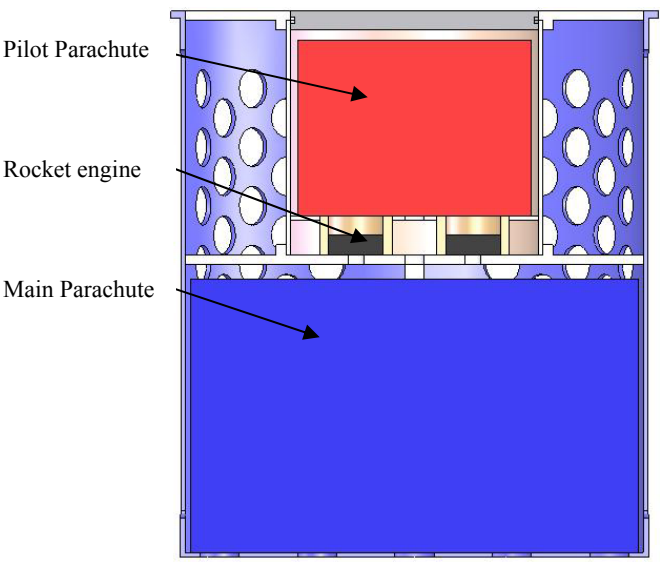

Fig. 3: Parachute Compartments

The first design decision the team faced was the selection of a probe material. After research, polycarbonate was selected. This material was a good choice because of its outstanding material properties for our application, including a high strength vs. weight ratio and a high fracture resistance.

Once we had selected a material for the shell, our team began to order parts. Our first focus was on the shell of the probe and it was soon determined that the University of Idaho machine shop was not capable of machining the desired sphere shape. The diameter of the shell was too big for the machine shop lathe. Also, if the shell was shaped from a large block of material then a large amount of waste would be produced. The team then began to look for available shells on the market that were injection blow molded. A 30 cm diameter prefabricated polycarbonate injection blow molded shell was selected for the probe body.

The next design change arose during the fabrication and testing process and required a modification in the parachute deployment system. The original design called for the parachute to be deployed by a large single mortar. However, after preliminary calculations and modeling it was clear that the size of explosion required to deploy the large (0.5 kg) parachute was not feasible for this project. The team then decided to use a smaller explosion to deploy a pilot parachute which would in turn deploy the main parachute. Standard model rocket engines were selected to deploy the pilot parachute and the rocket engines were modified to reduce the size of the blast. Also, even though one engine was sufficient, the new design called for two engines to deploy one pilot parachute for redundancy (Fig. 3).

Another necessary change was the parachute design. Originally, our design called for a round parachute with a hole in the center for added stability. However, the RISE class had a history of purchasing parachutes from a supplier that employed an alternative design shown in Fig. 4. This design is known for its stability and was a good choice for our team. [1]

Fig. 4: Parachute design

The next design change that the team made was to the shape of the sensor arms. Originally, the sensor arms were designed to place sensors outside of the boundary layer of air that surrounds the capsule during free fall. However, the dimensions that the arms needed to be were not known and the original design did not account for the velocity effects of air on the sensors. A new design was developed to eliminate the velocity effects and was molded after a standard pitot tube. This design is shown below in Fig. 5.

Fig. 5: Pitot tube

Once the fabrication process began it was determined that time constraints and lack of expertise prohibited the parts from being built as designed. Therefore, standard pitot tubes were purchased from a supplier. [2]

The final problem that arose in our project was the stability of the probe. To increase the stability and lower the center of mass we added a 0.5 kg lead weight to the probe and placed a battery pack (0.23 kg) at the bottom of the probe. These additions lowered the center of mass to the proximity of the sensor package (Fig. 6). Because a larger distance between the center of pressure and center of mass is desired to increase the stability of the probe we decided to add fins to the design. The idea was that the addition of fins would raise the center of pressure and further increase the stability of the probe.

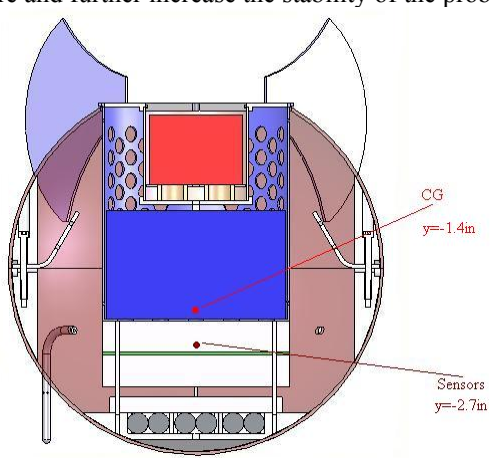

Fig. 6: Fins and Center of Mass

The finished probe design is shown in Figures 7 and 8. Several key features of the probe are: the shell, the parachute compartment, the pilot parachute compartment, the fins, the pitot tubes, the battery compartment, and the lead weight. More detailed pictures and explanation of the fabrication process of each part can be found on the V-Team website [3].

