MADEX:
Martian Drilling and Exploration

Metropolitan State College of Denver

Contributors: Ryan Cox, John Addante, Don Anderson, Dudley Bacon, Sam Bacon, Shara Barkovich, Jeff Bowman, Andrew Christianson, Jason Dorrier, Danielle Gallegos, Mike Giron, Yoshi Goto, Dan Harrington, Rachel Heise, Lindsay Lowe, Adam Mcglaughlin, Adrian Migacz, Jenny O'Brien, Gary Rasmussen, Gabe Webber, Eric Wilson

Faculty Advisor: Professor Howard Paynter

Outside Advisors: Dr. Robert Zubrin, Dr. Penny Boston, Denise Kato, Ralph Eberhardt, Dr. Tom Meyer, Dr. Joe Martin, Dr. Andrew Taylor

Foreword:

The work reported was done by students enrolled in a General Studies course, MET 3350: ROCKETS and STARS: a space trek, during spring 1999. Half of the multi-disciplined class of 26 attended Cherry Creek High School. Mr. David R. Paynter, who teaches biology at Cherry Creek, helped his father in the conduct of the class which met Tuesday and Thursday from 6:55 to 8:35 PM beginning 19 January. A number of outside advisors met the class separately and twice as a group to review results. The students visited the GATES Planetarium to view the Hubble Space Telescope Gallery. The class also visited the Lockheed Martin Astronautics Division at Waterton, Colorado.

The first several weeks were used to understand the HEDS-UP program objectives, the Mars baseline mission and design guidelines, and possible design concepts to satisfy certain objectives. Two groups were formed on 9 February to study, (1) inflatable structures, and (2) human powered applications, e.g., human powered vehicles, or power generation. A third group was formed one week later to search for life using a cliff-walker to house a drill to collect and analyze core samples obtained at various depths below the Mars surface. MADEX evolved after a preliminary design review conducted by the outside experts on 8 April.

Abstract

The concept will take samples and spectrometer data at various depths below the Martian surface. The unit will address three major objectives for the human exploration of Mars. 1) Can humans ultimately inhabit Mars? 2) Is there or has there been life on Mars? 3) What is the history of the Martian planet? Rather than drilling vertically from the surface of the planet and taking samples at predetermined depths, the Martian Drilling and Exploration Unit (MADEX), will be lowered over a cliff to drill horizontally at various depths. The unit will attempt to satisfy the objectives using spectroscopic data taken along the cliff wall and analysis of the core samples taken.

1. Introduction

NASA has proposed that to accomplish the Mars mission goals, it is important that a plentiful source of water be searched for including a water table or a high concentration of water within the polar caps on Mars. By using spectrometers with the capability of recognizing aqueous minerals along a cliff wall, it may be possible to select preferred regions to look for a plentiful source of water. Where this water is, assuming it exists, is where it is most likely that we could find present day life. Thus, core samples taken by the MADEX (Figure 1.1) could then be analyzed for suggestions of life. By analyzing other mineral compositions within the surface we will better understand the planet's history and past atmosphere.

By sending a large drill rig to the planet, a large amount of piping is required. The piping would greatly increase the mass of equipment sent to the planet. Rather than using pipe, it is suggested to bring a rover-type unit to descend a cliff wall to save mass and take data, such as spectrometry and photographs. Past designs of units similar to the MADEX such as the series of Dante units have shown that it is difficult to design a unit that will safely and consistently maneuver itself. Therefore, the MADEX unit will be controlled by a computer system atop the cliff wall. The maneuvering system will consist of two cable spools at 50 m from the edge of the cliff, 60 m apart. By releasing slack on each cable, the MADEX is lowered along the cliff wall. If there is a protrusion on the wall, one cable will release more rapidly thus slowly lowering the MADEX diagonally down the wall and avoiding the obstacle.

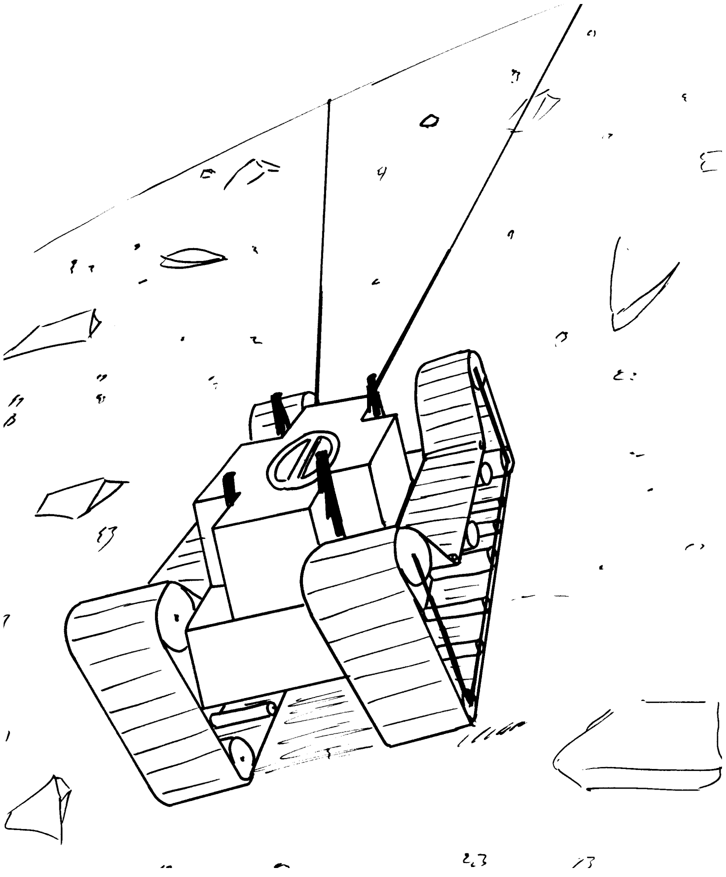


Figure 1.1 MADEX

MADEX will have a pair of treads which will allow the unit to roll down the cliff wall. The tread system will be equipped with a small motor that will control the unit's motion when atop the cliff. The tread system is sturdy, yet provides a somewhat soft ride. The treads will extend below the bottom of the MADEX in order to separate the equipment from the cliff wall by about 20 cm.

