MarsComm
Martian Communications Outpost

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Abstract

Interest in Mars exploration has peaked. Numerous proposals involving robotic mining, atmospheric testing, in-situ fuel production, and colonies are being considered. MarsComm, a long-life, self-powered communications outpost is an integral part of any proposed mission to Mars. Power is produced through solar panels and a Darrieus-style vertical axis wind turbine. Lithium-Ion cells are used for power storage for night-side use by the outpost or recharging rovers. Surface communications is extended over-the-horizon by high frequency ground waves using the axis of the wind-turbine as an antenna. Communications through dust storms is accomplished using digital transmission and equipping rovers with repeaters. Up and down links with Earth or satellites is achieved using a high gain cassegrainian antenna. Weather data is recorded using simple sensors and two miniature lidar systems. Analysis of weather data provides an ability to predict global dust storms and a better understanding of trace gases in the atmosphere. The installation of one ground-station is invaluable, but the potential for a global network cannot be ignored.

Introduction

Any interplanetary mission is dependent upon three factors: communication, power, and survivability. These factors become major problems when dealing with an adverse environment such as Mars. The production of solar power is limited to the spring and summer seasons when sunlight is transmitted unobstructed by dust particles blown into the atmosphere during the fall and winter seasons. The second problem is communications on the surface of Mars. When the rovers are on the night-side of Mars there is a communications blackout between Earth and the rover. The same occurs during a dust storm. Survivability is an issue any time a cost is associated with a proposal. Atmospheric and weather data for Mars is limited, so a prediction of survivability has extreme errors due to unknowns. The installation of a Martian outpost is essential in taking progressive steps to promote future manned and unmanned missions to the Red Planet. The requirements of the outpost are defined as the following:

(1) Land the outpost safely at a site determined for future missions
(2) Produce power continuously year-round
(3) Provide full-time night and day operation
(4) Store power for night-side operation and recharging of rovers
(5) Provide an outlet for rovers to recharge when power production is ineffective
(6) Minimize dust accumulation on the solar arrays
(7) Provide a stationary communications relay for NASA DSN transmissions to Mars
(8) Provide over-the-horizon communication for all missions
(9) Have enough memory for storage of time sensitive commands for dispatch during night-side operations
(10) Transmit continuous data streams to NASA DSN during day-side operations and save the data during night-side operations
(11) Gather atmospheric data useful in better understanding the local atmosphere and weather patterns
(12) Survive at least 10 years maintenance-free

Approach to the Problem

The areas associated with each requirement were divided among the team members as follows:

(1) Launch and landing: Jeff Gallagher
(2) Solar power generation and overall power storage: Chris Skow
(3) Wind power generation and dust removal techniques: David Thomas
(4) Subsystem architecture and communications: Anthony Maida
(5) Structural integrity, thermal analysis, and materials: Angelo Bonavita
(6) Weather data collection: Robert Beagley

Each team member approached the problem by researching current technology in use or planned for future use through books, documents, and the Internet. A weekly meeting between all members and the faculty advisor, Dr. Reyhanoglu, allowed for discussions and questions. Three possible solutions stemmed from the research conducted. Ultimately, one solution was the most feasible and met all requirements stated.

Final Design and Results

Launch and Landing

The landing of MarsComm consists of the cruise phase, Mars Orbit Insertion (MOI) phase, and the entry, descent, and landing phase. The Cruise Phase is the interplanetary flight between Earth and Mars. The MOI Phase is the delta V performed at the end of the Cruise Phase. This places the spacecraft in an elliptical capture orbit. The Entry, Descent, and Landing phase is the most crucial and complicated and occurs in 15 – 20 minutes [4] with no room for errors. Travel time to Mars orbit is 305 days on a Type-II trajectory following separation from the third stage of its launch vehicle, the Atlas III [4].

A set of four trajectory maneuver corrections (TCMs) adjust the interplanetary trajectory to ensure the spacecraft reaches the proper velocity and position targets prior to the MOI Phase.

The spacecraft is protected from cosmic radiation within the heat shield and back shell. To ensure success the spacecraft is equipped with cruising instruments and components as in the Mars Polar Lander Mission [2].

Following the final TCM a MOI burn commences. In the event the MOI burn fails to commence, the craft will speed past the planet at a velocity of 5,700 ^{m}/s. At the periapsis of this hyperbolic trajectory the main engine burns for approximately 20 minutes creating a delta V of about 1000 ^{m}/s which occurs tangential to the trajectory arc. Following completion, the spacecraft is placed in an elliptical capture obit about Mars. The orbital parameter uncertainties of this orbit cause the variation of the periapsis which lies somewhere between 229 km to 399 km. The spacecraft will remain in this orbit an average of ten days until its orbital parameters are determined.

