MINING WITH LIMITED FORCE TOOLS AND MICROSCALE MINING MACHINES. THE ANTS OF TOUTATIS L. P. Quinn, Chief Designer, The Martian Embassy LLC, Lakewood CO 80215 louis@marsemb.com

Introduction

Early in mans rise to our present technological plateau mining was done by heating the rock face and then quenching it with water. This would shatter the rock; this is called the thermal stress method. Later iron metallurgy gave miners picks and bars, wedges and gads, tools hard enough to drive into natural cracks in ore and force them apart.[i]

Technology for mining on Earth has moved beyond these tools. With the invention of rock drills and dynamite, technologies that consume large amounts of power and materials became the standard method. I suggest a reexamination of the older mining technologies and continuing their evolution with a different set of modern technology and methods. These older tools evolution had stopped when the new inventions became clearly superior for mining on Earth, but the evolution of these tools could continue on asteroids and possibly planets.

One of the evolved tools would be an adaptive wedge that could move deeply into fractures and fissures.

Another tool design evolved from the pickaxe, powered by heat differentials, could develop significant amounts of kinetic energy in small areas.

Still another tool design would be a solar powered rock crusher, to break rocks into fragments suitable for further processing.

And for moving, separating, and segregating materials, a miniature robotic Ant. It would have the ability to make crude separations of material from the crushed rock.

The adaptive wedge would work by taking advantage of materials that can change dimensionally. The wedges could use the principals of piezoelectric, magnetostriction, and thermal expansion. When the adaptive wedge is at its minimal dimensions, it is placed into a fracture. The wedge then increases its dimensions to force the fracture. The vibrations generated by the impacts of an evolved pickaxe could also power the wedge. Acting together with an evolved pickaxe, the wedges would exploit the minute vibrations created by the impact of the pickaxe. As these vibrations open and close cracks minutely, the wedges could creep deeper into the cracks and act to widen them. This would also pin some of the motion and resiliency of the rock to allow the evolved pickaxe to more effectively transmit kinetic energy to those points holding the rock face together.

The evolved pickaxe could use a thermal spring to power it. A thermal spring could be manufactured from a bimetallic material similar to those used in mechanical thermostats. It could be coiled much like a standard spring. When heated the spring would stretch out. The thermal spring could be positioned behind a mechanically latched weight. The spring would be heated and its thermal elongation will generate compressive forces. Releasing the latch holding the weight will accelerate the weight into impact with a cutting head. To reset the spring, just remove the heat source, it will cool and pull the weight back into its latched position. The difference between sun and shadow on an asteroid could power the evolved pickaxe.

The solar rock crusher would take advantage of thermally expansive materials or shape memory alloys. These mechanical effects could either, crush the material as in a vise, or both shear and crush the material, as in a mortar and pestle.

The Ants would provide mobility, crude analysis, and the basis for a multifunctional platform. With small sensors positioned near their “jaws”, they could determine if the fragment they were carrying were magnetic or conductive. This could be a first step in segregating materials for processing.

The mining of asteroids using the equipment and techniques that are available on Earth would be economically prohibitive due to the weight and size of the equipment used. Given the limiting factor of launch weight and the need for equipment redundancy, mining based on the use of swarming microrobots and adaptive mechanics would allow mining to be done, albeit at a slower pace. Advances in micro-fabrication, microassembly techniques, and robots with insect-like intelligence, a micro-robot with the capability to aid in mining hard rock could be designed.

These Ants could be an important part of a mining system for asteroids and planetary surfaces. Like the insects, the Ants would have a hierarchy of functions. The larger ants could move the rock pieces broken loose by the pickaxe to the solar crusher, while smaller Ants would sort the crushed material into segregated piles. Some functions would remain on the surface of an asteroid to generate power, and maintain communications to transmit and receive data with Earth.

Control of the relatively unintelligent Ants would be with a Central Artificial Intelligence that would coordinate their activities. Understanding the physical area of the control environment and obtaining relevant information from the Ants would be significant problems that are not well understood at this time. This can be overcome by experimentation. Current robotic colonies have few members and can perform only simple tasks due to the cost of building and maintaining large colonies of robots. These limitations on the type, complexity, and cost of robot colonies can be overcome by microrobots. Microrobots could be prototyped in large numbers, then used in concurrent experiments. Theories of robot colony control could be put to the test on actual rocks. The algorithms that control the colony could be modified and tested rapidly, under realistic conditions. Kind of an Ant farm.

The mining operation would obviously be a very slow process, a process that would work over long periods of time to complete large excavations or significant ore extraction. The primary advantage of such a system would be a very light launch package with a lot of redundancy.

Toutatis was placed in the title, because it is a very near earth-crossing asteroid that could be a potential long-term threat to the planet, and to Human civilization. If a small colony of these robots were landed on Toutatis, they could investigate the nature of the asteroid to determine its composition and structure. If it were then necessary to excavate a hole to place the nuclear charges to divert the asteroid, the Ants could see to this task. Or the hole could be drilled as a precaution to allow placement of nuclear charges at some future date.

I believe these ideas would require a multidisciplinary approach that is far beyond the resources at my command. I am sure that, as different people with different backgrounds, examine these ideas many unique uses will come to mind.

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[i] Larry C. Hoffman, The Rock Drill and Civilization, Invention and Technology summer 1999 pages 56-63

Microrobots as Analytical Tools

A mobile robot that could move down into fissures within the rock face could allow spectrographic analysis of rock several meters from easily accessible surfaces. The mobile robot could pull along two optical fibers, one to carry a large laser energy pulse to vaporize the rock and produce an optical spectra from the plasma. The second fiber is used to carry the light from the plasma for analysis. These two optical fibers could be combined. A larger system using these principles is called the LIBS Laser Induced Breakdown Spectroscopy. A PDF is attached.

Pillar Stack Ants

One of the more useful designs for rock fissure exploration would be a dual pillar stack design. The pillar stack would represent the smallest functional unit of the ants. The design would allow motion and movement along several different planes or axis. One pillar would remain wedged in between the walls of the fissure, in a static state, while the other moves. This could either be an inchworm type of movement or a side-by-side walking H movement.

Another use for the static pillar would be to obtain energy from vibrations sent through the rock. The mechanical energy of the vibrations would be converted to electrical energy by the piezoelectric pillars. This electrical energy could be used to power the other ant functions and motions.

This vibration energy would also be used to power the logic electronics. The processor would activate for short intervals, then store data in meta-stable memory. It could develop a Braille map of its environment and then keep this in memory. Another form of intelligence the ants could have may be resonant intelligence. The ants would apply a brief pulse of force and then observe the reaction of the rock to it. The ant would again pulse, but this time it would pulse again at the natural frequency or echo of the rock. This would set up a resonance in the rock, greatly strengthening the effect of the ants. Further these echo’s could give information on the presence of other fissures and structures within the rock body. This three dimensional map could aid in efficient planning for mining operations.

The vibrations for powering the ants could be generated by tapping on the external surface of the rock above the ants or by piezoelectric or magnetostrictive transducers sunk into the rock, nearby. This would transmit vibration energy through the rock, which would cause the rock crack to shrink minutely, squeezing the static pillar and generating an electrical charge. This charge would then be converted to electrical energy for the other ant functions. External electrical sources would not be needed to operate, or wire to, the ants.