As photographs and spectroscopy data are collected, the data will be sent via the communication link to a "base" situated between the two cable control units (CCUs). After every nine stops, the MADEX will transport the core samples to the top of the cliff. Should something happen to the MADEX preventing its return to the base, not all of the data taken is lost.

MADEX is lowered using the 3/8 g gravitational force. The lowering rate is controlled by a friction brake. Friction acting on the cable spools will allow a slow and safe descent of the MADEX and to stop the unit's descent. When stopped, MADEX will lower and position four individually controlled legs against the cliff wall for stability during data collection. The MADEX will drill two samples simultaneously and take spectrometer readings and high resolution photographs of the cliff wall. The digital images provided by these instruments are transported to the base via the communication cable. The MADEX then is lowered five meters and the data collection stage repeats.

Because of the limited knowledge regarding Mars' cliff walls, it is difficult to imagine how rugged they may be. It is therefore necessary for the unit to have the ability to maneuver itself around obstacles in its path. Sonars placed on the front and back of the MADEX will constantly take readings of the obstacles in its path. Thus, a basic map of the cliff wall can be created. Using this map, the computer system situated within the base decides the path to take in order to avoid such obstacles. The CCUs are used to maneuver MADEX around them.

With the CCUs 60m from each other MADEX may descend approximately 250m. As mentioned, the gravitational force is used to descend the cliff wall. The CCUs use friction to brake the descent of MADEX. The unit will make a total of 50 stops along the cliff wall (approximately every 5m) to collect samples and data.

We have located a cliff wall nearby the landing site proposed by NASA. NASA has proposed to land near the region between East and West Candor (Figure 1.2). The cliff wall on the northern end of East Candor is a preferred setting for the MADEX. This cliff works toward the mission's advantage because it is near NASA's landing site and it appears to contain multiple, detailed layers.

MADEX will be stationed and secured near this cliff wall by the human crew. Due to its relatively small size, the entire unit could be transported to the desired location from the habitat by a rover. The base will be set up 50m from the edge of the cliff with the CCUs extended 75m in each direction from the base along the cliff wall. Communications cables are attached between the CCUs and the base, and between the MADEX and the base. Cables from the CCUs are then connected to the MADEX.

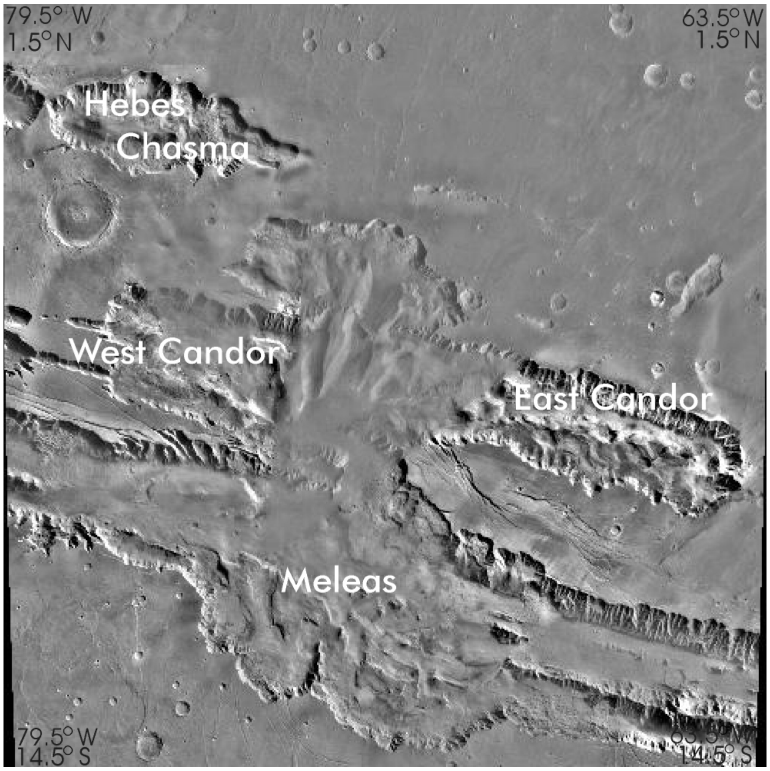


Figure 1.2 Proposed Landing Sites

A test run will be made before the astronauts leave the system. MADEX will descend approximately 20m, take data, and then return the data and samples. If there are problems, they will be assessed and fixed. When the system is functioning properly, it will be programmed to run and the astronauts will leave. They will return and replace the batteries as required with fully charged ones. While there, the system will be checked and inspected to discover any problems, core samples that were returned to the base will be taken to the habitat. This sequence will be repeated until the full 250 meter depth has been achieved. At this point, the MADEX will be returned to the top of the cliff by the CCUs operating on return mode. The unit will be lifted to the top of the cliff. The small motor on the MADEX will then move it the final 50m to the base.

2. MADEX Design

2.1 MADEX Unit

MADEX has been designed to use minimal power to descend the cliff wall and collect data. It allows for gravity to lower the unit. In the event that the unit reaches a ledge on the wall, there is one small motor attached to its tread system so that the unit may continue its descent. This motor is used to move MADEX atop the cliff wall when it moves the 50m distance between the base and the cliff wall.

2.1.1 Interior Layout

Vertically through the center of the MADEX unit will be the drilling cylinder. This cylinder will consist of two main parts: a storage ring and the drilling ring. The storage ring will be the lower 18 cm of the cylinder. It will contain eighteen cylindrical holes placed uniformly around the outer edge of the cylinder. Each hole will have a 3 cm diameter. The upper cylinder will have two holes that match up with the outermost holes on the lower cylinder. Through these holes penetrate the two core sampling drills. The upper cylinder is immobile relative to the MADEX, unlike the lower cylinder which can be rotated about its center axis.