Following the ten-day period the spacecraft begins the four-month process of aerobraking (AB). A total of six AB burns occur over a four-month period. After each AB burn, the spacecraft is brought closer to the Martian atmosphere and encounters atmospheric friction that causes a loss of momentum. This loss of momentum results in apoapsis reduction. After the sixth AB is fired the spacecraft switches to its inertial navigation, computing its position, course and speed from gyroscopes and accelerometers. Attitude and control thrusters are fired to orientate the craft so the aero shield is facing the atmosphere. When the craft returns to the periapsis, it will be 112 km above the surface of Mars [3]. This is the beginning of the final phase; the Entry, Descent and Landing Phase.

At 112 km above the surface the craft is now in the upper atmosphere. The cruise package is now jettisoned from the backshell with the help of the pyrotechnics. The descent rate is governed by the gravitational attraction of Mars and the atmosphere. The Aeroshield, which is made of an aluminum alloy with a lightweight, corklike ablative material adhered to the exterior, protects the craft from the heat generated due to friction caused by atmospheric particles during descent. Entry temperatures reach values up to 1,500ºC [3].

The Lander subsystems include descent engines, communications equipment, power sources, landing radars, data storage, and guidance and control. Four small Rocket Engine Module's (REM's) will be used to control the attitude of the descent during entry phase. A radar altimeter, consisting of a solid-state pulse radar and a redundant terminal descent radar system, is used to measure the landers altitude early in the entry phase. This system is switched on at 12 km above the surface.

At 6 km above the surface, the mortar in the aero shell cover deploys the parachute that is made of lightweight Dacron polyester. The Aeroshield is separated by spring devices and the landing gear is deployed approximately 7 seconds after parachute deployment. Aerodynamic lift will cause the Aeroshield to drift away from the targeted landing site. The parachute brakes the Lander down to a height of 1.4 km before the terminal descent engines (TDEs) kick in. At this time a pyrotechnic device separates the base cover and the parachute from the Lander. The TDEs fire for 30 – 40 seconds slowing the Lander down from 250 km/hr to about 8 km/hr. The Lander body is supported by four landing legs, which are 1.5 m in length [3]. Our Lander has a clearance of 20 cm from the ground. The main struts of the legs contain bonded, crushed titanium honeycomb to reduce the shock of the landing. After touchdown the sensors on the footpads of the Lander legs that will turn off the TDEs. After landing, our craft is in a position to deploy its main and secondary objectives.

Solar Arrays

The selection of solar cells is based on the material's ability to withstand the Martian environment for an extended period of time while giving maximum performance with low irradiance, and minimal package space. The amount of solar irradiance reaching the Martian surface with which power is generated is estimated to be 300 W/m^2. An inflatable array meets these requirements, further research led to the investigation of the accordion style inflatable array. The accordion style inflatable array consists of solar cells attached to a substrate then folded into an accordion style which does not bend the cells but rather bends only the substrate. This style benefits the outpost in two ways, 1) it is a tested type of solar array and 2) it adds strength and protection to the power supply. However, the number of sharp corners must be minimized in order to reduce stress concentrations [8].

Material

Thin crystalline silicon cells are used for the solar array. These cells provide space-tested technology, and the improvements in manufacturing processes have reduced mass penalties. These cells are etched to thickness of less than 0.01 millimeters and are then deposited onto a Kempton substrates [7].

Efficiency, Size, and Mass

Currently, solar cell efficiencies lie in the range of 10%-22% [7]. MarsComm's solar cells convert 20% of available solar power into usable power, this equates to 60 W produced per square meter. The dimensional constraints for the retracted array width is 1.5 meters and the length is limited by material support. The thickness of each solar array is 0.02 meter when deployed. When the arrays are retracted the thickness of two array pieces side by side is 0.05 m due to added padding to account for packing imperfections.

Power production is accomplished mainly through the solar cells and the wind turbine. Variations in weather conditions on Mars cause the need for each system to be independent of one another. A power production of 1 kilowatt from the solar cells is desirable. In order to attain this, approximately 16.7 square meters of solar array is needed. Assuming a degradation of 25% over ten years, based on estimations for the ISS [1], the solar arrays were designed with a total area of 24 square meters. This requires four identical solar arrays four meters in length on each side of MarsComm when deployed. Each of the accordion plates is 0.5 meters long, meaning 8 will be needed to construct each of the four arrays.

Each of the four "boxes" the array forms when stored is 0.52 meters in height, 0.4 meters in thickness, and 1.5 meters in width. Beginning of Life power production is 1440 Watts, with an estimated 1080 Watts of production after 15 years. The total mass of the solar arrays is 430 kg using an approximation of 19 kg per square meter.

Deployment and Retraction of Arrays

The vacuum pump is desired on this mission due to the presence of inert gases such as Argon that are damaging to compressors. The vacuum pump serves multiple purposes. These range from the deployment of the wind turbine and solar panels, and the retraction of the solar arrays. The pump operates as a variable horsepower vacuum pump between ¼ hp and ½ hp. The continuous operation of the pump requires 373 W of power which is supplied by the batteries that are launched fully charged.

