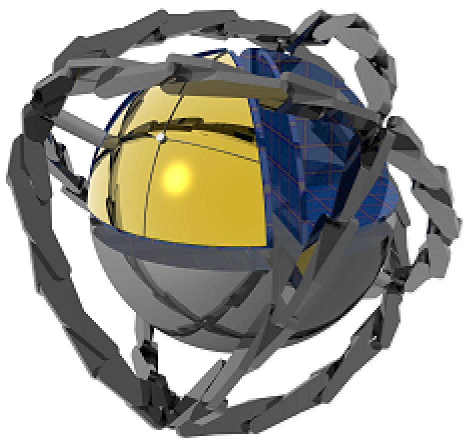
Martian Weather Station

Colorado School of Mines



Team ARES

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1. ABSTRACT

As the Earth's population continues to grow and resources continue to dwindle, humankind has looked to other planets for possible colonization. With current technology, colonization of Mars is the most viable option. Although general facts about Mars are known, such as its low temperatures, low pressure, and atmospheric density, more specific information is needed. To this end, team ARES from the Colorado School of Mines has designed a module to measure atmospheric conditions. Our module is capable of measuring temperature, pressure, wind speed, and particle concentration.

The module will take measurements every minute and the data will be transmitted twice daily to an orbiting satellite. In order to provide overlap in case of interference during transmission time, because of occurrences such as dust storms, the data will be stored for 24 hours.

Our design is an expanding modular structure, similar to a Hoberman Micro Sphere® by Hoberman Designs, Inc, in which the instruments are protected from the harsh atmospheric conditions yet are still able to take measurements. The interior will consist of eight octants. A rod attached to opposite sides of the frame expands upon landing, opening the frame. A swivel mechanism at the middle of the rod allows the octets to orient themselves. The bottom four octets will house the instruments, computer, and batteries while the top four will be solar panels and have the antennae.

This design is adaptable to various shell designs; also, it is both strong enough to survive and able to orient itself after deployment.

2. INTRODUCTION

This project originated from the Colorado Space Grant Consortium and Ames Research Center. Dr. Knecht, head of the Design (EPICS) Program at CSM, assigned the task of designing a weather station for Mars to the students of the EPICS program. The weather station must be able to measure:

- Temperature
- Atmospheric Pressure
- Wind Speed, and
- Particle Concentration

In the fall of 2001, team ARES designed an expanding module based on the specifications given in Table 1 after considering several possible shapes.

Table 1: Client Specifications

Specification	***Value***
Volume	2000 to 3000 cm^3
Distance Covered	100 kg^2
Operations	24 hours
Transmission	Twice daily
Data Storage	24 hours to provide overlap
Strength	Must withstand impact with the surface
Shape	Unspecified

The module must be strong enough to withstand impact, but, according to the client, will be housed in some sort of shell that will absorb most of the impact. Team ARES also had to address the issues of power, heat, and transmission. The module must have a transmission system able to send data to an orbiting satellite system; however, no specifications were provided for such a system, our team has stipulated certain requirements for the satellite such that our transmission system will be able to send data to it.

3. APPROACH TO THE PROBLEM

The first thing we did when given the problem was to brainstorm general ideas. Our main concern at this time was the limitations involved. First, we researched general facts about Mars and its climate and atmosphere. In comparison to the Earth's climate, Mars has very low temperatures and pressures, a thin atmosphere, and is subject to severe dust storms. So, one of our problems was to research instruments that would function under these conditions. The values in Table 2 were used in all the calculations.

Table 2: General Mars Data [1,2,3]

Properties	
Maximum Surface Temperature:	25 °C

Minimum Surface Temperature:	-125°C
Surface Pressure:	6 millibars
Composition of the Atmosphere:	95% Carbon 3% Nitrogen 1.6% Argon
Diameter:	6792 km
Distance from the Sun:	228,000,000 km
Density:	3940 kg/m^3
Surface Gravity:	3.7 m/s^2

Next, we considered the actual shell and deployment of the module. We felt that it should be able to guarantee an orientation such that the devices could take measurements as well as transmit the data to the satellite. Since the maximum volume was so small, we decided to focus on designing a shell module that would give a maximum amount of space in which we could place the instruments.

3.1 Shell Design

We decided that the best design would be one that expanded upon landing. One possible design would be a cube shaped module that opens up after landing and lies flat on the surface. Another design would be shaped like a pyramid, which would also unfold after landing. A third is just a simple sphere. The main problem with the spherical design was that there was no way to prevent it from rolling after it landed. Although the cube and pyramid design would remain stationary after landing, neither optimized the maximum allowed volume nor guaranteed correct orientation. So now the problem became how to make a spherical module that would remain stationary and guarantee orientation. We decided that the best design would be an expandable sphere that will allow the instrumentation to deploy with the proper orientation (see Table 3).

Table 3: Module Shape Decision Matrix

	Maximize Volume	***Ability to easily fit into a Shell***	***Stationary After Landing***	***Space for Instruments***	***Total***
Cube	8	7	10	7	32
Pyramid	5	4	10	4	23
Sphere	10	9	3	6	28
Hoberman	10	8	8	10	36

The sphere's geometry is similar to that of the Hoberman Micro Sphere® [4] by Hoberman Designs, Inc. The frame includes an axial, spring-loaded shaft that allows it to expand after deployment and a swivel mechanism that allows it to orient itself. Thus, after deployment and expansion, the module is able to remain stationary. However, should something happen, such as being moved by the dust storm, the swivel mechanism would allow the module to correct its orientation.