Microrobots

Determination of conductivity or magnetic properties can be done with simple techniques, which can be miniaturized. A simple method would be a small magnet, a Hall Effect device, and an inductor that is a component of a resonant frequency circuit, are built into a microrobot. A magnetic material near the robot would cause a change in the field of the magnet, which the Hall effect device could detect. The frequency of the resonant circuit will also change in the presence of the magnetic material. In the case of a conductive material the inductor resonant frequency would be affected, but not the Hall effect device. These detection principals have been used in metal detectors for many decades.

A potential energy source for microrobot actuators could be thermal differences. A low power way of creating these thermal gradients would either being blocking or allowing sunlight to pass through a liquid crystal shutter. When the crystal segment is optically blocking, light transmission to the object shielded by the liquid crystal shutter will remain cool. When optically conducting, sunlight will pass through the shutter and be absorbed by the thermally affected component. Liquid crystal displays are capable of running on very little power and this power usage will leverage another source of power, sunlight.

The thermally affected component could be thermally expansive materials, memory metals such as Nitinol, and fluid or gas filled tubes.

Potential problems for a liquid crystal shutter.

1. Operation in a vacuum
2. Temperature extremes breaking down the chemistry.
3. Size and weight of the liquid crystal assembly.
4. It would be preferable if an electrically activated paint or polymer were developed with photo shuttering properties. Speed of operation would only need to be about a second.

Thermally sinking the heat would also be a problem in operating the robots. If the robots were operating below the surface where temperatures will be below 0°c, this thermal sink would not be necessary. Light could be “piped” to the underground mobile robots through optical fibers. Optical fibers could maintain flexibility over wider temperature extremes than metallic conductors. A robot that would occasionally move into shadow would also need this optical fiber tether. An optical checkerboard of shadows could allow for the highest efficiency of transport, the shadows would allow the thermal sink to cool down.

Another use for microrobots would be for optical steering. Used to control reflectors in the weak gravity of an asteroid, they could track the sun and focus sunlight onto optical fibers. The optical fibers could bring sunlight underground for heating and potentially cutting rocks. This would require knowledge of their position relative the target position and the sun. The microrobots could also heat a small furnace by steering the reflections from mirrors on the surface.

As the Ants, (microrobots), pick up something, they could flip it back into one of several bags or carriers they are pulling along with them according to some loose sorting criteria. This would give them the mass to allow digging into the compacted regolith when they detect something of interest. They could use an arc from a piezoelectric stack to allow for crude spectrographic analysis, kind of like the flame color in chemistry class.

MINING

Project Fact Sheet

Mine Compatible Laser Analysis Instrument for Ore Grading

Benefits

- Estimated energy savings of 1.3 trillion Btu per year by 2020
- Decreases wear on equipment by avoiding low quality ore
- Increases production time on high quality ore
- Decreases processing and transportation costs

Application

The laser analysis instrument being developed applies to all surface mining applications. This technology can also be used in various other industries. Specific examples include: the process control of steel production, monitoring off-gas emissions, and thermal waste treatment.

In-situ analysis tool reduces amount of ore to be processed by avoiding low quality ore

Laser Induced Breakdown Spectroscopy (LIBS) is an important new analysis technology that permits fast, direct, inorganic analysis without sample preparation. Presently, most surface mining operations rely on laboratory-based analysis to monitor the extraction process. This method includes numerous steps that increase the chance of contamination and error, and increases the time for analysis. X-ray fluorescence is the commercially used method for in-situ analysis of ore, but its instruments contain radioactive sources that must be regulated, and they lack the sensitivity needed to identify a variety of elements in different sample matrices.

LIBS technology will improve the efficiency of mineral ore extraction through real-time measurements of ore quality. The cost savings are realized by reducing the out-of-seam dilution of the ore being recovered, transported, and processed, without increasing the cost of sampling and analysis. Also, because the proposed instrument is capable of measuring virtually all inorganic elements, it is directly applicable to all surface mining applications. Use of this rugged technology will improve the energy efficiency of mining and processing of ore by limiting the need to move excess top soil or overburden.

LIBS Instument

LIBS instrument (left) performing analysis at mine site (right).

Project Description

Goal: To better understand the composition of ore at the rockface and during transport to ore processing facilities using new laser analysis technology.

Laser Induced Breakdown Spectroscopy (LIBS) is an ideal analytical method for real-time quantitative analysis of inorganic elements in solids and liquids and requires no sample preparation. In laser spectroscopy, a laser pulse is focused to a spot just above the sample surface. This intense radiation initiates a series of processes including the formation of a hot plasma cavity above the sample that ablates a small amount of material from the sample surface into the hot plasma cavity. Ablated atoms that enter the plasma region are dissociated and ionized. Time-resolved optical emission spectra are collected from the plasma fireball and analyzed to determine the wavelength and intensities of the line radiation from constituent elements of the sample material. The major spectral lines in this data are compared with a stored database to determine the identity and determine the concentration of the constituent elements. Using this technique, sensitivities of parts-per-million have been achieved for a variety of elements in different sample matrices.

Progress and Milestones

This project includes the following activities:

- Compile detailed requirements for the LIBS field instrument
- Design and test a pre-production prototype instrument
- Manufacture an instrument for on-site testing
- Perform an extended on-site demonstration

Project Partners

Idaho National Engineering and
Environmental Laboratory
Idaho Falls, ID

Advanced Power Technology
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Washington, DC

JR Simplot
Pocatello, ID

Chemostrat
Houston, TX

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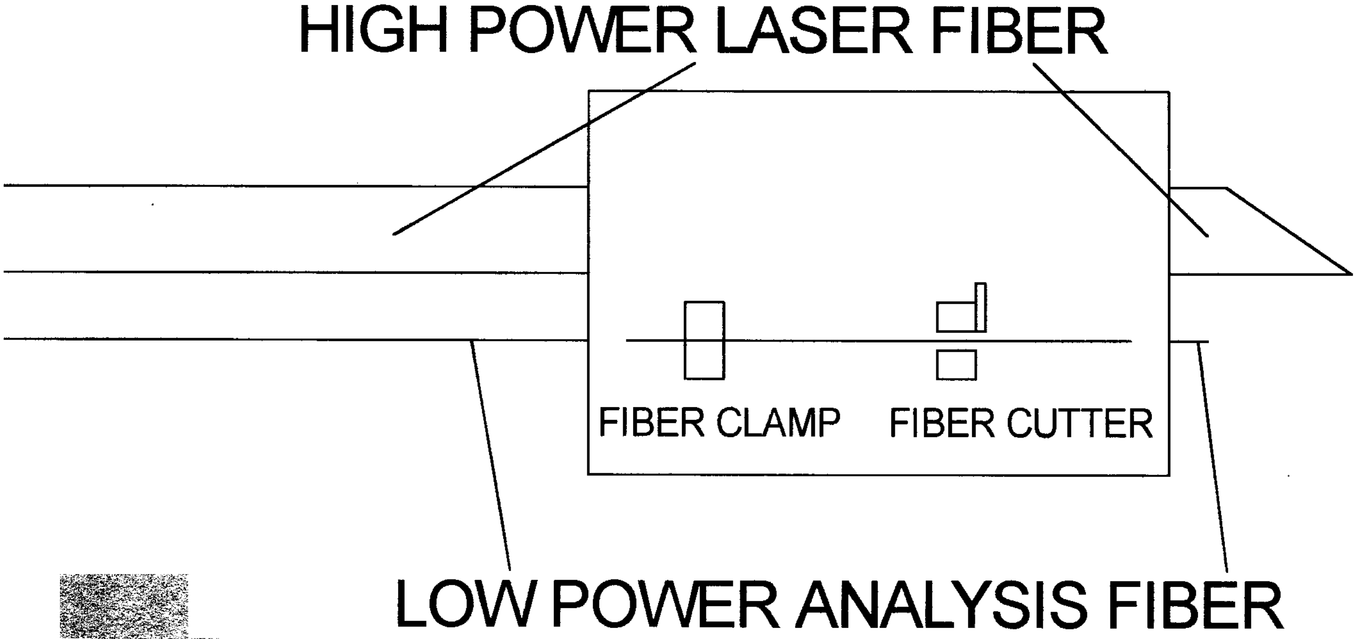
OIT