The vacuum pump is used to inflate and deflate the arrays. The inflation or deflation of the arrays takes 120 seconds with a peak pump air velocity of 0.04 m/s following the velocity profile shown in figure 1. This slow deployment allows for minimal stresses and is less damaging to the moving parts of the array. The deployment device is a collapsible central piston underneath the panels with a radius of 0.05 meters which deploy with a pressure of 12 kPa.

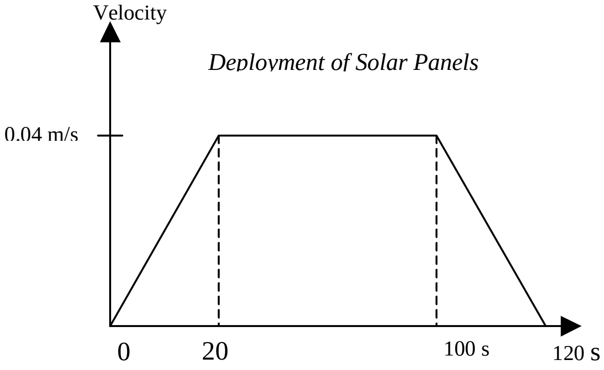
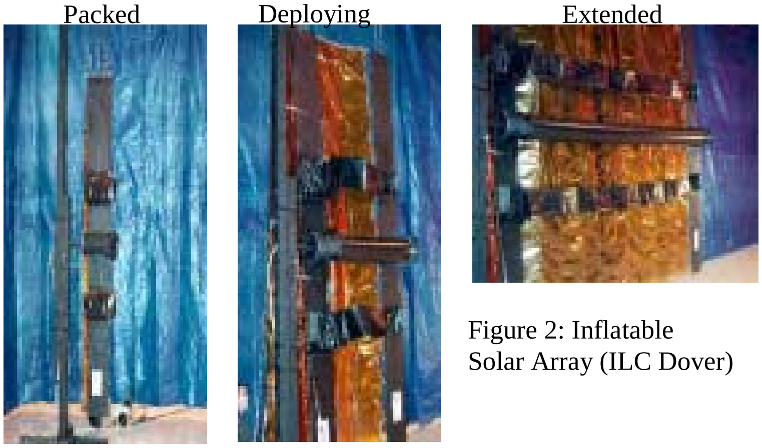


Figure 1: Deployment time of array



Packed Deploying Extended

Figure 2: Inflatable Solar Array (ILC Dover)

The retraction of the arrays is handled in a similar, slow manner. The arrays are "preset" in the closed position by a spring system that retract the arrays in the case of malfunction as seen in figure 2. When the arrays are retracted their survivability is increased during Martian weather conditions that would destroy them otherwise.

Batteries

MarsComm uses a Lithium-Ion battery array, shown in figure 3, for power storage. Lithium Ion offers many advantages over Nickel Cadmium, including mass savings, increased power output, and smaller size.

Figure 3: Prototype 25 A-hr, 28-V lithium-ion battery selected for Mars 2001 Lander
http://www.grc.nasa.gov/WWW/RT1999/5000/5420manzo.html

Power Requirements and Size

Lithium-Ion batteries have a power density of 100 Watt-hours/kilogram [14][15]. During a Martian rotation at the equator, there are 12 hours of daylight, and 12 hours of darkness. In order to provide continuous operations during the night hours, 1 kilowatt needs to be constantly available to MarsComm. Therefore, 120 kilograms of Lithium-Ion batteries is needed as a minimum. In order to accommodate surges in nighttime use, a battery mass of 150 kilograms should be considered. A battery with dimensions 6.2cm x 11.2cm x 12.7cm is capable of 15 V at 8 A-hr, or 30 V at 4 A-hr [15]. This is equal to 120 Watt-hours, and for mass and size approximation purposes, MarsComm has 0.0882 cubic meters allocated for battery storage. Excess power produced beyond operational and battery storage needs is cutoff from the batteries by a regulator system that bleeds off the excess power as heat.

Dust Repulsion Device

The purpose of the dust repulsion device is to minimize the degradation of solar cell performance due to dust accumulation. It is reported that dust accumulation will decrease solar cell performance by 77% after only 2 years [13]. It is because of this serious impact on our power system, that Martian dust cannot be ignored. Due to the size of the array the only feasible option that is available is the electrostatic device under development by LPI, as shown in figure 4.

Specifications

The electrostatic device sets up an electric field around the solar panels, and creates an umbrella around them. The dust particles are repelled, and the solar cell is then free to collect sunlight. One difficulty with this, beside the actual design, is that the atmospheric pressure on Mars is close to the Paschen minimum and thus sets a significant limit to the maximum voltage which can be applied to any exposed conductors. The estimated minimum breakdown potential is in the neighborhood of 400 Volts, and could be lower than this [3].