The frame has a collapsed radius of 8.95 cm and an approximate expanded radius of 13.35 cm. The swivel mechanism, located at the midpoint of the shaft, provides the instrumentation housing with 360° spherical rotation. The mechanism consists of an axial cylinder for rotation around the axis and mounting pegs for rotation along the axis.

The framework divides the instrument housing into eight separate lobes, each lobe having an approximate working volume of 375 cm^3. The upper four lobes will be used for solar power collection, while the bottom lobes will house the instruments, batteries, CPU and Data Storage. This modular design gives us an advantage by allowing us to insulate and heat each lobe to a different temperature, depending on the instrumentation requirements, and separate heating allows us to minimize unnecessary power usage.

As for construction material, we will use an Aluminum-Lithium alloy similar to those used in many current aerospace and cryotank applications. Specifically, McCook Metals Weldalite™ 049 Aluminum-Lithium Plate [5] is ideal because of its high strength, fracture toughness, corrosion resistance, and low density

3.2 Components

After we decided on a module design, the next step was to research instrumentation and components. We discovered, upon research, that there are a limited number of instruments that will function under Mars atmospheric conditions. We narrowed our research to finding types of instruments that would function.

Initially, the following are components we felt would work. One year ago, these are the components we felt would be most suitable.

3.2.1 Computer

This component interfaces with the rest of the instruments as well as handling data storage. The best data processor we found was the Sharp LH75410 microcontroller, which was designed for industrial use and can withstand a harsh environment. It is able to handle converting the analog signal from the instruments to a digital signal and contains a timer to control when to take measurements and when to transmit to the satellite. It also contains several serial interfaces to communicate with the transmission device. The storage aspects of the module will be handled by a Sharp LRS1331 chip also designed for use in industrial applications; thus it is highly resilient to extreme surroundings. This chip has enough storage to hold data for about 1300 days of measurements each minute, as well as the functionality program [6].

3.2.2 Thermometer

For a thermometer, we looked at the Thermometrics CTFP10 thermal resistor [7]. Although there are many on the market that meet the requirements for our module, not all of them are guaranteed to function properly under the conditions within the range required for our purposes. A thermal resistor is basically a loop of wire connected to a resisting material that reads temperature by changing its value of resistance as the temperature changes. As the temperature changes, the electrical current is allowed to flow at different rates. However, this simple design is more durable and reliable than other types of thermometers, and it costs far less. Most important though, thermal resistors do not sacrifice accuracy at all. In fact, for the cold temperature range expected on Mars, thermal resistors are among the most accurate devices for temperature measurement.

3.2.3 Barometer

We were unable to find any barometers that both meet the requirements and were also guaranteed to work under Martian conditions. Any available barometer we chose would have to be modified, and thus we decided the Paroscientific model 215A [8] would be easiest to modify to meet our specifications. This pressure sensor applies quartz crystal resonator technology to measure changes in the atmosphere. As the pressure changes a small vibrating crystal inside the barometer changes its oscillating frequency. This barometer is designed to work at low pressures--less than 1500 millibars. Even though this range is relatively low compared to those of other barometers, it will still not be low enough for Martian pressures, which are typically around 10 millibars. If we can modify this barometer to work at lower pressures, possibly by changing the size or shape of the oscillating crystal, it would be accurate enough to provide useful data.

3.2.4 Anemometer

We chose to use a constant temperature type of anemometer, which will operate by running a current through a film or wire to maintain a constant temperature. As wind blows across the film or wire, more current is needed to maintain that temperature and the change in current is converted to wind speed [9]. Wire anemometers tend to be more accurate, but hot film anemometers are more durable. Since our module must gather data for at least one year, we chose to use the hot film type. Since the wind speeds on Mars are not higher than 40 m/s, we do not have to worry about the film overheating [1]. We evaluated Model 1230 from TSI, Incorporated, which has a thin film of platinum on an Alumina substrate and an automated calibrator to attach to the probe. Because the hot film anemometers have no moving parts and can be attached to the frame of the weather station, this type of anemometer significantly reduces the possibility of broken parts. Platinum films have a wide range of operating temperatures, thus reducing the concern over that Mars' low temperatures would affect operation [10]. Constant temperature anemometers were used on the Viking expedition to Mars [9], and in the upcoming 2003 Beagle mission, hot film anemometers will be used [11].

3.2.5 Particle Detector

We chose to use the Microdust Pro™ probe [12] manufactured by BGI, Inc., which is an aerosol photometer. The system emits an infrared beam and uses a near-forward light scattering technique to measure TSP (total suspended particulate matter) in milligrams per cubic meter. The beam passes through the volume of air being sampled where the light is scattered by dust particles. A photo detector picks up the scattered light where the signal can be converted to a mass concentration.

While taking static measurements, the probe must be connected to an air pump to pull a sample volume through the instrument and to keep dust from settling on the lenses [12]. Sensidyne, an air sampling company, manufactures pumps that are ideal for this process [13].

3.2.6 Heat

Logic is written into the central process to determine if any excess power is being generated by the solar panels and also if there is over a 10% excess in expected battery power consumption. Any such excess power, along with an allotted amount of power, will be used to heat the module in order to keep the temperature in the lower octets within the operational temperature of the components they contain. The lower four octets are equipped with insulation and heating elements to accommodate their requirements. Each octet has different requirements and components in each octet radiate variable amounts of heat when in operation, so the central processor takes control of heat management. Finally, space is allotted in both octets for voltage control and management circuitry, as there are two different voltages required for operation of the module and both batteries and solar panels provide widely variable voltages.