Situated to the front of the drill cylinder will be the Mössbauer Spectrometer and the Miniature Thermal Emission Spectrometer. Because the outermost holes on the cylinder are the only holes that interact outside the MADEX, a digital camera will be situated between the cylinder and the cliff wall. Attached to the front wheels on the treads is a small motor which controls the unit's motion when atop the cliff. One small sonar will be placed at the front, and one at the back of the unit. A small computer which translates commands sent by the base and data to be sent to the base will be placed near the back of the unit. At each of the four corners of the unit will be a small, low output motor that drives its respective support leg.

2.1.2 Exterior Layout

The dimensions of the MADEX will be 120 cm x 120 cm x 100 cm. Much of the volume within these dimensions is empty space, however. For instance, the top of the unit will be cut away to save overall volume of the unit.

On each side of the unit will be a tread system which primarily rolls freely with the motion of the unit, but drives the unit when atop the cliff. Each tread will extend beyond the front and back of the unit by approximately 35 cm. The width of each tread will be 40 cm, approximately 1/3 of the total width of the MADEX. For added support when the unit is stopped for data collection and drilling, the MADEX will be equipped with four legs (one on each corner of the unit). To the front and back, the sonar lenses will be visible through a grate-like shield. The back of the MADEX will be the same as the front except that it will have two eyeholes for connections to each CCU and one port for the communication/power cable. Viewing the top of the unit, one would see the drill cylinder centered. No holes are visible from the top, though two holes (those through which the drills penetrate) are visible from the underside of the unit.

2.1.3 Tread system

The tread system planned for MADEX Unit is somewhat unique (Figure 2.1.3.1). It is different than tread patterns on common tanks where each wheel is on its own frame. MADEX will use only three frames for the wheels. This results in fewer moving parts required. The system will allow for a relatively smooth ride.

As the treads touch a protrusion, the middle wheel pushes against the cliff and the front wheel will rise. As the protrusion reaches the middle wheel, it is raised and the outer wheels are lowered. The front wheel is thus in contact with the wall again sooner than it would without this design. As the unit passes over the protrusion, the treads slowly return to their "relaxed" state. This smoother ride will help ensure that the core samples remain intact and that the electronic equipment on board the MADEX is kept undamaged.

{ EMBED Word.Picture.8 **}**
Figure 2.1.3.1 MADEX Tread Design

2.2 Base

The base will be situated at the top of the cliff 50 meters from the edge. It serves as the brain and the storage space for the mission. It stores the power, samples, and data collected.

2.2.1 Computer

The computer that the base will be equipped with will run the entire mission. Stored within the computer are spectrometry data, photographs, detailed records of progress, and maps of the cliff. The computer must tell the CCUs when and how rapidly to release slack or to pull the MADEX back up to the top of the cliff. How quickly to release slack depends upon what obstacles lie ahead in its path. The computer thus must calculate what the best route to avoid such obstacles would be. Once the descent of the unit is halted, the computer must tell the MADEX to take data: first spectroscopy data, then photographs, then core samples.

2.2.2 Battery Storage

The batteries which store the energy necessary to run the MADEX and all of its components will be stored within the base. In order to minimize the weight of the unit itself, thus minimizing the work required to raise it to the top of the cliff, all power necessary to run the MADEX unit itself will be transferred from the batteries to the unit through the communication/power cable.

2.2.3 Sample Storage

After samples are taken from the MADEX to the base, the samples will be removed from the cylinder, packaged safely, labeled, and stored within the base. The system ejects the sample from the cylinder into a small bag made of Mylar. The labels are then labeled with the depth from which the samples were taken and the date of sampling. The sample is then stored in the base until it is retrieved by astronauts.

2.2.4 Mechanical Arm

When the MADEX reaches the top of the cliff after loading the cylinder completely (eighteen total samples), the unit moves to the base to unload the samples (Figure 2.2.1). The base is shaped to funnel the MADEX into the correct location for unloading. Once in this position, a mechanical arm attached to the base grabs the cylinder and pulls it out of the MADEX. Contained within this cylinder are the drills, drill motors, and the samples. Once the cylinder has been removed from the unit, a new cylinder, containing drills and motors is placed into the unit so that more samples can be taken immediately. The MADEX then moves back down the cliff to continue its research. While more samples are being taken, the base removes the samples from the used cylinder.