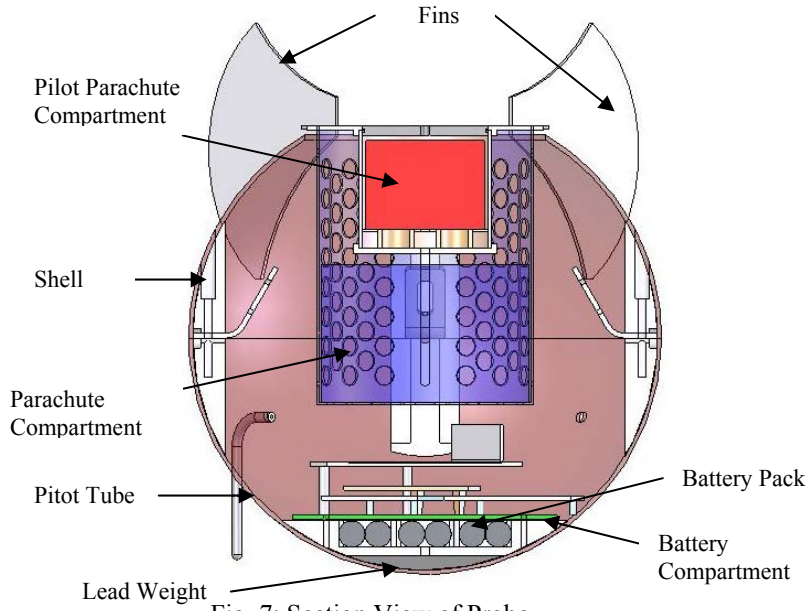

Fig. 7: Section View of Probe

The resulting probe is shown in Figure 8 and the finished electric equipment is shown in Figure 9. Additional pictures of the probe and testing processes can be accessed on the team's website. [3]

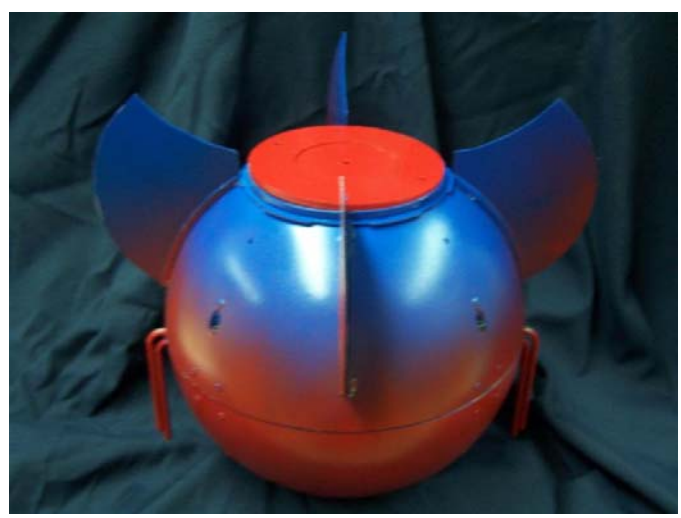

Fig. 8: Finished Probe

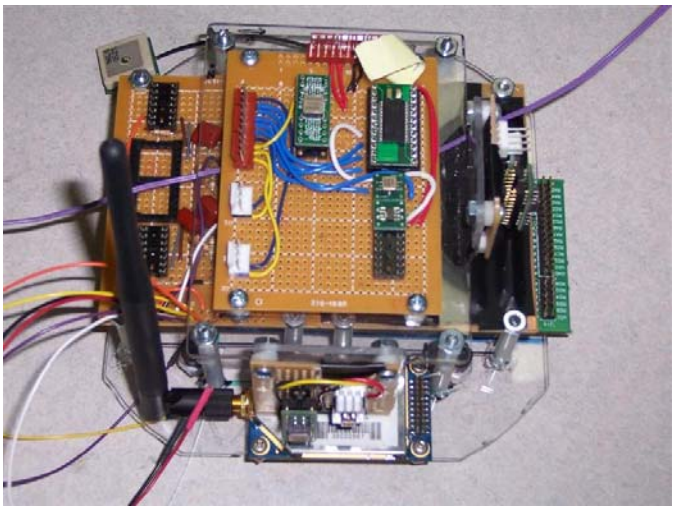

Fig. 9: Completed Electrical System

The V-Team probe design will continue to evolve as the Idaho RISE team continues to refine the electrical and mechanical design. Ultimately this will lead to a complete working probe that can demonstrate the use of acceleration, and pressure and temperature data to accurately reconstruct the profile of the atmosphere, and the probe descent trajectory.