3.2.7 Power Consumption

The power consumption for the module ranges is widely based on its mode of operation. The module will take readings every minute. Therefore, the sensors will only need to be operational for a short fraction of each minute. When the module is not taking measurements, the sensors are turned off and the computer is put into nap mode. The module's third cycle is transmission. In order to provide for the power needs of the module, a system of solar panels and batteries has been implemented.

3.2.8 Solar Cell

The top four octets of the module are based around solar panels. While there are four octets, not all will be exposed to the sun at any given time. Modern, commercially available solar panels range from 10% to 14% efficiency and specialty panels made by companies such as Boeing created 26% efficiency panels in 1999, expecting it to rise to 40% by 2002 [14]. To meet the power requirements of our module, any commercially available panels will suffice, assuming they are able to operate in the Martian environment.

3.2.9 Batteries

To accommodate operation when the module is not exposed to the sun, and when the power demand exceeds what the solar power can provide, such as during transmission, a series of batteries will be used. They are located in two bottom octets of the module, opposite each other to balance their weight when the module is orienting itself. The batteries should be able to provide the majority of the power so that if severe dust storms block sunlight or some of the solar cells are damaged, the module can still function. Furthermore, whenever the solar power makes it possible, no load will be placed on the batteries. This will minimize cathode freeze-over, which can dramatically affect battery life over long periods of time [15, 16].

3.2.10 Radio/Transmission

The transmission device we looked at is a dual crystal controlled UHF transmitter made by Radiometrix, part number TXM-418-10. This transmitter will be combined with a low power amplifier and a dish antenna and will be used to transmit the data collected by the instruments. The amp will consume no power when idle. Twenty-four hours of data, at 16-bit accuracy for each measurement, taken once every minute will occupy 11.25kb of space. Thus, the transmitter ideally would be capable of sending data at 45kb/s, yielding an actual data output of about 10kb/s, so that it would be able to transmit all of the data collected, as well as have enough room for protocol overhead and still be able to transmit, even through moderate interference fields [17, 18].

4. RESULTS

However, after considering the overall design and instrumentation of our module and making a computer model, we found several flaws. While all of the instruments are small, we found that when put together in the module with the batteries, the octets were barely large enough to hold all the components. This left little room, literally, for adjustments. Although we liked the concept of how the components functioned, the components were not satisfactory. Thus, we decided to keep the shell design and the type of instruments, but change the instruments themselves wherever possible. We feel that these are the instruments that best meet the requirements.

4.1 Computer

The data processor we are now considering is the S3C44B0X 16/32-bit RISC microprocessor by Samsung, which is based on a 16/32-bit ARM7TDMI RISC CPU core (66MHz) designed by Advanced RISC Machines, Ltd. [19]. This processor is square in shape, with dimensions of approximately 26.0 mm x 26.0 mm. There are four operating modes: Normal, Slow, Idle, and Stop, but the processor will be in either Normal or Idle for the majority of the time. During Normal mode it will consume up to 235 mW but less than 5 mW when Idle. It handles converting the analog signal from the instruments to a digital signal using its 8 input, 10-bit Analog-to-Digital (A/D) converter. The data processor also contains a timer to control when to take measurements and when to transmit to the satellite. It also contains several serial interfaces to communicate with the transmission device. Finally, it contains Direct Memory Access (DMA) channels to communicate with up to four banks of memory [19].

A memory chip [6] attached to a DMA channel will handle the data storage. It has both volatile and non-volatile memory, so it can handle the operation and storage aspects. The amount of data (collected, stored, etc.) in one-day amounts to approximately 57kbit, assuming data is taken once every minute.

4.2 Instruments

4.2.1 Thermometer

For the thermometer, we will be using Honeywell's model HEL 700 T1A. We are using this model instead of the Thermometrics model because it is smaller and is better able to accurately measure the low Martian temperatures with better accuracy. This is a Thin Film Platinum Resistance Temperature Detector (RTD). These operate by running a current through the film and measuring the resistance, which can then be used to calculate the ambient temperature by the equation

$$R_T = R_0(1 + AT + BT^2 - 100CT^3 + CT^4)$$

where R_T is the resistance (Ω) at the ambient temperature (°C), R_0 is the resistance (Ω) at 0°C, T is the ambient temperature (°C). The constants A, B, and C are calculated from the equations

$$A = \alpha + \frac{\alpha\delta}{100}$$

$$B = -\frac{\alpha\delta}{100^2}$$

$$C_{T<0} = -\frac{\alpha\beta}{100^4}$$

For the 1000Ω thermometer, these constants are provided in the table below.

Table 4: Constant Values for 1000Ω Thin Film RTD [20]

Alpha (α) ($°C^{-1}$)	0.003850 ±0.000010
Delta (δ) (°C)	1.4999 ±0.007
Beta* (β) (°C)	0.10863
A ($°C^{-1}$)	3.908×10^{-3}
B ($°C^{-2}$)	-5.775×10^{-7}
C* ($°C^{-4}$)	-4.183×10^{-12}

*For T>0°C, β=0 and C=0

For our thermometer, both the operating and storage temperature range from -200°C to 500°C. The range of temperatures found on Mars is -125°C to 25°C, so this thermometer will easily be capable of operating on the Martian surface. This thermometer also has high accuracy, with a ±0.1% error.

We will use the Honeywell HEL-700, whose dimensions are 1.90 mm by 1.27 mm. There will be one thermometer inside each octet for heating purposes and one on the outside of the module to take measurements. With an operating current of 1 mA (2 mA maximum), this thermometer will require very little power to operate [20].