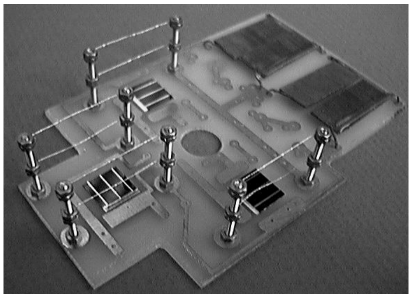


Figure 4: Electrostatic Device Designed by NASA, LPI

As a redundancy a coating is applied to the underside of the solar panels. This coating is a “paint” that emits UV radiation [11]. These UV photons help to repel the dust through levitation, in much the same way that lunar soil is suspended, except that the Martian atmosphere and wind will help to carry the dirt away from the panels. Thus providing a continuous passive method of dust removal.

Wind Power

Dust storms form in the northern hemisphere during the winter season and renders solar power production ineffective. These storms, which range from 0-2 per season, can last for several months and encompass a majority of the planet’s surface. Winds produced by storms peak at 30 m/s with higher peaks and gusts near complex topography [25]. These storms create the perfect environment for a wind turbine.

The Martian atmospheric density is ~ .020 kg/m^3 and the atmospheric pressure is ~ 6 millibars [26]. Due to the low density, the wind force delivered to the turbine blades is greatly reduced. Power generated is governed by the following equation:

$$P = \frac{1}{2} C_p \rho A \nu^3$$

Where P is power in W, C_p is the efficiency of the turbine, ρ is density in kg/m^3, ν is wind velocity in m/s and A is area swept in m^2 [27]. The wind velocity on Mars varies from 17 m/s to 30 m/s. These high winds speeds compensate for the decrease in atmospheric density, due to the cubed velocity factor. The turbine operates when wind speeds exceed 15 m/s, therefore at speeds less than 15 m/s, bending moments are present.

A Darrieus style vertical axis wind turbine (VAWT) is incorporated into MarsComm for its symmetrical design that allows for generation independent of wind direction and for its high efficiency at wind speeds common to Mars. The gear ratio is moderate, guy wires are required for stability, and the generator components are at ground level. [21].This style turbine rotates using aerodynamic lift and can rotate into or out of the wind. Because of this, the blades do not suffer fatigue stresses from gravity, the centrifugal loads are balanced by pretension forces in the blades, thus eliminating bending moments. The central shaft of the turbine suffers only axial and torque loads. Darrieus turbines achieve a 30 % efficiency maximum at 16 m/s and 20 % efficiency at 30 m/s [24]. This leads to an average power production of 6.35 kW-h during 87.6 hours operation without a dust storm, and 4.32 MW-h during a three-month dust storm.

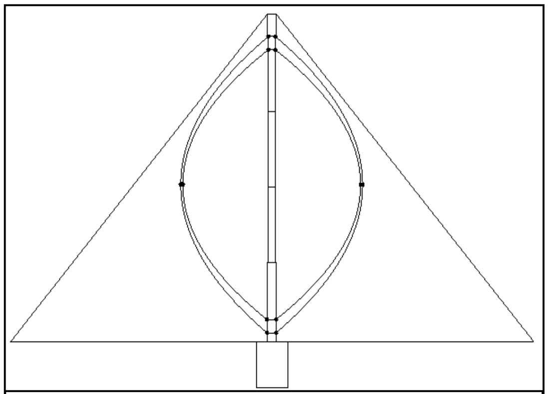


Figure 5: Darrieus Turbine deployed, with guy wires

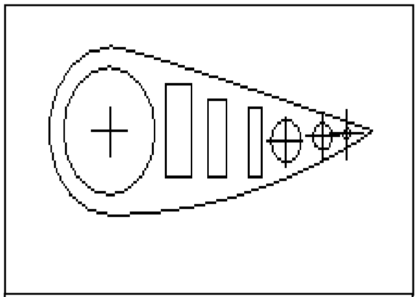


Figure 6: Darrieus Turbine blade cross-section

The VAWT stands 12 m tall fully deployed with two air foils extending 10 m of this height. For deployment, the guy wire support poles will deploy first, followed with the turbine that will rotated five and a half times during deployment. Once fully deployed the joints in all telescoping cylinders will lock, the guy wires will form an angle of 40° with the central axis, and the turbine will not rotate until started during conditions where the wind is greater then 15 m/s. The central axis is a series of four main cylinders and one capping cylinder to ensure a proper seal. A graphite lubricant is used to create a seal around the joint edges and minimize friction. This allows the cylinders by telescopically deployed following extruded grooves on the interior. The cylinders rotate five and one-half revolutions until reaching the locking point, much like the cups used for camping. The table below gives the specifications for the turbine.