November 1999
(Revised August 2001)



BLOCK DIAGRAM EXPLORATION ANT

Exploration Ant Block 1	
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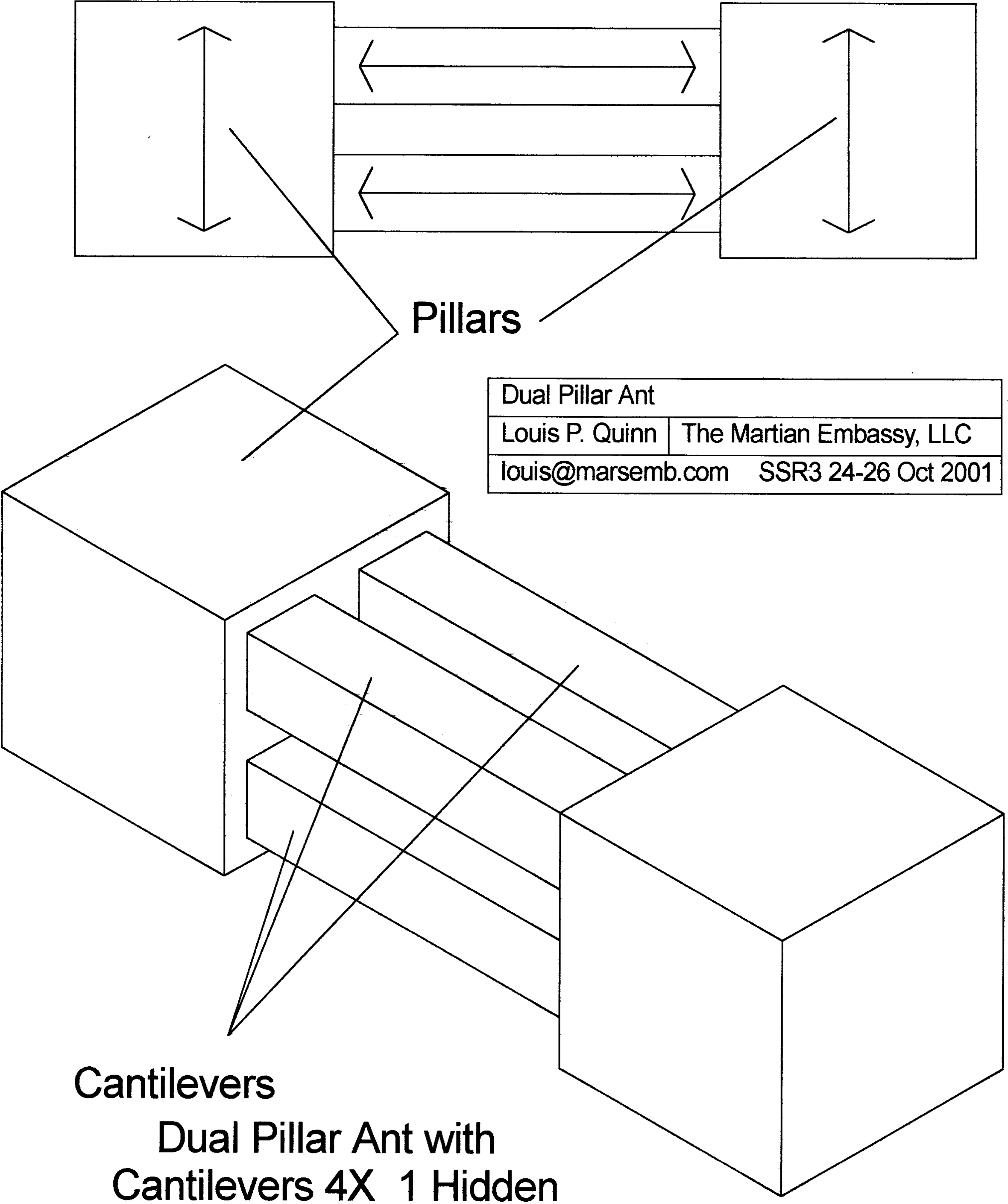
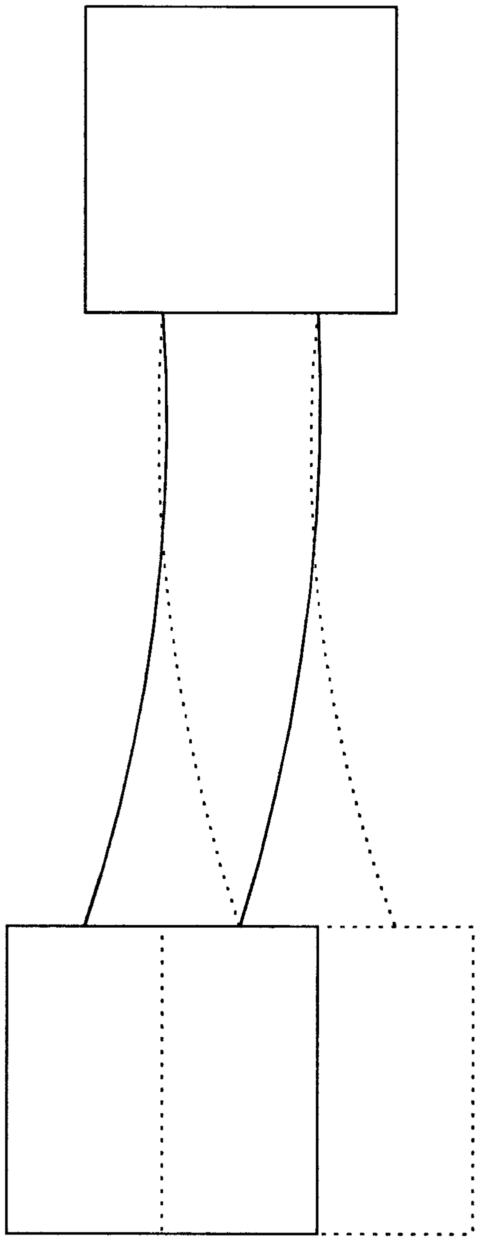
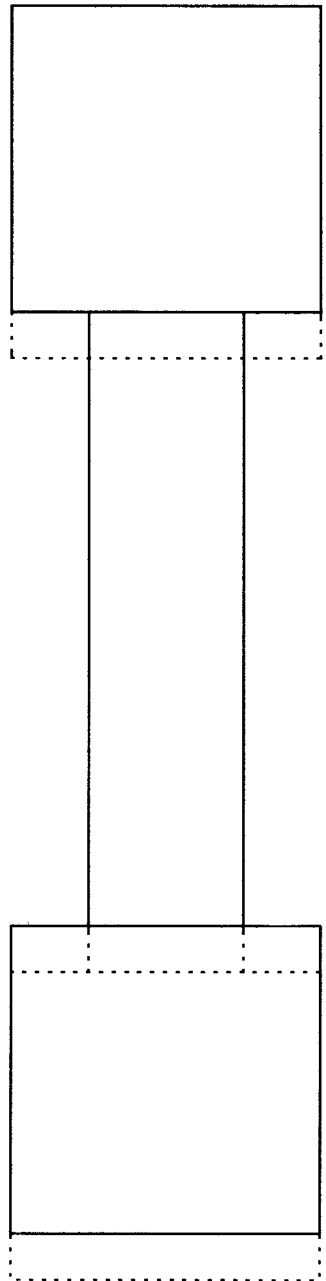


Dual Pillar Ant with
Cantilevers 4X 1 Hidden



Left and right motion of center cantilever.