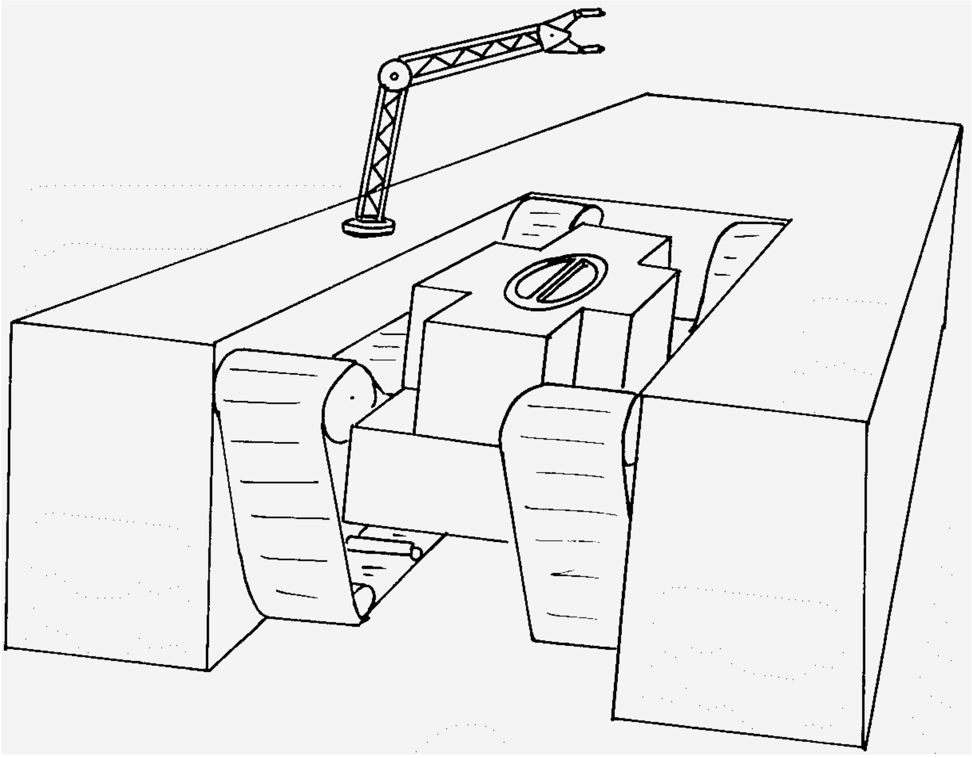


Figure 2.2.1 MADEX Base

2.3 Cable Control Units

Atop the cliff wall and separated by 60 m, two CCUs will be situated. Each unit will have three parts: 1) cable spool, 2) friction brake, and 3) winch. The cable spool must be large enough to hold approximately 350 meters of cable. During the descent stage of the MADEX, the winch will be inoperative. The rate of descent will be controlled entirely by the friction brake. Likewise, during the ascent stage, the brake will be inoperative as the winch pulls the unit to the top of the cliff.

2.4 Communication Devices

The transfer of power and data between the base and MADEX is through a single cable. The spool of extra cable will be stored in the base. Power from the batteries in the base will be delivered to MADEX through this cable, along with instructions as to when to drill, take pictures, and collect spectroscopy data. The sonar readings, digital images, and spectroscopy data taken by the MADEX will be sent to the computer memory bank in the base through this cable as well. Because the map of the cliff made by sonar readings is held within the computer in the base, it must send signals to the CCUs as to when to release slack, when to stop the unit, and when to return it to the top of the cliff.

3. Drills

It is essential that during our stay on Mars we drill core samples. With these samples, it will be possible to return pieces of the Martian planet to Earth for further analysis. The samples that the MADEX will return will range from the surface to 250m below the surface of Mars. This will allow sufficient knowledge of the planet's history and composition for future studies to be designed specifically for certain areas of research. This task is not easy, and our goal was to design a system that would allow for low probability of failure, low mass, minimum power consumption, but high quality samples.

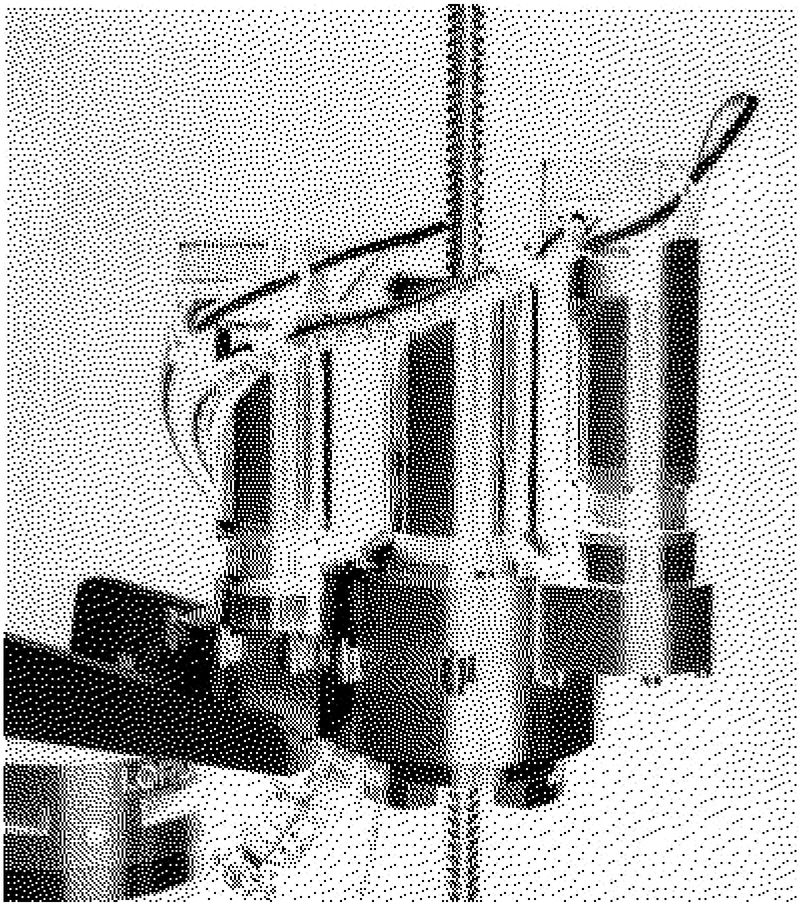


Figure 3.1.1 NASA's Drill

3.1 Sampling Methods

NASA has developed a drill for extra-terrestrial purposes (Figure 3.1.1). This drill weighs about 2.2 kg and runs off only 20 Watts. We have selected this drill for these reasons. The motor has been designed to work in temperatures found on the Martian surface. The drill bits we will use with this drill are diamond bit, and have an inner diameter of about 2.5 cm. The samples will be 15 cm in length. The drill may be attached to a computer system that will "tell" the drill motor how fast to drill depending on what the spectrometer readings are. The motor may drill into the surface from 0.0825 to 0.49 cm/min. This results in the samples taking from 30 to 180 minutes to drill.

At each level that drilling will take place, two samples will be taken. This will be done using two separate drills situated opposite each other within the drill cylinder. Two samples will be taken in case one becomes damaged. This will also allow two separate samples to be analyzed more carefully once returned to Earth.