4.2.2 Anemometer

For the anemometer we will use two Honeywell HEL-705-T-1-5-C3 models, the HEL-705-U-1-5-C3 and HEL-705-T-1-5-C3. These models are similar to the thermometer but will be connected in such a way that allows them to measure wind speed. These models measure wind speed using the hot film anemometer concept we were originally considering. They are Teflon coated with three point NIST calibrators so their accuracy is 0.01%, which allows the detection of much smaller wind variations.

The U1A model has a resistance of 1000Ω and the T1A model has a resistance of 100Ω. These will be connected in a bridge configuration in which current self heats the smaller resistor. We then look at the equation

$$T = T_{amb} + \Delta T$$

where T can be found from the resistance. As T_{amb} changes, the larger resistor compensates so that ΔT does not change. The power required to keep ΔT constant can be related to wind speed.

For these thermistors, both the operating and storage temperature ranges are from -200°C to 500°C. The range of temperatures found on Mars is -125°C to 25°C, so the anemometer easily is capable of operating on the Martian surface. Since the wind speeds on Mars are no higher than 40 m/s and the atmosphere is so thin, we do not have to worry about the films overheating. The operating current for each resistor is 1 mA, with a maximum of 2 mA. Since the current stays the same, and only the resistance varies, the anemometer should not draw more than 4 mA of current. Thus, little power will be consumed during operation [20].

4.2.3 Barometer

For the barometer we will be using the Honeywell 40PC015G1A. It uses Silicon Piezoresistive Technology, which is a silicon pressure sensor. The device consists of thin chemically etched silicon wafer with piezoresistors buried in it. As the pressure changes, it causes the wafer to flex. This results in a strain on the resistors, which produces an electrical output.

The Honeywell 40PC015G1A has a range of 0-15 psi (0-1 bar), with an accuracy of 0.2%. Its operating temperature is –45°C to 125°C and its storage temperature is -55°C to 125°C. All of these specifications are important to our module for several reasons. The average surface pressure of Mars is 0.087 psi. The average pressure on Earth at sea level is 14.696 psi (1 atm), so this barometer will be able to measure the comparatively low pressures on Mars. The temperature for both the storage and operating of the device are low but still not quite low enough to operate on Mars. So in order to accommodate the barometer, it will be inside a heated portion of the module, with only the small port exposed to the atmosphere. The Honeywell 40PC015G1A needs about 5VDC of supply voltage and 10mA max supply current. Thus, the barometer will not drain much of the limited power supply. The barometer is also small in size, which makes it appropriate for the module. The dimensions are 30.9mm x 13.2mm x 19.8mm. Since it is so small it will fit in the module wherever it will take the best measurements [21].

4.2.4 Particle Detector

Since off-the-shelf particle detectors do not meet the criterion for our module, we will be using a particle detector that is based on the concept used in three manufactured models. These models are the Microdust Pro™ by Casella USA, Haz-Dust III™ Particulate Monitor by SKC® Inc., and the DustScan Scout Model 3020 Aerosol Monitor by Rupprecht & Patashnick Co., Inc [22, 23, 24].

These devices use near-forward light scattering technology (N-FLST) to measure TSP (total suspended particulate matter) in milligrams per cubic meter. Our prototype contains a laser diode, which emits a visible beam (630-680nm). As the beam passes through the volume of air being sampled, the light is scattered by dust particles with a barrier to block directly transmitted light. A photo transistor picks up the scattered light where the signal can be converted to a mass concentration. The approximate range of our system, based on the specifications of the three previous models, is 0 to 2500mg/m^3, with a resolution of ~0.001 to 0.1 mg/m^3. This instrument will operate at ~2.5 V and draws approximately 60 mW.

4.3 Heat/Insulation

To heat the bottom octets, which house the instruments and batteries, we will use a standard heater. This will be regulated by the computer and thermometers placed inside each octet. The octets will be heated to at least –35°C.

Mars' surface temperature varies from 0°C at noon –120°C at night, which we found from the measurements of a currently orbiting satellite at Mars' equator. Our module must be at 0°C during the day while the batteries are charging and no less than -35°C at night. Each octet will be independently heated in order to conserve power. The heat lost from our module goes through 2 mm of insulation, 3 mm of shell and then encounters the heat convection of the Martian atmosphere directly outside the module. Based on this, we made a simulation using the inside temperature, outside temperature and the equivalent thermal circuit of the three materials to calculate the heat flux. We calculated an average heat loss of 0.876 W. Figure 1 in Appendix A shows the heat loss over a 24-hour period [25].

We are using the CryoCoat™ UltraLight™ made by Composite Technology Development, Inc. This is a modification of their CryoCoat™, a spray on cryogenic insulating element. CryoCoat™ is a

> 2-part epoxy system that utilizes microspheres as the acting insulating component…noted for its excellent adhesion to almost any substrate, high toughness even at cryogenic temperatures, and a specific gravity of nearly 1 (~60 pounds per cubic foot [pcf]). [26]

The UltraLight™ versions of the insulators have an even lower specific gravity of less than 0.2 pcf. They consist of three layers, an adhesive layer, the CryoCoat™ UltraLight™, and a protective coating, which keeps out moisture and is fire-retardant.

This material also has a low thermal conductivity. According to tests performed by Composite Technology Development, Inc. CryoCoat™ is the best insulation in many ways. For instance, a tensile test was conducted with aluminum and carbon composites, each at 77 K and 4 K. While the UltraLight™ insulation had cracking for the carbon composites, it was shown to work very well for the aluminum. At 77 K, the higher temperature, the substrate yielded, while at 4 K, it had no failure. The poor performance on carbon composites should have little to no effect because we will be using an aluminum lithium alloy for our module. This product will be used to insulate all of the instruments, batteries and data storage devices, which is necessary in order to keep all of the devices working in the harsh climate of the Martian planet.