Elongation of Pillar for inch worm extension

Turning Cantilever 1	
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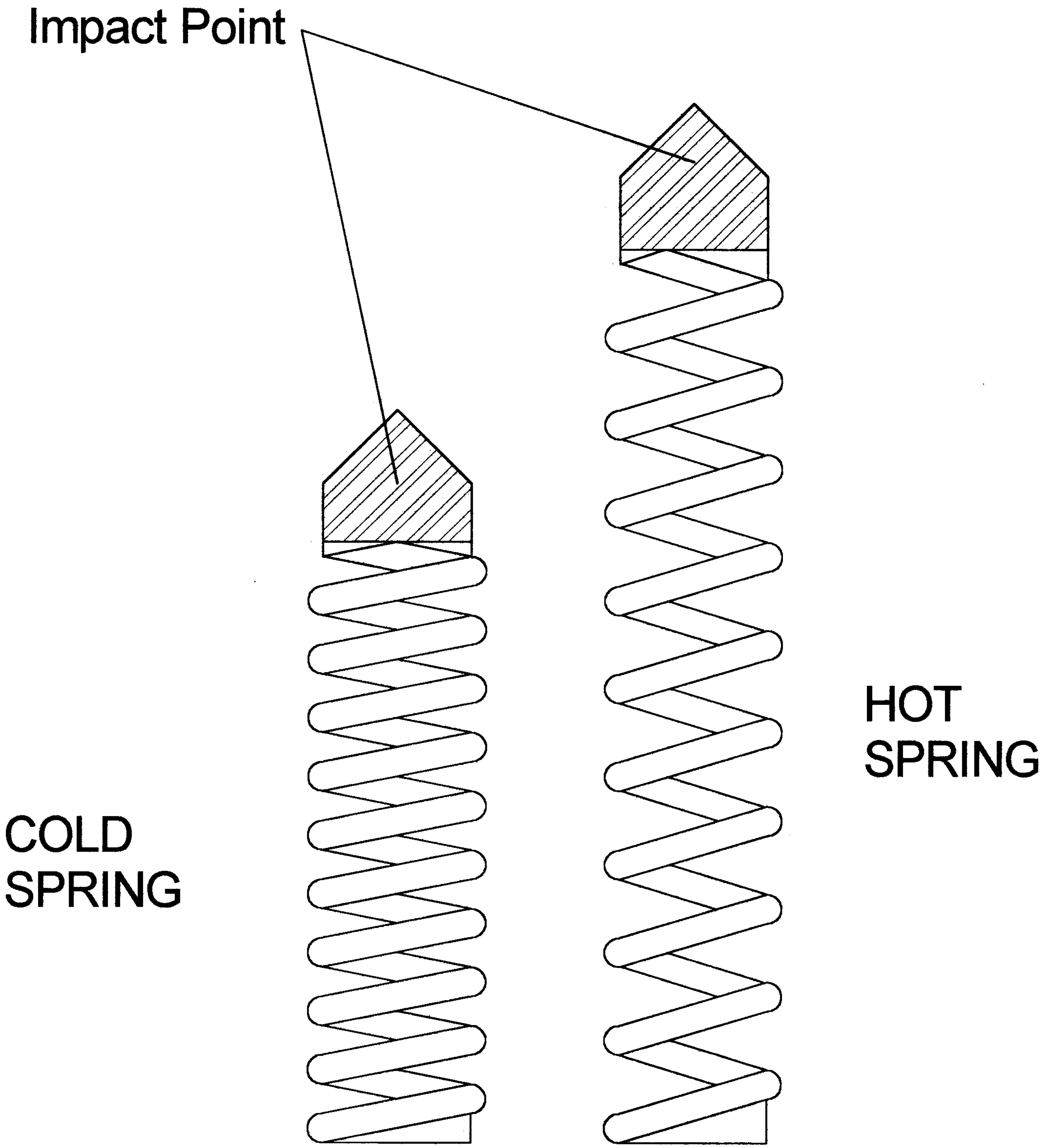
The Thermal Spring Powered Pickaxe

A form of evolved pickaxe that could incorporate a thermally compressed spring. The spring would differ from the ordinary spring by the material from which it is constructed. It will be made from a bimetallic material similar to those used in electromechanical thermostats. As the spring gets hotter it lengthens, its expansion will be restricted behind the mechanically locked impact point. The thermal expansion will build up a large amount of force with a large increase in temperature. This spring is attached to, and will drive forward, an impact point. The impact point will transmit kinetic energy and shattering force to the rock face.

The spring will be shortened and the impact point returned to its locked position by shielding the spring body from sunlight and allowing the spring to cool back down. As it cools, the spring will shrink, pulling the impact point back to its locked position. When the impact point is locked, the spring body will again be exposed to sunlight or a similar heat source, lengthening the spring. The spring will then press with increasing force on the impact point till the impact head is released to strike the rock face again.

The spring body could be shielded from the sun by a moving reflective panel or by a liquid crystal filter that could let sunlight through, using only a small amount of electrical power.

Another form of an evolved pickaxe is essentially a modified crossbow. It can generate significant velocity and high enough impact forces to be suitable for a good mining pick. With the use of spaced sliding weights in the bolt, it could generate multiple impacts from a single release.