3.2 Sample Return

As the drills pull the sample into the cylinder, the sample will remain within its respective hole as the drill bit pulls out into the upper portion of the cylinder. With the top portion of the cylinder immobile, the lower portion turns 20 degrees, thus positioning the next two holes beneath the drills. This cycle repeats itself until 18 samples have been taken. At this point, the MADEX returns to the cliff top and moves to the base.

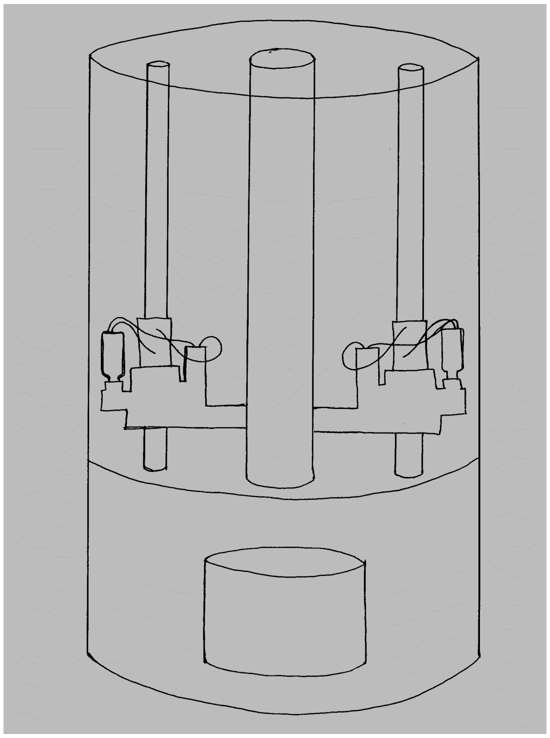


Figure 3.2.1 MADEX Drill Cylinder

Once the MADEX reaches the base, a mechanical arm reaches down and pinches the top, thus "unlocking" the drill cylinder. The cylinder is then removed and placed within the base. An empty cylinder is then placed in the MADEX so that collection may resume. As collection is performed, the base removes, labels, and stores the samples from the first cylinder. When the unit again reaches the top, the cylinders will be switched again.

This system requires two cylinders to be sent. As a precaution, however, a third will be sent. Thus, in case one of the drills is damaged, two cylinders are still available. Thus, in total, six drills must be sent.

{ EMBED MSWorks.Sheet.4 \s **}**

Figure 3.1 Drilling Force Applied at Various Inclines
(Assuming MADEX weighs 750 lbs. on Earth)

4. Spectrometers

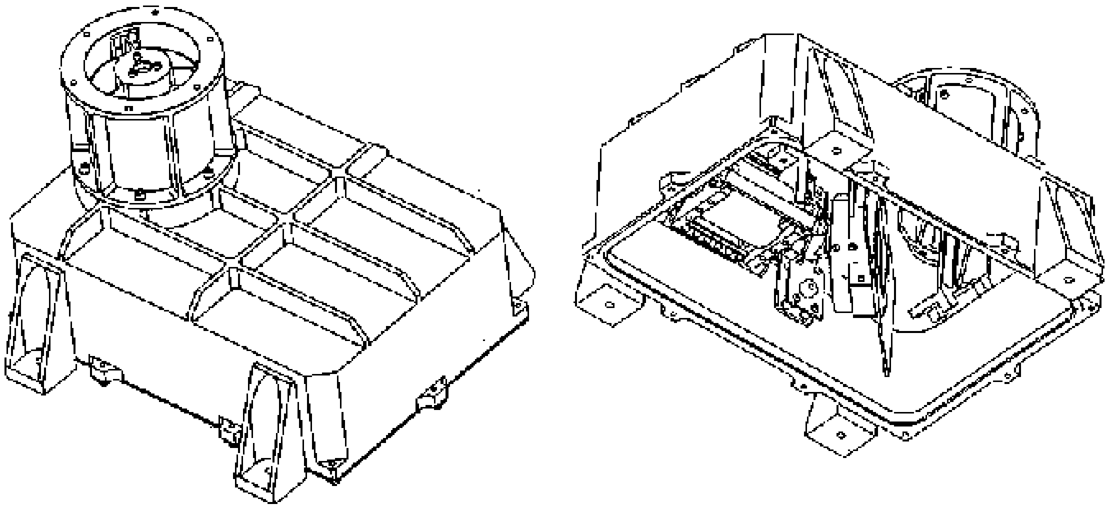
Spectrometers play a vital role for the MADEX. They will assist in uncovering some secrets of Mars by revealing: the proportions of soil bearing elements on Mars, locations of the geologic layers in the soil, previous hydrothermal settings and areas of volatility, and possible water tables.

There are different types of spectrometers with a wide variety of capabilities. One is the Thermal Gas Analyzer (TGA). Using the highest quality laser spectrometer technology, this spectrometer seemed to be the best in its field. However, due to its physical and power requirements, we found that it was impractical for the MADEX. TGA analysis of samples taken by the MADEX is desirable. It may be practical for the TGA to be at the habitat or on Earth rather than at the cliff, itself.

Two other spectrometers that we found to be more practical for MADEX were the Mini-TES and the Mössbauer spectrometer. Both are practical due to size and mass. One of each of these spectrometers will be placed on the MADEX and used at each stop made by the unit.

4.1 Miniature Thermal Emission Spectrometer (Mini-TES)

The Mini-TES, (Figures 4.1.1 and 4.1.2) which is currently being designed by Arizona State University and the Hughes Santa Barbara Research Center, will address geologic and atmospheric science objectives through the study of the mineralogical and physical properties of Martian rocks. The Mini-TES excels at the recognition of aqueous minerals, such as salts that were formed on hydrothermal springs. Salts can provide us with valuable information on the evolution of the atmosphere and its interaction with the surface. The Mini-TES will also search for carbonates, sulfates, phosphates, condensate, hydroxides, oxides, and silicates. In addition to mineralogy, the Mini-TES is able to provide information on thermophysical properties of rocks and soils. It can measure dust aerosol abundance, condensate, gas content, and pressure of the atmospheric boundary layer.