To protect the instruments from radiation, second surface aluminized polyimide tape with acrylic (966) adhesive from Sheldahl will be applied to the interior of the lower octets. The polyimide thickness ranges from 12.5 to 127 μm and the aluminum coating is approximately 1000Å thick. Standard width sizes are from one to four inches, but it may be ordered in any width. The continuous temperature range is from –60°C to 150°C, but the bottom octets will be heated to at least –40°C [27].

4.4 Power Consumption

In order to calculate the power consumption we wrote a computer simulation to model the module as it collects data every minute. The simulation included a list of the equipment in the module and determined whether or not any one would be on at any given time. Both the sleep and alive power consumption of each piece of equipment were taken into account. The number .0398 W was calculated as the average consumption of power due to electronic components. The majority of the power will be consumed during transmission. Since the antenna is a half wave dipole, we approximated the gain to be 3 dB on the satellite and the module. The maximum distance that the module will have to transmit is 1695 km. Using this distance and a frequency of 2.4 GHz, we calculated the loss of free space using the equation

$$LossofFreeSpace = 32.45 + 20\log(d_{\max}) + 20\log(f)$$

which gives a loss of 164.6 dB.

We assumed that the receive sensitivity is –95 dBm and the satellite sensitivity is –120 dBm. Then we calculated the power received by the radio with

$$-120 = 10\log\left(\frac{P_r}{0.001}\right)$$

The satellite needs 1E-15 W to receive the transmission. From there we were able to calculate the power the antenna requires during transmission.

$$2 \cdot 3dB - 164.6dB = 10\log\left(\frac{1\times10^{-15}}{P_{antenna}}\right)$$

For a 2.4 GHz system, 7.24 W are needed. Using these same equations, the desired frequency of 1.4 GHz would need 2.51 W, which would significantly reduce overall power consumption [28, 29].

4.5 Solar Cells and Batteries

Our main source of power will be solar cells. The solar panels that we will be using are 26.8% Improved Triple Junction (ITJ) Solar Cells made by Spectrolab Inc. These are “active, radiation-hard solar cell junctions” that are cut to customer specification by the company [30]. We will use quarter-circle shaped cells, which will be attached to the surface of the top four octets of the module. Since the cells cannot be cut to exactly the measurements of the module, we have estimated approximately 90% coverage.

The solar panels have a minimum average efficiency of 26.8% at maximum power [30]. The panels are composed of three layers of Gallium based material to for maximum efficiency. We assumed a Magnesium Fluoride anti-glare coating. As well as providing most of the daylight power, they will also be used to charge the batteries so the module will have power overnight.

We calculated the power from the solar panels by making a program that simulates one complete orbit of Mars around the Sun. The program takes into account such things as the elliptical orbit and the tilt axis. It assumes that the module is located at the equator, and takes into consideration the vectors between the Sun and the module, the reflective coefficient, and the reflection due to the angle.

Assuming that the light is equally polarized and using one of Fresnel’s equations

$$t_{//} = \frac{2n_i \cos\theta_i}{n_i \cos\theta_t + n_t \cos\theta_i}$$

where n_i, the refractive index of magnesium fluoride, is approximately 1.38 and n_t, the refractive index of Mars’ atmosphere, is approximately 1.00. Since the pressure and density are very low, we assumed vacuum like conditions. From Fresnel’s equation we calculated the coefficient of transmitted energy, $T_{//}$

$$T_{//} = \frac{n_t \cos\theta_t}{n_i \cos\theta_i} \cdot t_{//}^2$$

Using an average solar constant of 622 W/m^2, we found the power generated by the solar panels

$$P = T_{//} \cdot 622W/m^2 \cdot \cos\theta_i$$

During daylight hours, the solar panels will provide 2.6 W, which averages out to 1.3 W of continuous power over a 24-hour period (see Appendix A) [31].

We will be using Lithium-ion batteries. They come in a variety of sizes and can be specially designed. The best option would be a shape that maximizes the volume of the octets.

4.6 Radio/Transmission/Antennae

For our radio transceiver, we will use the Honeywell HRF-ROC094XC. It is a "half-duplex transceiver" that can be used for digital applications. The chip is used for both control and data transfer using the microprocessor. Data rate of the chip is 128.8 Kb/sec. The Honeywell HRF-ROC094XC has an operating temperature of –40°C to 85°C and a storage temperature of -40°C to 150°C. Since Mars has a low temperature of –125°C and both the operating and storage temperature have a low of –40°C it will be necessary to insulate and heat the chip in order to keep it in operating condition. It operates from a 2.5V power supply, which consumes little of the restricted power that we have available. The optimal frequency to transmit data is 1.4 GHz, but this radio transmits at 2.4 GHz. None of the radios on the market will transmit at 1.4 GHz because it is a licensed frequency. Although 2.4 GHz is feasible, transmitting at 1.4 GHz would significantly reduce power consumption from 7.24 W to 2.51 W.