Thermal Spring 1	
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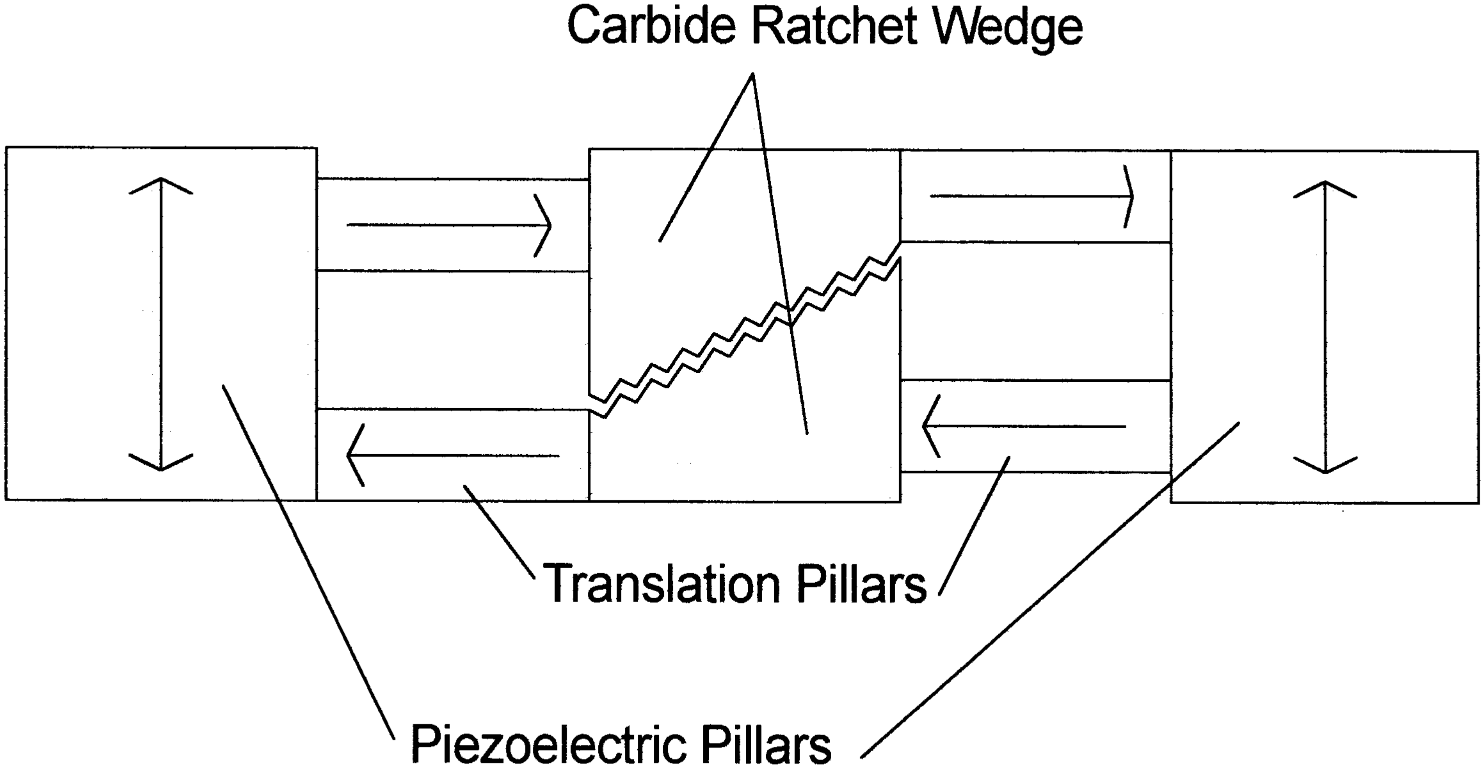
Adaptive Wedges

Wedges that can move along cracks in a stepping fashion. One part of the wedge tightly locks into the rock fissure while the leading portion either generates mechanical pulses or moves forward. The adaptive wedges could also provide mobility for guide rods that could carry devices capable of cutting rock at right angles to the guide rod.

Another use for the adaptive wedges would be for lengthening the crack rather than deepening it. Extending it along the surface of the rock rather than going deeper into the rock. Skinning the rock by layers like an onion.

Another way to use for the adaptive wedge is to amplify any natural oscillations in the rock. The mechanical energy of the vibrations would be converted to electrical energy by spring loaded piezoelectric pads contacting the rock face on the adaptive wedges. This electrical energy could be used to power the other adaptive wedge functions and motions.

A form of intelligence the adaptive wedges could have would be resonant intelligence. The adaptive wedge would apply a brief pulse of force and then observe the reaction of the rock to this mechanical pulse. The adaptive wedge would again pulse, but this time it would pulse again at the natural frequency or echo of the rock. This would set up a resonance in the rock, greatly strengthening the effect of the adaptive wedges. This could also exploit other fractures within the rock by repeated stressing the rock structures. Further these returning vibrations could give information on the presence of cracks and other structures within the rock body. The amount of movement and force that each wedge detects could map the mechanical pinning points of the rock. This three dimensional map could aid in efficient planning for mining operations.



Adaptive Wedge

Carbide Ratchet Wedge	
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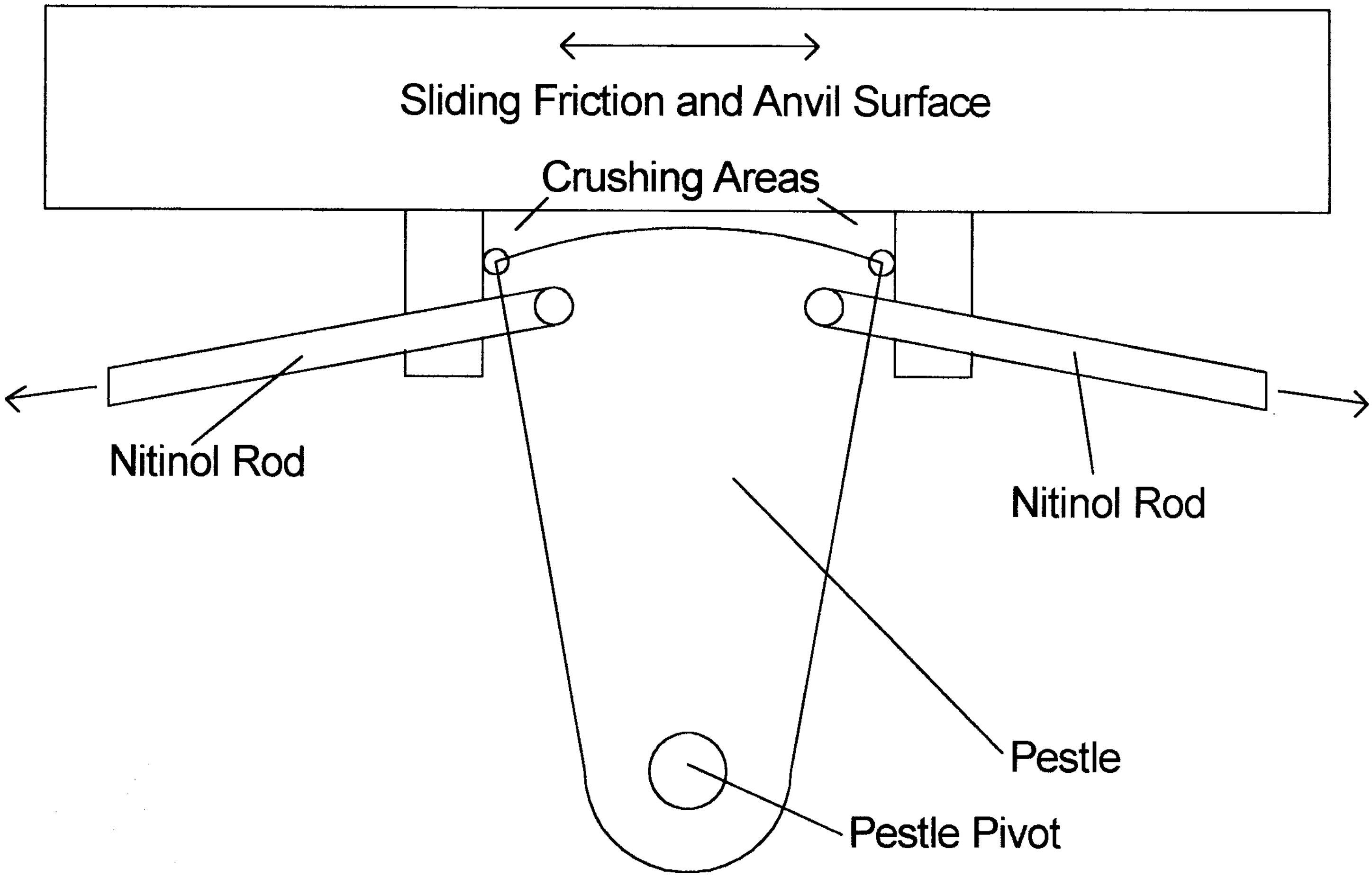