Figures 4.1.1 and 4.1.2 Miniature Thermal Emission Spectrometer

The Mini-TES is designed so that it can examine a specimen as small as 1 mm and determine the mineralogy of the individual grain. The Mini-TES can acquire useful data in 16 seconds in 20 µRad mode or in 120 seconds in 7 µRad mode. The system takes data from wavelengths within the range of 5 to 40µm. This range allows the instruments to penetrate through dust coatings and weather rinds on rocks. The Mini-TES is set up in such a way that the fore-optics, spectrometer, and electronics may be configured in whichever fashion would effectively utilize space within MADEX.

Table 4.1.1 Miniature TES Specifications

Parameter	**Mini-TES**
Spectral Range	2 – 25 µm
Spectral Resolution	10 and 5 cm^{-1}
Field of View	5 and 20 mrad
Detectors	Uncooled Deuterated Triglycine Sulfate (DTGS) Pyroelectric
Cycle time per measurement	1 and 2 sec
# scans to achieve SNR of 400 at 10 cm^{-1}	15 (on 20 mrad); 110 (on 5 mrad)
Bits per spectral sample	12
Bit Rate	2-6 bits/sec
Size	18 x 20 x 32 cm

Mass	1.9 kg
Power	4.4 W operating; 0.28 W daily average

The Mini-TES has the ability to take data 360° around its position by means of a scope. Because the main focus of data collection by the MADEX is the cliff wall, this scope is not essential. Without the scope, the Mini-TES has a mass of 1.9 kg, and uses 4.4 W of power.

4.2 Mössbauer (MOS)

The Mössbauer specializes in detecting the oxidation states of iron-bearing elements. Oxidation states are the key to determining the ratios and the timeline of the various rock and soil compositions and might lead us to areas of high volatility such as a water table.

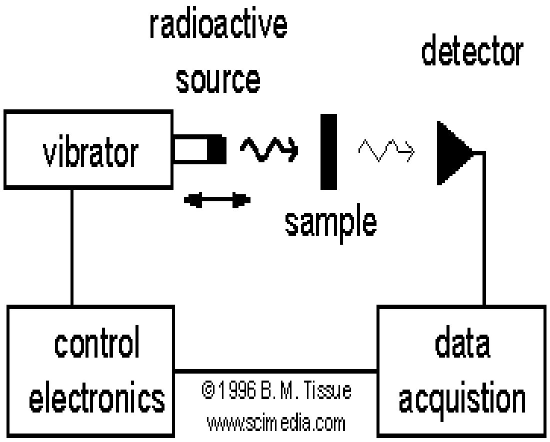


Figure 4.2.1 Mössbauer Spectrometer

The Mössbauer excels in the magnetic study of ferromagnetic samples taken (Table 4.2.2). The Martian soil consists of different levels of oxidative magnetic iron-bearing compounds such as magnetite, maghemite, and pyrrhotite, which bears directly on the formation of different rocks throughout geologic time. This will give us information as to whether Mars has had large river valleys or other types of environmental or chemical weathering. The MADEX is not time limited. Core samples will be taken cautiously and slowly. After each sample is taken, the Mössbauer will take temperature readings and provide information on the magnetic phases and, subsequently, information on the different layers of Martian rock.

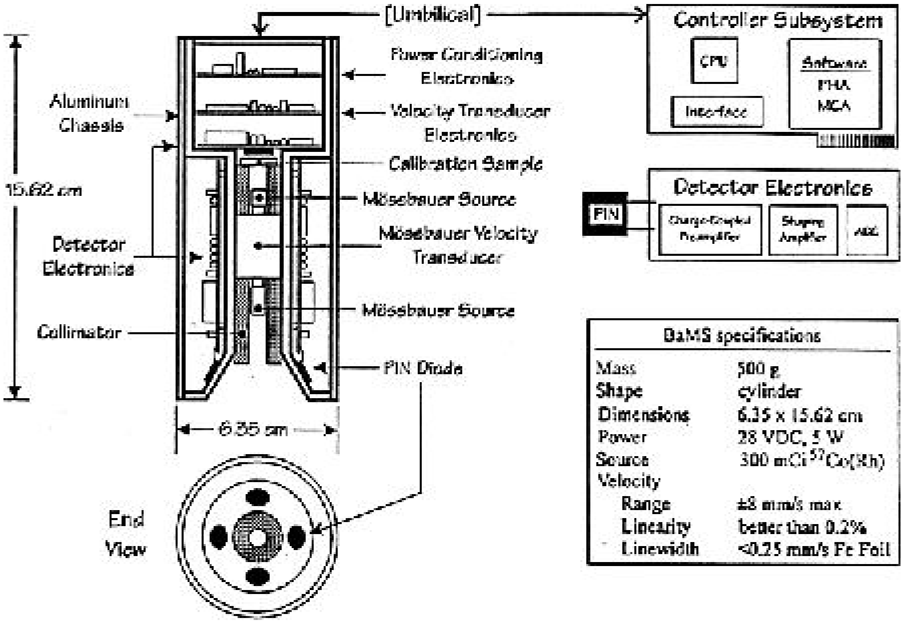
Though the Mössbauer excels at recognizing those compounds listed in Table 4.2.2, it is also useful at detecting other mineral groups such as silicates, carbonates, phosphates, and nitrates, which are vital in determining precious geologic information on the layers and the environmental activities.

Table 4.2.2 Mineral Phases and Detection Limits

Mineral Phase	Detection Limit (%)
Hematite (αFe_2O_3)	2.0
Maghemite (γFe_2O_3)	2.0
Magnetite (Fe_3O_4)	2.0
Goethite ($\alpha FeOOOH$)	2.0
Lepidocrocite ($\gamma FeOOOH$)	0.3
Triolite (FeS)	1.0

Siderite ($FeCO_3$)	0.6

The Mössbauer spectrometer is extremely small (250 cm^3) and uses very little power (0.6 W). The Mössbauer is therefore practical for application with the MADEX Unit. Other benefits of the Mössbauer are that no sample preparation is necessary, thanks to the use of back scatter geometry (Figure 4.2.1 and 4.2.4), and it is designed to electronically store the collected data within itself. Despite this advantage, the data will be sent to the base atop the cliff as a safety precaution.