We will use half wave dipole antennae for our module. It will be folded inside the module and after the shell expands the antennae will unfold. There is a gold reflector attached to one of the top octets, which will rise after the frame expands. Extending vertically from the reflector is a pole that rises to 4.46 cm away from the reflector in order to have maximum transmission pattern. Attached to the end of the pole are two 5.94 cm dipoles at 90° to each other and curved parallel to the sphere. We calculated the height of the pole by using a gain pattern that would give us the maximum transmission time. The gain pattern is elliptical, with a dip in the middle. Although the signal is slightly weaker in the middle, this gain pattern allows the module to communicate during more of the satellite's orbit than a circular gain pattern. According to the gain pattern, we calculated the optimal pole height for 2.4 GHz from the relationship

$$h = \frac{3}{8}\lambda$$ [29, 31]

The satellite orbiting Mars will have to be more powerful than our radio in order to properly transmit data. We calculated the amount of time the module will be in contact with the satellite, which is approximately 17 minutes. We calculated this time frame by calculating the satellite's orbit time, assuming it is 400 km above the surface of Mars. We then found the acquisition circle radius of the module. From that, we found the arc length on Mars and the angle of the arc length. By projecting that angle 400 km above Mars' surface we were able to calculate the transmission time. However, these calculations were made assuming a perfectly smooth sphere. For more detailed calculations and equations see the Appendix B [32].

The satellite will be sending out beacons, which will be picked up by the module when the satellite is within contact range. The first beacon the module picks up can then be used as a reference for when transmission can begin. We will use packet-based transmission to send the data to the satellite. This will work by sending little packages of data and waiting for confirmation from the satellite before the next packet is sent. We plan on losing some packets in the transmission but there will be enough time to resend lost packets. Weather disturbances, such as dust storms, will prevent the module from transmitting data but the data storage in the computer will be able to store this information until the next transmission window.

4.7 Shell

The frame is made from an Aluminum-Lithium alloy, with 2.6% Li, which has a high ductility, good damage tolerance, and good corrosion resistance compared to other Aluminum alloys. It also has a lower density than pure Aluminum. It is commonly used in space applications such as the fuel tanks for space shuttles. Alcoa, Inc. manufactures such an alloy (Alcoa 2090) that meets our requirements [33].

The frame has a collapsed radius of 8.95 cm and an approximate expanded radius of 13.35 cm. To find the dimensions, we wrote a computer model (see Appendix C). The frame expands upon deployment because of a spring-loaded axial shaft. A swivel mechanism guarantees orientation due to gravity. The complete inner mechanism includes small pathways for wiring. There are several possible ways to build it depending upon the strength needed.

4.8 Mass and Cost Analysis

After deciding on which components to use for the module, we made a table of the approximate cost and weight of the complete module as shown below in Table 5. The majority of the mass is from the frame, octet frames, and batteries, which total 2576 g. The solar panels account for the majority of the cost at

$465.37. However, since the panels are available in such small sizes, we can closer approximate the shape of the octets as well as have little waste.

The insulation is also worth noting because, while it is labor-intensive to make, the cost of making enough insulation for 1000 modules would be approximately the same amount as making insulation for one module [25, 34].

Table 5: Approximate Weight and Cost of Module

Component:	***Quantity***	***Cost ($)***	***Mass (g)***
Thermometers	7	99.40	7*
Barometer	1	44.00	30*
Nephelometer	1	45.00*	20*
Radio	1	6.95	10*
Antenna	1	10.00*	125*
Amplifier Transistor	1	0.30*	5*
Octet Frames	0.576 kg	25.40	576
Frame	1.0 kg	44.10	1000*
Insulation	1	55.63	41.3
Computer	1	20.00*	25*
Memory Chip	1	4.00*	10*
Batteries	1	125.00*	1000*
Solar Cells	672cm	465.37	56.448
	Total:	945.14	2905.748

* indicates estimated values

5. CONCLUSION

Team ARES has designed an efficient, innovative and appropriate weather station. The spring loaded axial shaft and swivel mechanism guarantee the module's orientation upon deployment. The data processing and storage chips are more than capable of withstanding the climate and operating the entire system. They will control when measurements are taken, convert the data from analog to digital, and store and transmit the data. They will also control the heating of the octets so that the instruments are at a proper operating temperature. The instruments chosen will operate in Mars' harsh climate, and return accurate data concerning the changing atmospheric conditions. With a combination of solar panels and batteries, the weather station will have sufficient power to gather, store and transmit data for at least one Martian year. The insulation allows for low heat loss as well as protecting against radiation hardening. The spherical shell design is versatile and small enough to fit in any deployment shell, and the instruments are arranged in the lobe to guarantee the correct orientation.

Overall, our module will have a mass of approximately 2.9 kg, cost less than $1000, and is versatile enough to be used in many applications.

6. FUTURE STUDIES

At this point, much of the module is purely hypothetical. In order to test the extent of its capabilities, funding is needed to build a working model and expose it to a simulation of the Martian climate. Such testing would enable experimental observations to be taken into account, such as radiation effects and severe weather effects, particularly those resulting from dust storms. One of the most important aspects that must be considered when testing is the instrumentation exposure to radiation. It is important to look further into radiation hardened components and/or radiation insulation.

Other possible applications for our design include employment to the far side of the moon for research. It could also be dropped in the middle of forest fires to gather information. With these things in mind, we feel that our module is worthy of further development and research.