Solar Powered Rock Crusher

Solar Rock Crusher 1	
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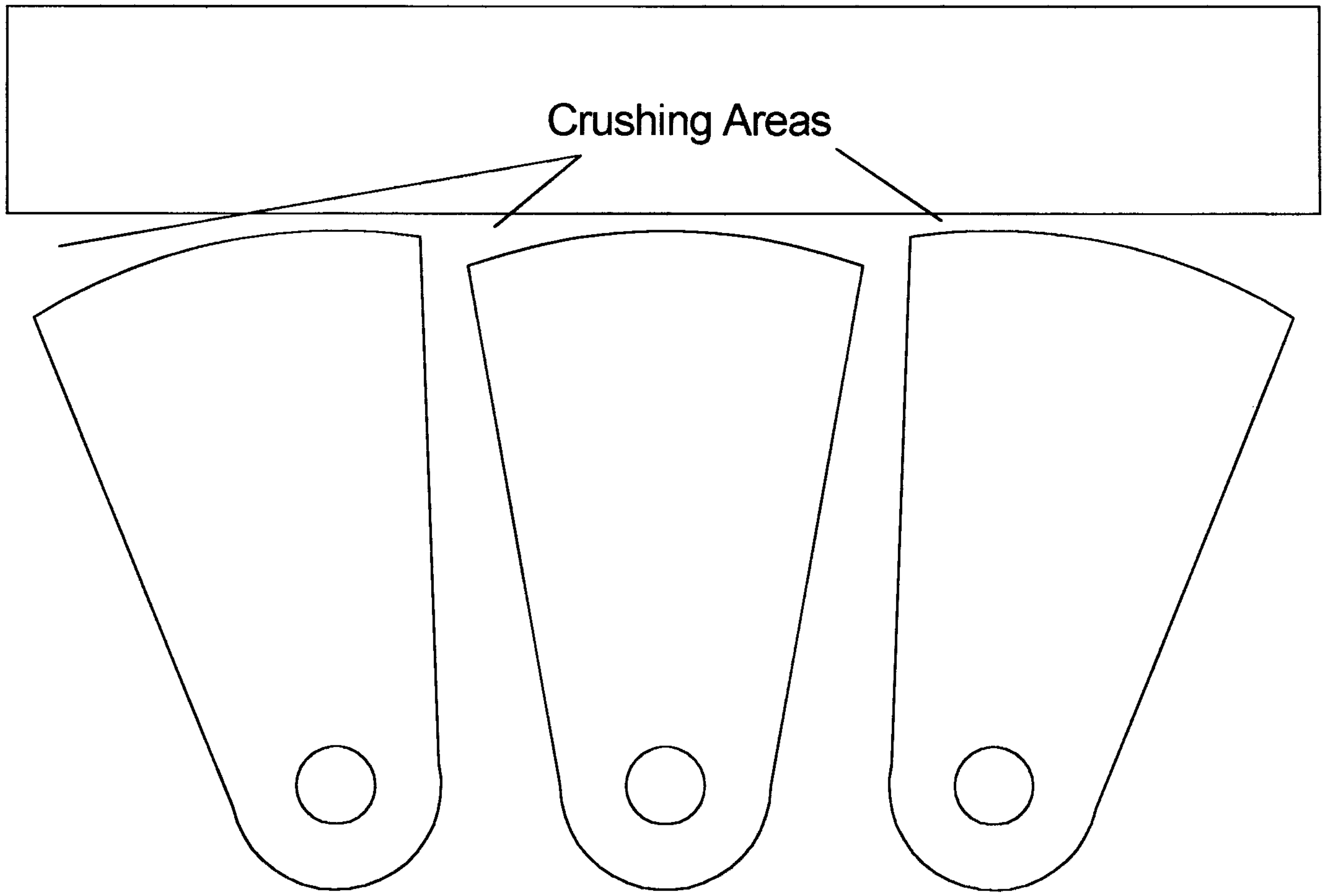

Solar Rock Crusher Rotated 1	
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OPERATING PRINCIPLES OF NITINOL

1.MEMORY OF ORIGINAL STATE MUST BE PROGRAMMED BY SOAKING THE MATERIAL, HELD IN THE DESIRED SHAPE, FOR SEVERAL HOURS AT APPROX 540 C.

2.MATERIAL MUST BE REDUCED BELOW IT'S PHASE TEMPERATURE -200 TO 110 CENTIGRADE.THIS TEMPERATURE IS SET BY THE PROPORTION OF METALS IN THE ALLOY.

3. MECHANICAL STRESS MUST BE APPLIED TO CHANGE IT'S SHAPE FROM THE PROGRAMMED FORM. STAYING BELOW 3 TO 5 PERCENT ELONGATION WILL INSURE LONG OPERATION.

4.APPLY HEAT TILL IT IS ABOVE IT'S PHASE TEMPERATURE. IT WILL REVERT TO ITS PROGRAMMED SHAPE WITH FORCE.

5. FORCES GENERATED CAN BE UP TO 40 TONS PER SQUARE INCH.

Nitinol Principles	
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Nitinol Rod Sequencing

1.COOL BOTH RODS.

2. HEAT THE ROD ON THE SIDE THAT THE PESTLE WILL MOVE TO, THE ROD WILL REVERT TO IT'S SHORTER MEMORIZED SHAPE.

3. THIS WILL PULL THE PESTLE TO THE HEATED SIDE, CRUSHING THE MATERIAL THAT HAD BEEN IN THE GAP.

4 THE COOLED NITINOL ROD OPPOSITE WILL BE STRETCHED FROM IT'S PROGRAMMED SHAPE.

5. ALLOW HEATED ROD TO COOL.

6. HEAT OPPOSITE ROD, REVERSE PESTLE POSITION.

Use of Orbital Processing Facilities for Asteroids

An orbital material processing facility for asteroids would have certain advantages. Most asteroids have significant rotation and any solar furnaces used on the surface of the asteroid would track the sun to maintain constant heating of a solar furnace. The mechanics to track the sun would need a lot of equipment operating in harsh conditions. A processing station in orbit of the asteroid would not have any significant machinery requirements for tracking the sun. The asteroid rotation will not need to be stopped to ease tracking problems on the surface. The processing facility could be in geostationary orbit so that it will always be located in the same part of the sky. For asteroids with complex rotations this orbit will need to be modified. By orbiting the asteroid the processing facility could also act as a link for communications to the mining operation on the surface. The mining operation could go into communications blackout due to line of sight problems with Earth.

Materials could be moved from the asteroid surface by high accuracy catapults. The catapults would give the materials package just enough velocity to reach the orbiting station. For most asteroids this will be about 9 meters per second or less.

The package should only be moving at centimeters per second when it closes with the station, this to lessen vibration and shock from the capture. The station will capture these packages and process their contents. A portion of the package would be used as reaction mass to maintain orbit of the asteroid and maintain the sun facing orientation of the solar furnace.

To maintain position the station could use sand impulse engines. Sand impulse engines are essentially small cups full of sand or similar material that is accelerated by small mechanical or electromechanical catapults. For something more technological, the material could be magnetic and relatively simple mass launchers might work. Some of the material being launched from the asteroid surface could be used for this purpose. The processing station would not need volatiles to maintain orbit and orientation. This means it could begin processing with materials made from regolith. A potential problem would be sand given the velocity and vector to be kept in orbit of the asteroid. A lot of the principles and devices put forth here would have been familiar to Leonardo Da Vinci.