BaMS specifications	
Mass	500 g
Shape	cylinder
Dimensions	6.35 x 15.62 cm
Power	28 VDC, 5 W
Source	300 mCi ^{57}Co(Rh)
Velocity	
Range	±8 mm/s max
Linearity	better than 0.2%
Linewidth	<0.25 mm/s Fe Foil

Figure 4.2.3 Mössbauer Spectrometer

Table 4.2.4 Mössbauer Spectrometer

MOS	Mass (kg)	Dimensions (cm)	Op. Power (W)
Electronics	0.15	1.0 x 4.5 x 8.0	0.6
Sensor	0.25	3.1 x 4.5 x 8.0	

5 Power

5.1 Batteries

We have selected batteries made by Northwest Energy Storage (NWES) for use with the MADEX. NWES’ Deka batteries have an output of 12 Volts, and 180 amp hours (2.25 kW-hrs). Each battery weighs 168 lbs. and is 10” x 11” x 20.8”, and costs $419 from the company. The Deka battery utilizes Gel-Cell technology, which allows the battery to work without damage at temperatures as low as -40° C. The battery’s capacity drops by only 2% every month.

By setting up a number of these batteries in parallel we would be able to leave the site unattended for longer periods of time and allowing more time to charge up the replacement batteries.

Table 5.1.1 Battery Specifications

Model	NES GC-8D
Volts	12
Amps Hours	180
Watt Hours	2,250
Dimensions (inches)	20.8 x 11 x 10
Weight (lbs.)	168
Cost	$419

5.2 Human Activity Recharging Trainer (HART)

The crew's health, both mental and physical, is vital to the success of this mission. With this in mind, MADEX will include the HART system. HART will allow the crew to perform the many necessary hours of exercise to maintain muscular strength. In addition, HART will provide power to operate MADEX and its subsystems. HART will also satisfy the goal of using available resources. Without a system similar to HART, the valuable energy expended during the crew's exercises would be wasted.

The need for exercise in a low-g environment is strongly supported by human experience aboard the MIR Space Station. The cosmonauts, who did not do their exercises regularly, required stretchers upon return to Earth, whereas the American Astronaut Shannon Lucid walked away by her own power. She followed her exercise routine daily. This physical activity, likewise, is needed to help astronauts keep their strength on their journey to Mars so they are productive upon arrival. The micro-g during space travel is replaced by a 3.8-g environment on Mars. Human exercise is a key part of the daily life on Mars. HART simply uses the energy for a meaningful and desired purpose.

5.2.1 Health Benefits

HART offers both mental and physical health benefits to the crew. The system will train both the upper and lower body, by means of pedals and a pair of reciprocating handlebars in the form of an exercise bicycle. An alternator and flywheel assembly will provide resistance for the astronauts.

The mental health of the astronaut will also benefit from HART. The astronauts will tend to feel that they are more in control of the fate of the mission. Without this motivation, they may become overwhelmed by work and ignore their physical needs. The trainer will force them to use the equipment in order to power one of the critical pieces of scientific equipment. Exercise has also been proven to relieve stress. The surface of Mars will be an extremely high stress location, and being able to get away from this situation without feeling guilty will be invaluable to the future astronauts.

5.2.2 Power Supply Benefits

The HART system will deliver the power that the MADEX requires to operate. The human body can generate approximately .5 hp for up to an hour (Figure 5.2.2.1). If a crew of six astronauts each exercises for 60 minutes every day, a total of 2.237 kW-hrs will be produced each day. This will approximately charge one battery to completion. However, losses are inherent with a charging device. We are approximating a 20% efficiency. This would mean that one battery would be fully charged in about five days.

5.2.3 Design

HART will use a basic stationary bicycle set up with some minor adjustments. The pedals and arm booms will turn a gear which, in turn, will spin an alternator (Figure 5.2.3.1) used to charge batteries. The battery will have a small LED which will indicate when the battery is fully-charged. At this point, a new battery is connected to the alternator allowing for more exercise and stored power.

{ EMBED Word.Picture.8 **}**

Figure 5.2.2.1 Human Output

{ EMBED Word.Picture.8 **}**

Figure 5.2.3.1 HART's Alternator

6 Results

Once the MADEX returns to the top of the cliff wall, the core samples will be returned to Earth. With the ability to use equipment unavailable or impractical to send to Mars we will be able to further analyze the samples. In comparing data taken on the surface with experimentation of the samples on Earth, we could create a timeline of Mars' history. We would know what the Martian planet is composed of. We would know where to find a supply of water. If we are extremely lucky, we will find fossils within the samples proving that life has existed on Mars. If not so lucky, we will know how deep to look for possible fossils. We will know much more about Mars than we know today.

7 Conclusion

MADEX is a design which we believe has great potential. While in its conceptual stage there are still a number of issues to be explored and resolved. Primarily stability while on the cliff face with regard to overturning due to wind and the lack of normal force desired to overcome the drill force reactions. We believe that the former has been sufficiently addressed by the use of outriggers previously mentioned. The latter case could be resolved by the use of pitons fired into the rock wall and then anchored to for drilling, or perhaps an auger system that screws itself into softer mediums. In either case once the drilling at the particular level is completed the anchor is released or unscrewed and the MADEX is moved to the new location.

Additional areas of further research are listed in *Figure A.* Any and all of our proposals will be fully tested and modified when NASA adopts the design.