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APPENDIX A

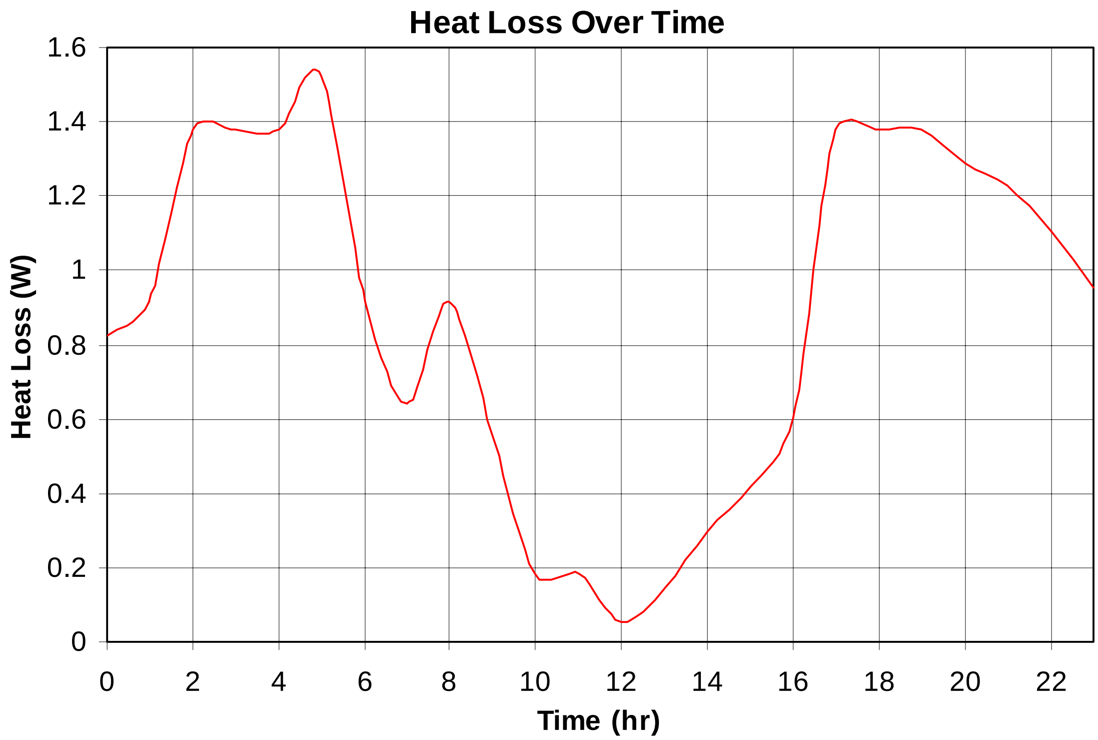


Figure 1: Heat Loss of Module over 24-hour period

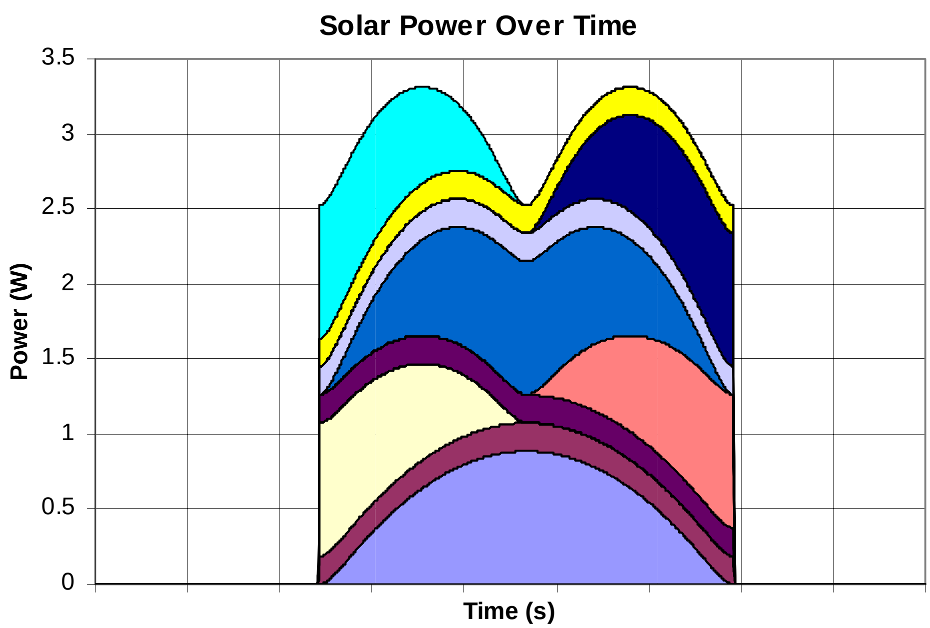
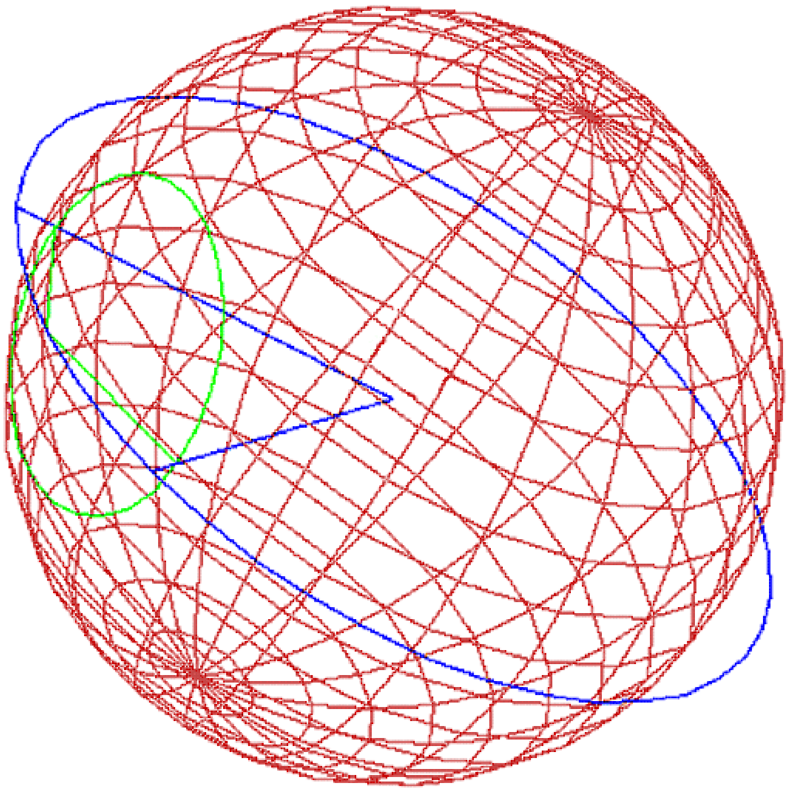