4.0 UNRESOLVED ISSUES

A number of remaining open issues remain must be addressed prior to flight.

4.1 Tracking system

The tracking systems have not been fully demonstrated. The units themselves have been verified to be completely functional when operating external to the probe. However, once the GPS units are integrated into the probe they have difficulty receiving satellite signals. Relocating the antennas, possibly external to the probe, will improve the performance of the GPS units.

4.2 Telemetry system

The telemetry system has been verified to be fully functional in lab and during moored launches. However, the system has not yet been range tested. It is recommended that the system undergo extensive range testing prior to launch.

4.3 Balloon release mechanism

The balloon release system was demonstrated in lab testing, but failed during moored flight tests. In the first moored flight the failure of this system was due to an external connection failure. In the second moored flight, the release mechanism worked, but because of a programming error the nichrome wire was heated at the wrong time.

4.4 Parachute release mechanism

The parachute deployment system was successfully demonstrated in lab testing. The microcontroller successfully burned fuses at the correct times. The team also successfully tested the deployment of a pilot chute with a single rocket engine that was manually triggered. However, the parachute deployment mechanism failed during moored testing. This failure is believed to have been caused by a fuse failure when the components were integrated. The fuse likely failed or was broken when it was inserted into the rocket engine. Also, a failure could have occurred due to connection shorts when the probe was assembled.

4.5 Main parachute deployment

One of the major concerns in the project was the deployment of the main parachute by the pilot parachute. Our design called for the pilot parachute to be deployed by rocket engines. The pilot parachute was then designed to pull its compartment out of the probe and then deploy the main parachute. However, this deployment has not been tested. Additionally, concern was raised following the results of thermal testing. After the probe had been exposed to -20ºC for two hours the force required to deploy the pilot chute compartment from the probe was measured to be 3.6 kg. From wind tunnel testing, the pilot parachute could only generate 3.4 kg at the time of deployment. Further testing is required to gain confidence in the design.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of this project demonstrate that a small, light weight, low cost instrumented descent probe designed to collect useful atmospheric data can be built with off the shelf components. From our research we believe that low cost microprobe entry science technology for planetary atmospheric science is feasible within the near future. The V-Team encountered many of the challenges that engineers face when attempting to develop miniature, low cost, descent vehicles, including aerodynamics, power, mass distribution, sensors (type, location, and configuration), and environment (pressure, temp) considerations. Some of the challenges were addressed by utilizing commercially available (off the shelf) components, lightweight materials, and mass reduction techniques.

The aerodynamic design of an entry probe is one of the critical factors due to the high velocity probes have when entering an atmosphere. This speed must be reduced quickly in the upper atmosphere in order to avoid unmanageable heating and accelerations that would occur if the high speeds were maintained down to the dense lower atmosphere. To most efficiently dissipate the energy of entry, entry probe aeroshells are designed with blunt bodies. The descent probe themselves, however, are often spherical or near-spherical in shape.

The V-Team probe's initial velocity is zero, so heating is not a major consideration in the aerodynamic design of the probe. However, the probe shape is still critical to the success of the design because one of the goals of the project is to construct the density, pressure, and temperature profiles of the Earth's atmosphere based on acceleration data. The more accurately the aerodynamic behavior of the probe is, the more accurate the atmospheric profiles will become. This consideration lead to selection of the spherical probe since the aerodynamic behavior of a sphere is the best understood of all geometries considered.

Another factor in the design of entry probes is the power supply and usage. Batteries are relatively heavy and their size is proportional to the power required. So the lower the power consumption of the instrumentation packages the lower the battery's mass. For the V-Team probe this was not a major problem because MEMS sensors and a low power microprocessor were used. Modern electronics continue to become more miniaturized and consume less power. If the space industry can certify this technology for space flight, entry probes can easily become smaller and possibly less expensive.

Traditionally engineers have thought of entry probes as vehicles for the instruments they carry. As entry probes get smaller and less expensive, engineers and scientist may start to view micro and pico probes as instruments in themselves. This shift in thinking may change the way engineers and scientist design and deploy entry probes in our solar system, and in turn will enable the collection of significantly more atmospheric data which is needed to further our understanding of the bodies in our solar system.

6.0 REFERENCES

[1] The Rocket Man. 1 Feb. 2006. Rocketman enterprises, inc. http://www.the-rocketman.com/

[2] Aircraft Spruce and Specialty Co. 1 March 2006. http://www.aircraftspruce.com/

[3] NASA V-Team website: http://seniordesign.engr.uidaho.edu/2005_2006/nasavteam/

7.0 SPECIAL THANKS

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