Table 7.1 MADEX Specifications

Part; quantity	Mass (per) (kg)	Power Required (per) (W)	Volume (cm^3)
Drill; 2	2.2	20	TBD
Drill Bit; 2	TBD	N/A	N/A
Drill Cylinder; 1	TBD	Negotiable	~24,000
Mössbauer; 1	0.4	0.6	147.6
Mini-TES; 1	1.9	4.4	11,520
Computer; 1	TBD	TBD	TBD
Sonar; 2	TBD	Negotiable	TBD
Tread Motor; 2	TBD	TBD	TBD
Leg Motor; 4	TBD	TBD	TBD
Sum of Known Parts	6.7	45	35,667.6

Future Studies

1. Exploration of Different Locations

By exploring more locations (*Figure A*) with the MADEX, we will create a more general timeline for Mars. We will then know approximately where to find different layers at various positions around the Martian planet.

Figure A Landing Sites For Future MADEX Missions

Site	Location	Landform	Reason for Interest	Problems With Site
Chasma Boreale	85 N, 110 W	Canyon in polar regions; between the residual ice cap and layered Martian terrain	Conducting climatic studies; further analysis of ice caps	High latitude may cause difficulty in utilizing human interaction
Ganges Chasma	10 S, 45 W	Canyon in Valles Marineris	Study debris from large landslide and more analysis of cliff layers	N/A
West Candor region (primary site selected for SIMM manned mission)	6 S, 75 W	Canyon in Valles Marineris	Further analysis of layering on Mars	Difficult terrain; the proposed site is 50 km from canyon wall

2. Materials

Studies exploring what materials best suit the MADEX unit are necessary. Cost, weight, and coefficient of expansion are all important factors that must be considered. The MADEX frame, treads, lubricants, and cables.

3. Testing

Once the first MADEX unit is created, tests must be run to ensure the reliability of the unit. First the MADEX must be tested in normal Earth conditions followed by fine tuning of communications and storage use. Then the unit must be tested in simulated Mars conditions, such as in Antarctica. This must be followed by further fine tunings. One the unit proves to work efficiently, it is ready for use on Mars.

4. Backup System Check

It must be ensured that if something goes wrong when the unit is put to use on Mars, any necessary repairs may be done by astronauts present on the surface or automatically by systems present in the base.

5. Exploring the possibility of a portable MADEX unit

Further development of the MADEX may lead to the possibility of a system where one cliff is fully explored before the unit is moved to another cliff on Mars. Should this be possible, a better understanding of the entire planet's composition and history could be achieved.

Bibliography

Abott, Alan V., and David G. Wilson. *Human-Powered Vehicles*. Illinois: Human Kinetics, 1995.

Agresti, David G. University of Alabama at Birmingham. "Backscatter Mössbauer Spectrometer (BaMS)." Online. Available **{** HYPERLINK http://www.phy.uab.edu/exobiology/bams.html **}**, 19 April 1999.

Chappell, David T. "Mars Information Page-Home Page." Online. Available **{**HYPERLINK "http://krypton.dorm.duke.edu/Mars/filelist.htm"**}**. 12 April 1999.

Christensen, P. R., D. L. Anderson, S. C. Chase, R. N. Clark, H. H. Kieffer, M. C. Malin, J. C. Pearl, J. Carpenter, N. Bandeira, F. G. Brown and S. Silverman, Thermal Emission Spectrometer experiment: The Mars Observer Mission, *J. Geophys. Res., 97, 7719-7734*, 1992.

Christensen, Philip. Arizona State University. "Miniature Thermal Emission Spectrometer (MINI-TES)." Online. Available **{** HYPERLINK http://phy.uab.edu/exobiology/minites.html **}**, 26 April 1999.

Garcia, Patty. "PDS Planetary Image Atlas- Mars Levels Page." Online. Available **{**HYPERLINK "http://www-pdsimage.wr.usgs.gov/PDS/public/explorer/html/marslvls.htm"**}**. 7 April 1999.

Goodall, Kirk. Mars Global Surveyor MOC2-59 Candor Chasma Release. Online. Available **{**HYPERLINK "http://mars.jpl.nasa.gov/mgs/msss/camera/images/7_20_98_marineris_rel/index.html"**}**. 7 April 1999.

Jet Propulsion Laboratory. "Technology Development and Information: Drill." Online. Available **{** HYPERLINK http://esb.jpl.nasa.gov/drill.html **}**, 26 April 1999.

Kyle, C.R. *Ergogenics for bicycling.* In D.R. Lamb & M. H. Williams (Eds.), {Perspectives in exercise science and sports medicine: Vol. 4. Ergogenics: Enhancement of performance in exercise and sport.} William & Brown: 1991

Moersch, Jeffrey E. "Mössbauer Spectrometer." Online. Available **{** HYPERLINK http://helio.estec.esa.nl/intermarsnet/redreport/node77.html **}**, 4 April 1996.

Northwest Energy Storage. "Batteries." Online. Available **{** HYPERLINK http://www.nwes.com/page6.html **}**, 26 April 1999.

Polar Power, Inc. "3500 and 6200 Alternators." Online. Available **{** HYPERLINK http://polarpowerinc.com/products/alternator/3500&6200alternator.htm **}**, 24 April 1999.

Sjogaard, G., Nielsen, B.< Mikkelsen, F., Saltin, B., & Burke, E.R. (1982). {Physiology in bicycling.} Ithaca, NY: Mouvement.

Squyres, Steve. "Mössbauer Capabilities." Online. Available **{** HYPERLINK http://astrosun.tn.cornell.edu/athena/text/moessbauer/node2.html **}**, 28 November 1997.

Swain, D.P., Coast, J.R., Clifford, P.S., Milliken, M. C., & Stray-Gundersen, J., (1987). *Influence of Body Size on Oxygen Consumption During Bicycling.* {Applied Physiology.} 62(2), 668-672.

Tissue, Brian M. "Mössbauer Spectroscopy." Online. Available **{** HYPERLINK http://www.scimedia.com/chem-ed/spec/material/mossbaue.htm **}**, 12 September 1996