Figure 2: Combined Solar Energy from Solar Panels

APPENDIX B



Acquisition Circle
Satellite Orbit

Calculations for Satellite Orbit [32]
Satellite Path=23 860 000 m
Orbital Velocity (v_0)=3.358 km/s
Orbit Time=7105 s
Mars Radius (R)=3397 km
Satellite Height (h)=400 km
Satellite Radius (r) =3797 km

$$s_o = 2R\cos^{-1}\left(\frac{R}{R\_+h}\right) = 1573km$$

$$Arc_{mars} = 3146km$$

$$R\theta = Arc_{mars}$$

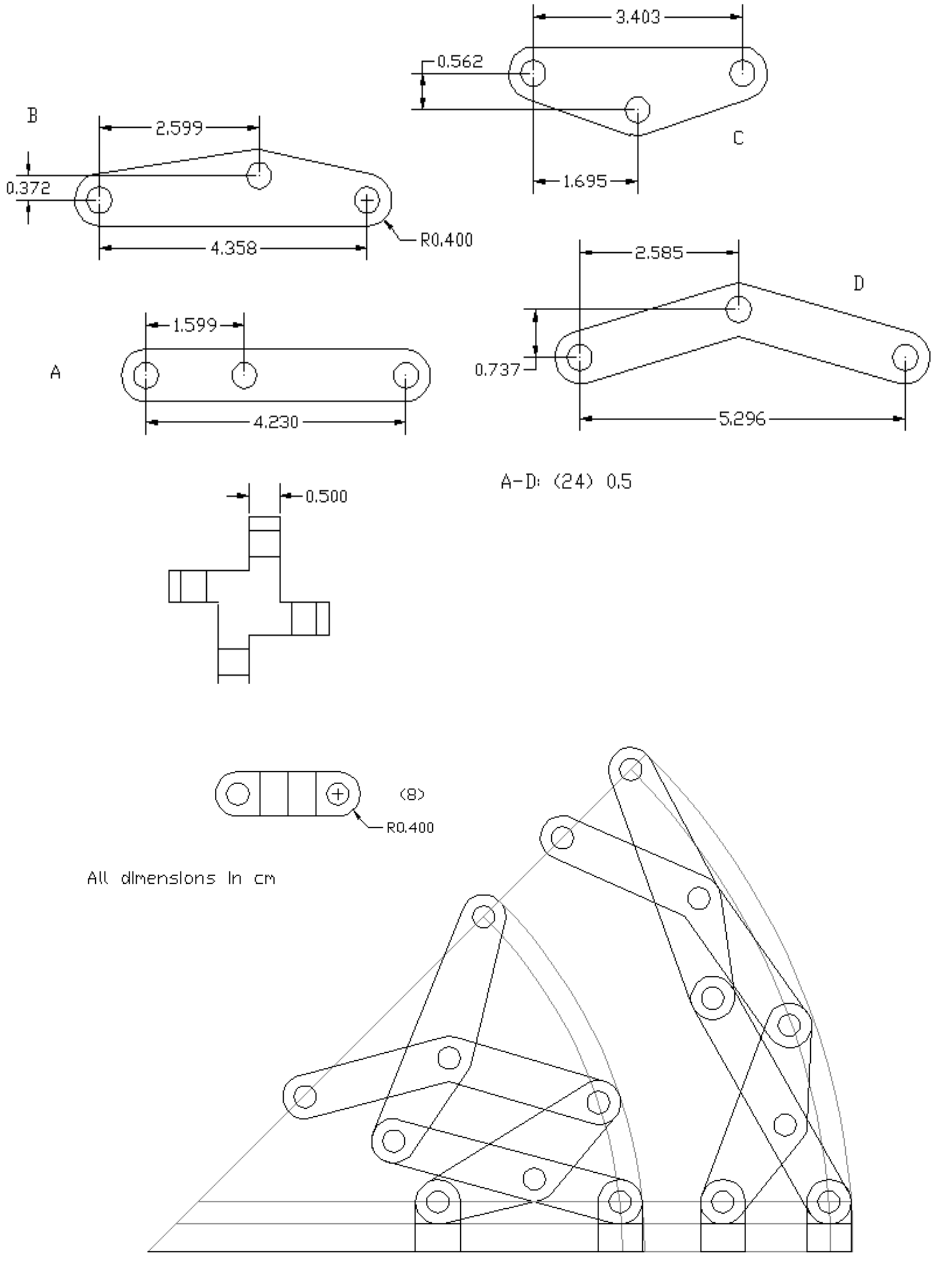
$$\theta = \frac{3146km}{3397km} = 0.926rad$$

$$r\theta = Arc_{satellite}$$

$$Arc_{satellite} = 3797(.926) = 3517km$$

$$time = \frac{Arc_{satellite}}{v_0} = \frac{3517km}{3.358km/s} = 1047s = 17.46\min$$

APPENDIX C



B
2.599
0.372
4.358
R0.400
3.403
0.562
C
1.695
A
1.599
4.230
2.585
D
0.737
5.296
A-D: (24) 0.5
0.500
(8)
R0.400
All dimensions in cm