Central Axis Cylinders				
Segments			Height in m	
4.000E+00			2.750E+00	
wall thickness in m			Material density	
3.175E-03			kg/m^3	4.730E+03
Initial tube diameter in m				
3.048E-01			Gravity on Mars m/s^2	
Spacing between in m			3.270E+00	
3.962E-04				
Tube	Outer dia	inner dia	Vol. m^3	Area m^2
One	0.3048	2.921E-01	1.637E-02	1.191E+00
Two	0.2913075	2.850E-01	7.899E-03	1.162E+00
Three	2.842E-01	2.778E-01	7.704E-03	1.133E+00
Four	2.770E-01	2.643E-01	1.484E-02	1.078E+00
Force due to gravity (N)			Volume in metric m^3	

1.191E+03			4.681E-02		
Pressure required in interior (Pa)			Area in metric m^2		
2.841E+02			4.564E+00		
Total Mass in kg					
3.318E+02					
Guy Wire Supports					
Segments	Length m	Total Length	Shear modulus Pa		
3.000E+00	3.124E+00	8.839E+00	4.900E+10		
wall thickness m		Material density			
3.175E-03		kg/m^3	4.730E+03		
Initial tube diameter m					
1.524E-01		Gravity on Mars m/s^2			
Spacing between m		3.270E+00			
3.969E-04					
Tube	Outer dia	inner dia	Vol. m^3	Area m^2	Mass kg
One	1.524E-01	1.461E-01	4.648E-03	2.169E-02	6.224E-01
Two	1.453E-01	1.389E-01	4.425E-03	2.065E-02	5.926E-01
Three	1.381E-01	1.318E-01	4.203E-03	1.961E-02	5.628E-01
Total acting force (N)		Total Volume in m^3		Total interior area m^2	
1.057E+02		1.328E-02		6.194E-02	
Shear stress ave. Pa		Total Mass in kg		Max deflection in nm	
1.707E+03		6.280E+01		1.638E+00	
Pressure required in interior (Pa)					
1.707E+01					
Guy Wire Cables				**Airfoils**	
Tension in cables N		Cable length m		Voulme of airfoils m^3	
1.112E+03		1.439E+01		8.700E-02	
Cable diameter m		Density of material kg/m^3		Airfoil density kg/m^3	
8.000E-03		4.730E+03		1.230E+03	
Force in z axis N		Cross sectional area m^2		Airfoil mass kg	
8.518E+02		5.024E-05		1.070E+02	
Force in x axis N		Total volume m^3			
7.148E+02		7.228E-04			
		Guy wire mass kg			
		3.419E+00			
Interior components					
generator, greabox, bearings, brakes kg					
	5.000E+01				

Packaged for launch , the turbine is bound up like a corkscrew. The main cylinders are nested together and the turbine blades would in a helix attached by both ends to the cylinders. In total the compacted turbine will be 4.0 meters tall, with generator, gearbox, bearings and brakes. The guy wire support poles will nest together and be fixed to each corner and parallel to the main cylinders, with guy wires wound and spooled. In the end the turbine will be 1.6 meters X 1.6 meters X 2.75 meters, and have a dry mass of 643 kg.