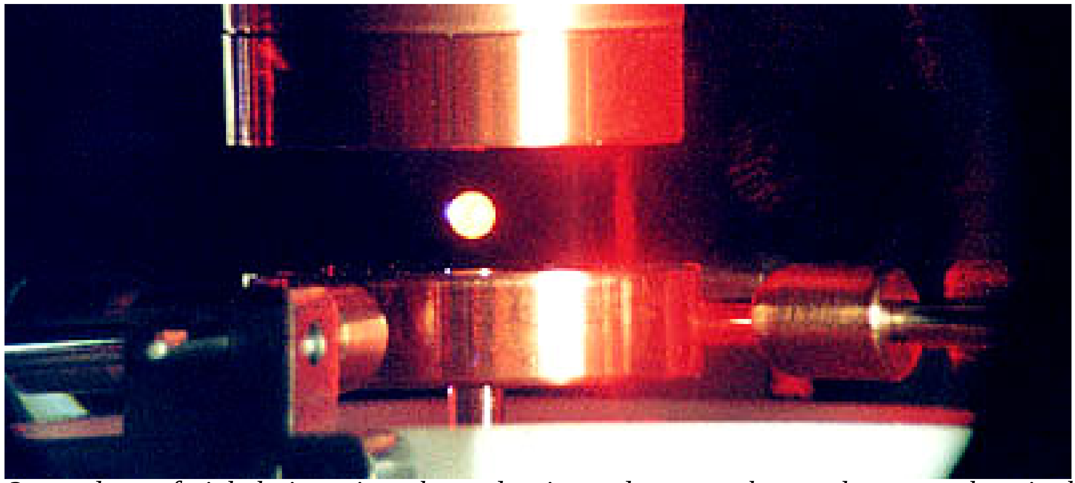
At first the station will use the surface material to build more mirrors to add to the power of its solar furnaces. The original mirror sent from earth will be adequate for making crude mirrors. The additional mirrors would be made from molten glass extruded into flat sheets and then plated with a thin metal coating. The mirrors would be added to a framework with each mirror being focused to the same point. Individual mirrors could be positioned for minor furnaces or all the mirrors focused together to liquefy large spheres of molten material contained in refractory wire meshes. Ultimately the mass of the processing station will be many times that which left Earth.

The wire meshes could also allow manipulation of the molten material. One method would to induce a charge in the molten material from a charged electrode nearby. This will cause the material to bow outward toward the charged electrode. This bowing might take the shape of a of a parabola and could be useful addition to the solar furnace. Another shape could be semi-hemispheres that could be bonded together to make enclosed containers.

Another method would resemble soap bubble toys. Frames inserted into the molten mass could form webs of molten material in the frames. These frames could be folded together while still in a molten state to form enclosed structures. Controlling the surface tension of the liquid and the way it wets to the framework would be key to operating and perfecting this technology.

It floats

New MSFC tool levitates molten materials



A 3 mm drop of nickel-zirconium, heated to incandescence, hovers between electrically charged plates inside the Electrostatic Levitator.

March 9, 1998: A new lab tool doesn't exactly defy gravity, but it does hold it at bay so scientists can run materials experiments that could be spoiled if the samples touched a container wall.

"It's what I consider to be the next generation in containerless processing," said Dr. Mike Robinson of the Electrostatic Levitator (ESL) recently installed at NASA's Marshall Space Flight Center.

The ESL uses static electricity to suspend an object inside a vacuum chamber. While that happens, a laser heats the sample until it melts, so scientists can record a wide range of physical properties without contact with the container.

To make improved alloys and other compounds we must understand the physical properties that govern ingredients behave. These include:

- Surface tension, the same effect that lets small bugs walk on water
- Viscosity, how "thick" a liquid is
- Heat capacity, how slowly heat is absorbed or released
- **Undercooling** and nucleation, how far below freezing it will stay liquid

Determining these properties precisely is difficult, because anything that handles or contains a molten sample will alter the results. It can dampen vibrations or rapidly cool the sample. In some cases, the metal is reactive enough to damage its container.

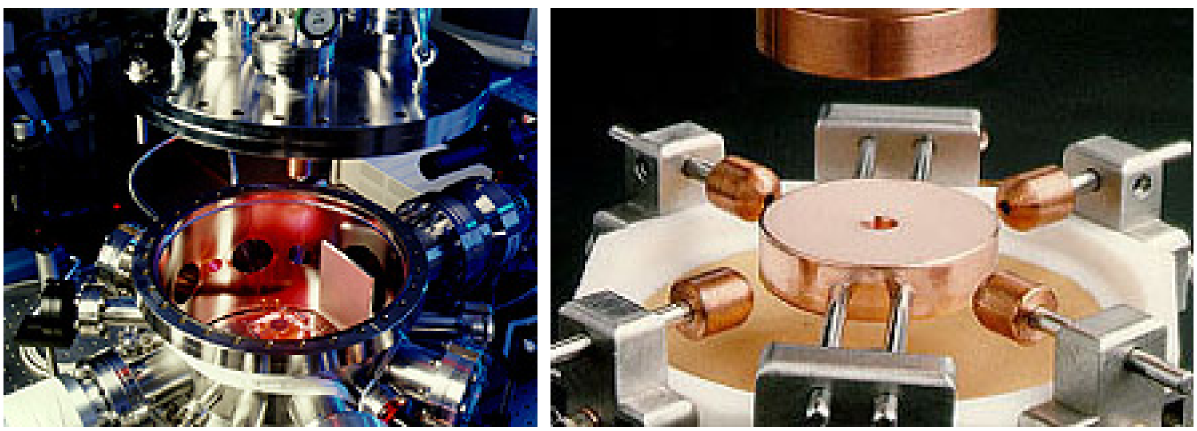
One answer to this problem is "hands off" processing using static electricity to levitate a small sample. This is possible with the ESL, developed by Loral Space Systems of Palo Alto, California, and recently donated to NASA's Marshall Space Flight Center in Huntsville, Alabama.

"They wanted to give it to a national laboratory where it would be available to the scientific community," Robinson said of Loral's generosity. "We're the only national laboratory doing containerless processing."

The ESL will complement research with NASA/Marshall's Drop Tube Facility and with flight facilities such as the TEMPUS electromagnetic levitation furnace flown last year on the MSL-1 Spacelab mission. ESL holds the samples in full view of the detectors for several minutes at a time, but they are still under the effects of gravity. Drop Tube experiments are truly weightless, but for just 4.3 seconds, and the samples quickly fall past detectors. TEMPUS and other orbital facilities allow weightless experiments for long periods, but must be scheduled years in advance on Spacelab missions.

The ESL suspends liquid samples, including metals, without the sample touching a container and without the scientists handling equipment that might alter measurements. This makes ESL a premier tool for investigating fundamental physical properties of advanced materials, including undercooling and metallic glasses.

"It's a very quiet, controllable environment with completely independent heating and positioning systems," Robinson said.



The heart of the ESL is the vacuum chamber (left) containing a pair of electrostatic plates and four electrodes that position the sample being processed (right). The sample's position is determined from the shadows cast on detectors as two lasers shine at right angles through the vacuum chamber onto the sample.

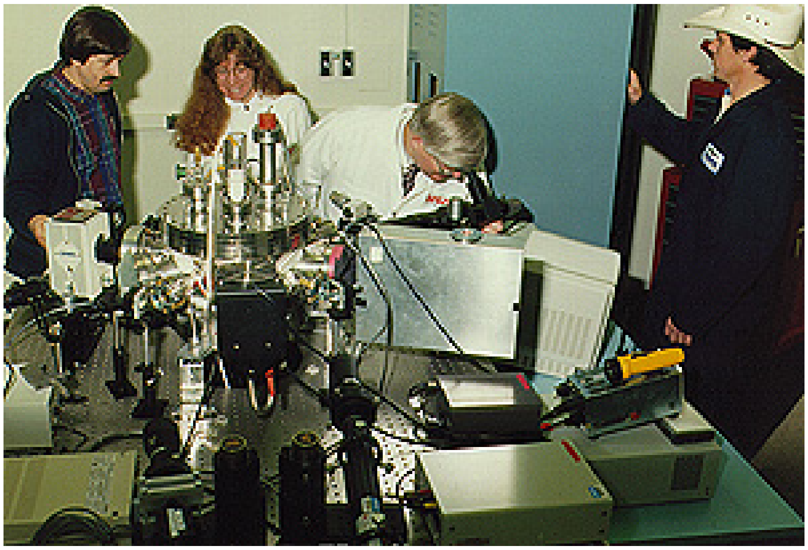
Rise...