Subsystem Architecture

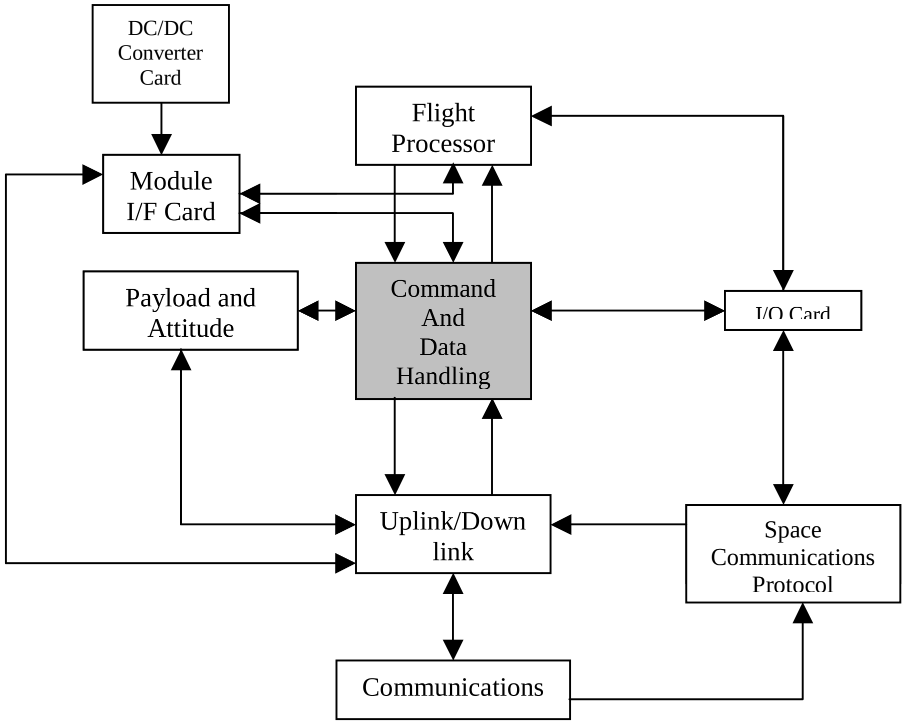


Figure 7: Subsystem Architecture

Command and Data Handling Subsystem

The substructure architecture is composed of a series of interdependent cards and processors: Command and Data Handling Card (CD&H), Flight Processor Card (FPC), Uplink/Dowlink Card (ULDL), input/output Card (I/O), Payload and Attitude Control Card (PAC), Module Interface Card (MIC), and a DC/DC converter card. The dependency is shown by the above flowchart, with the interconnectivity of the communications architecture and the addition of the Space Communications Protocol.

The CD&H subsystem is contained within a single 6U VME compatible housing, and contains two fully redundant VME buses (A and B); with fully redundant FPC, I/O, PAC, and ULDL. One bus is powered at a time while the other remains in a cold back-up condition. In the case of failure, the internally redundant MIC gives the command for the backups to power up and take over.

The FPC has a self-contained 32 bit, Power PC 604 single chip processor, space qualified single board computer with 256 MB of DRAM storage, and 2.5 MB of EEPROM for non-volatile storage of the operating system.

Attitude Control Subsystem

The Attitude and Control Subsystem design is based on an updated *Viking* Lander approach. The subsystem includes the following: Reaction Control Subsystem that controls the thrusters and the pointing of the solar arrays, Star Camera that contains the navigation data, Sun Sensors that provide the sun vector information, and Landing Radar that is used to guide the Lander safely to the surface.

Thermal Control Subsystem

MarsComm thermal control is designed primarily as a passive system to protect the payload in all mission phases. The main thermal failure mode for the mission centers on the sensitive equipment stored beneath the turbine structure. The overall thermal subsystem uses insulation, heat pipes, heaters, and radiators to maintain the required temperature window of 10-20 degrees Celsius.

During Launch and descent, the payload will experience tremendous heat, which could cause damage to the equipment. This is the purpose of enclosing the payload within the heat shield and backshell, which compose the fairing of the launch vehicle. Solar Radiation becomes an issue following the ejection of the heat shield and the backshell.

The cruise stage thermal design uses Multi-Layer Insulation and heaters for temperature control. Excess heat is radiated naturally through the aero shell without the need for a mechanical coolant pump.

The key element to the Lander's thermal design is a heavily insulated thermal enclosure that houses the batteries and sensitive electronic equipment. The lander itself will be coated with a Kapton-Teflon overcoat to protect against both atomic oxygen and radiation in the longer wavelength IR spectra.

Once the Lander finds a home on the Martian surface maintaining proper operating temperatures is of great concern to the survivability of the mission. The surface temperature on Mars is –40 degrees Celsius while the survivability temperature is 10-20 degrees Celsius. Aside from the use of MLI and heaters, heat capacitors are utilized. Heat capacitors store excess thermal energy that otherwise escape as an outward heat flux using a Phase Changing Material. The majority of the heat that is stored within the capacitor is obtained from the entry phase when the spacecraft experiences the greatest heat.

Communications

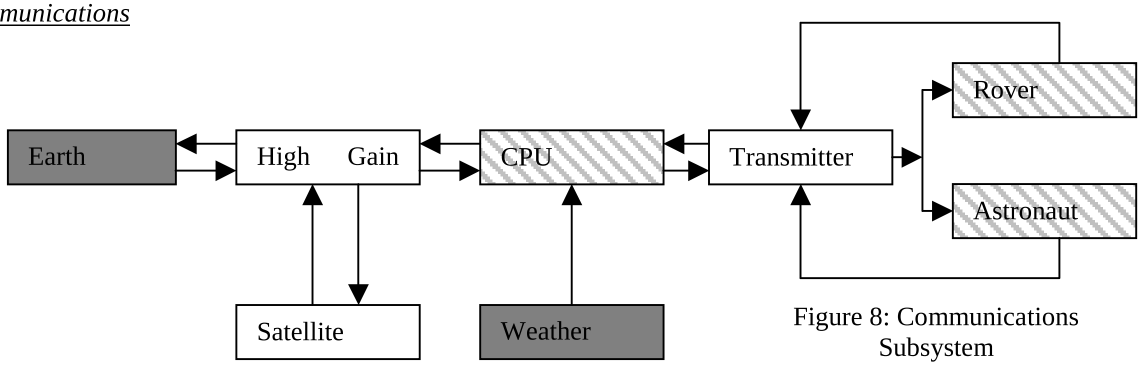


Figure 8: Communications Subsystem

The communication systems onboard MarsComm serves multiple purposes in aiding both manned and unmanned missions. The communications subsystem consists of three portions: the integrated half-wave sleeve dipole antenna, the high gain antenna, and the electronics associated with the transmission and reception of the signals.

The high gain antenna is comparable to that used on the Galileo mission. The antenna resembles an umbrella with a height of 0.75 m and a width of 0.5 m. The reflective surface is composed of a silver mesh with a spacing of no more than 0.075 m which inhibits dust accumulation on the reflective surface and still capture the incoming transmission wavelengths. The parabolic dish is used for up/down links to and from Earth and orbiting satellites. This antenna is deployed from the side of MarsComm and is required to be at least 1.5 m away from the tip of the spinning blade of the VAWT. The operational power required for these transmissions will have a minimum of 20 W and a peak of 35 W [35]. This link with Earth allows for the use of MarsComm as an amplifier and error analyzer for transmissions to unmanned exploration vehicles. This capability allows received and compiled commands to be relayed to unmanned vehicles with precision and clarity, without high transmission loss and errors due to atmospheric or cosmic noise and scattering.

The above mentioned objectives are accomplished through the use of high frequency ground waves. The dust storms, Paschen discharge, and poor conductivity of the ground would cause any low frequency communications system to fail or be severely limited. These waves must have a high enough frequency to be unaffected by these noises and still be considered ground waves. It is for these reasons that the waves have a frequency of 30 MHz for communications, and a single side band (SSB) for compiled data transmissions.

The transmission of the ground waves is through the VAWT. The turbine axis is integrated as a half-wave sleeve dipole. The integration of the wind turbine with the communication system requires an induced current to flow through the axis that is composed of a conductive material, and create a sleeve dipole in the geometric center of the axis through the use of Teflon, a dielectric material. The completion of this design creates an electromagnetic radiating antenna that will be capable of transmitting and receiving data and voice. The transmission of data through dust storms is very possible if the information is transmitted as a digital signal. This will require the conversion of analog voice to digital. The human voice is a continuous signal in the range 0-4 KHz. Digital communication, on the other hand, is based on discrete bits (0 and 1). Therefore, there is a need for converting the human voice into a stream of bits and vice versa.

Sampling the sound wave and denoting the level of the wave by a number that is transmitted over the digital link do the analog to digital conversion. Creating a wave according to the received numbers does the reverse process. According to Nyquist law, the minimum number of such wave samples needed for complete reconstruction of the wave is twice the number of the maximum frequency of that wave. This yields: 2*4 K = 8 K samples per second. The most common method for denoting the level of the wave is called PCM with 256 quantization levels (8 bits). Thus, if sampling 8 K times a second, each sample in the range of 0-255 we need 8 K * 8 = 64K bits per second per voice line.

The electronic components that are required for the mission will be tied into the Command and Data Handling subsystem. The C&DH subsystem will provide the A/D and D/A conversions and modulations for transmissions and receptions. The amplifier will be one that is part of the MESFET family of amplifiers. [35]

Weather Sensing

Martian weather patterns are important to future manned and unmanned missions to the red planet. Three instruments are included on MarsComm to provide a fairly complete ground-based weather profile and complete the goals mentioned above [48]:

- Integrated Dust/Aerosol Analyzer
- Miniature low-power LIDAR system
- Multiple temperature, pressure, and wind speed sensors

Integrated Dust/Aerosol Analyzer (IDAA)

The IDAA measures the angular distribution of light scattered from individual dust grains, their velocity vectors, and masses. The IDAA in a base configuration detects particles as small as 0.1 micrometers in diameter at velocities less than 1 km/sec, and larger particles at greater velocities. When active, a detected particle passes through two mutually perpendicular polarized light screens and then impacts a piezoelectric mass detector array. Standard polarized scattering elements of the scattering matrix are determined at 6 to 10 discrete scattering angles ranging from approximately 40 to 160 degrees. The total intensity and the degree of linear polarization is then calculated; this is sufficient to estimate the particle cross-section and reliably distinguish fluffy aggregate particles from compact dust and absorbing compounds from dielectrics. The time of flight between light curtains defines the dust velocity along the instrument axis; the complete velocity vector is calculated from other associated data. From this data, the IDAA estimates the particle density from the cross section and mass measurements.

The IDAA is 12x10x10 cm in size, 1 kg in mass, and has an entrance aperture of 1 cm^2. While waiting for dust particle detection the instrument is in an inactive mode, consuming 200 mW of power. Upon particle detection, the instrument enters active mode, and consumes 1 W.

Temperature, Pressure, and Wind Speed Sensors

Simple temperature and pressure sensors are included on the base of the outpost as well as on the turbine guy wires. These sensors, spread out over a height of 10 meters, give a low altitude profile of temperature and pressure gradients. A 0.15 meter Horizontal Axis Wind Turbine is included on the outpost base to provide a profile of near ground-level wind speeds, and help predict wind speeds affecting the turbine. This HAWT rotates into the direction of the wind via a simple weather-vane type arrangement. Overall power usage for the temperature and pressure sensors is 3 W.

Mini-LIDAR System

MarsComm has two mini-lidar systems, each with a 2 W silicon diode laser and a 15 cm diameter Cassegrain telescope. The silicon diode laser is similar to those found in commercial applications such as CD players and hand held laser pointers, and is the most rugged, lowest mass, and most efficient laser available today. The two systems are configured to measure all of the following at once:

- Aerosol profiles
- Gas species density profiles

- Trace gas concentration measurements
- Wind profiles
- Temperature profiles

A short light pulse is emitted from the laser head and fed into the lidar system's coaxial centerline. The backscatter from aerosols in the beam path is then detected and digitized by the scope. The distance 'r' from the lidar head to the aerosols is given by the time delay of the echo for each range gate, and the strength of the echo at range 'r'. The received power P(r) is related to the aerosols' effective volumetric backscatter coefficient β(r) through the lidar equation below [45].

$$P(r) = P_o(\frac{ct}{2})F(r)A_t\frac{1}{r^2}\beta(r)[e^{-2\int_{r0}^{r}\kappa(r')dr}]$$

P(r) is the power received from the range r = ct/2, where c is the speed of light. The ½ factor arises from the pulse traveling to the distance r and back to the receiver in time 't'. P_o is the power transmitted at time zero. The effective length of the laser pulse is cΔt, where 't' is the laser pulse duration. A_t is the effective area of the telescope, and divided by r^2 defines solid angle acceptance. F(r) is an overlap function accounting for overlap of the receiver's field of view from the laser pulse. This overlap function is only important at very short ranges (r < 100 meters). β(r) denotes the volumetric backscatter coefficient of the atmosphere at range 'r', and κ(r) is the corresponding extinction coefficient.

The backscatter and extinction coefficients depend on wavelength, particle size, and optical properties of aerosols in the atmosphere. The lidar equation above applies specifically to a relatively transparent medium where only a single scattered wavelength is accounted for.

The lidar uses a simple semiconductor laser in the wavelength region of 980-1015 nm in the 80 mW-5 W output power range [44]. The power received must be at least that of the Noise Equivalent Power (NEP) of the photodiode receiver, so a low NEP is desirable. A Hamamatsu InGaAs PIN Photodiode, model G3476-03 has an NEP of $4\text{x}10^{-15}$ W [46].

β(r) for the molecular Martian atmosphere is estimated from the Rayleigh attenuation value on Earth, the value arrived at is $6.73\text{x}10^{-10}$ m^{-1}. The estimated extinction coefficient is the overall Martian Rayleigh attenuation value of $8.458\text{x}10^{-9}$ minus the estimated backscatter coefficient just calculated, for a resultant κ(r) of $7.785\text{x}10^{-9}$.

When discussing aerosols and dust in the atmosphere, which must be considered at all times on Mars, it is necessary to adjust the backscatter and extinction coefficients. An additional complication is the great variability of the aerosol coefficients. The amount of dust in the atmosphere is much greater in the winter season than in the summer, and even greater during a large-scale dust storm.

Another difficulty lies in the dust accumulation on the telescope and other optics. It is necessary to cover the telescope apertures so dust does not accumulate on the telescope reflecting surfaces. Previous missions outlined dust accumulation occurs on horizontal surfaces and wherever a static charge is present. Since it is unlikely that a static electric charge will be produced on the optics, an angled cover will reduce the amount of dust accumulating on the optics significantly. To this end, a conical cover made of silicon or some other durable transparent material utilizing an anti-reflective coating will be used (Figure 14).

It will be impossible to have the lidar systems in a vertical orientation due to the size of the turbine; the beams would intersect the turbine blades and offset the results significantly. Therefore the lidar axes will be offset 30 to 45 degrees from the vertical. This should not affect the scattering in any way, but it significantly reduces the vertical distance able to be sampled.

Conclusions

MarsComm is designed with the three major constraints in mind: power, communications, and survivability. All three requirements were met. MarsComm is capable of producing power year round through the use of solar arrays and the vertical axis wind turbine. The communications is taken care of by the integrated turbine antenna design and the cassegranian high gain antenna which allow for extended communications night and day. The weather sensing experiments allow for a better prediction of future survivability rates of future missions. The probability of a ten year survival is high with an estimated survivability of 80%.

Future Studies

For future academic research, several recommendations have been proposed. These include:

- Design a better dust removal technique
- Construct a system that better stabilizes the VAWT through other geometrical shapes being used as the base, such as a pyramid or a dome.
- Design a thermal system that will not deteriorate significantly over ten years
- Produce an overcoat for the solar arrays that better protect against sandblasting
- Research a higher efficiency solar array and batteries
- Additional loads produced by cross winds on the VAWT should be considered

Outreach

On the first day of the HEDS-UP forum an article on the Embry Riddle HEDS-UP team is set to print in the local paper, the Daytona Beach News-Journal. The article will also print on their website for twice the exposure. A website has also been setup and maintained since January.

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