The ESL uses the same effect that makes freshly dried socks push away from each other, although the application is controlled and precise. Two large, horizontal electrode plates electrically charge the sample and repel it upward until it balances between the two plates. Two smaller pairs of electrodes position the sample horizontally. A high-power deuterium arc lamp shines on the sample to replace the electrical charge the sample loses as it emits electrons while hot.

To keep the sample centered, a sophisticated three-dimensional digital feedback system controls the electrode charges. Two lasers (operating at different wavelengths or colors and at right angles to each other) shine through the vacuum chamber to cast a shadow on position sensors on the outside. The ESL computer, in turn, uses those positions to calculate subtle changes in the electrode charges, recenter the sample, and to aim the heating laser. The power of the electrostatic levitators is limited, so samples can be no more than 3 mm (0.12 in) in diameter.

Most experiments require melting a sample so scientists can record viscosity, surface tension, volume, and undercooling. A 50-watt laser, controlled from 0 to 100 percent and with a spot size from 10 mm down to 0.5 mm, heats samples, or controls cooling by supplying slightly less energy than the sample radiates. Experiments can also be run without laser heating.

The whole system is held in place by a special optical bench mounted atop an air-bearing table to isolate the system from vibration.

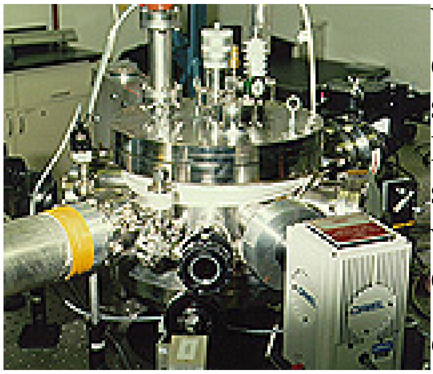


Right: ESL team members - Larry Savage, project scientist Jan Rogers, and Michael Robinson of NASA, and Doug Huie of Mevatec - check a test in progress. Robinson is peering through the long-distance microscope which is includes a TV camera. The vacuum chamber is just in front of Rogers. Positioning lasers are in the foreground, and the heating laser is mounted under the table.

... and shine

To make "hands off" measurements, the ESL employs several sensors looking in through viewports in the vacuum chamber wall. A CCD video camera behind a long-range microscope provides a magnified view of the sample illuminated by a conventional lamp until the sample is hot enough to glow.

Images can be recorded as standard and high-speed video, and digitized for analyses. A pyrometer, viewing through an infrared filter, measures the heat radiated by the sample. The images collected by the position sensors can also be used in scientific analysis. Scientists using the ESL may also supply their own instruments.



While the samples "float" in the ESL, they are not in a microgravity environment and convective flow effects can occur. The ESL is one of a suite of instruments for studying the physical properties. Others which NASA employs include drop towers, in which a sample is in free fall for 2-3 seconds and passes quickly through an instrument's field of view, and a variety of space-based facilities in which samples are under microgravity for extended periods.

Optical ports ring the ESL vacuum chamber to admit light from the heating laser (the beam passes through the at left), positioning lasers (one port is at center), and lamps (such as the deuterium arc lamp at right), and to allow diagnostic instruments to view the sample.

A large number of studies - primarily in undercooling research - will use the ESL. Measurements will include thermophysical properties such as heat capacity, viscosity, surface tension, and thermal conductivity. The ESL can also accommodate measurements of nucleation temperatures and rates, and solidification velocities.

Print quality JPG copies of these and other ESL images, and a Quicktime movie are available.

The ESL is available for use by scientists who are competitively selected through NASA Research Announcements (NRA), which solicit guest investigators to use NASA facilities and resources.

For additional information, check NASA Research Announcements (NRA) or the Microgravity Program Office, or e-mail the Microgravity Program Office. An NRA on materials science, including the ESL, is to be released later this year. Scientists can also propose to use the ESL through Advanced Technology Development agreements, which are reserved for promising, high-risk research.

More Space Processing **Headlines**

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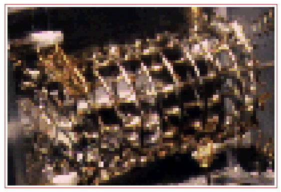
Author: Dave Dooling
Curator: Linda Porter
NASA Official: Gregory S. Wilson

Holes Hold Water



Cages show new way to hold liquids in space experiments

When you were a kid did you ever serve someone a drink in a dribble glass? You know, with little holes that leak out on your "friend's" chin?

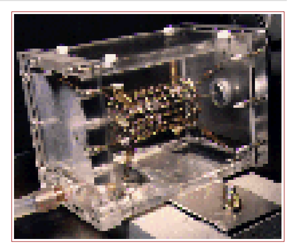
Well, it wouldn't dribble in space, and that may lead to a new way of holding liquids in place for experiments in growing crystals in weightlessness.

"It's a whole new ball game in microgravity," said Dale Kornfeld, a microgravity scientist with the Space Sciences Laboratory at Marshall Space Flight Center in Huntsville, Ala.

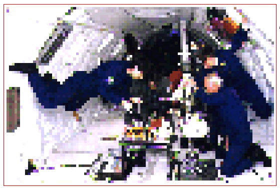
"With space, we have to throw away all our experiences in one-gravity," added Basil Antar, a fluid dynamics professor at the University of Tennessee Space Institute in nearby Tullahoma, Tenn.

Closeup pictures show two of the cages tested by Kornfeld and Antar on the low-gravity KC-135 aircraft. All of the models - including those with half-inch-wide meshes - performed as if they had solid walls during tests.

Click on pictures for larger view.



The reason the dribble glass won't work in space is because of surface tension, the same force that causes water to act like it has a thin skin on the surface (and allows bugs to run across water without sinking). Water forms drops - instead of spreading into a thin sheet - because surface tension pulls the water together. Surface tension also makes water cling to objects, which is why a window screen looks like a million tiny lenses after a rainstorm or a drink rises slightly inside a straw - or the drink dribbles down your friend's neck instead of dropping away.



Scientists from MSFC's Space Science Lab "fly through the air with the greatest of ease" as they test the liquid cages during weightless periods aboard the KC-135 airplane..

A window screen is one of several materials that Kornfeld and Antar used in flight tests aboard NASA's "Weightless Wonder." Their findings point the way to solving problems that some scientists have had in growing crystals in space.

Like many scientific developments, they started with someone else's problem. On the U.S. Microgravity Laboratory-1 mission (USML-1 on Columbia, STS-50; June 25-July 9, 1992), payload specialist-astronaut Larry Delucas (a scientist from the University of Alabama in Birmingham) kept getting bubbles in the fluid for a crystal growth experiment he was running.

Kornfeld, NASA's 1984 Inventor of the Year, has spent more than 30 years designing and testing microgravity experiments for space. He was working as an Assistant Mission Scientist on USML-1 in Marshall's Payload Operations Control Center when he noted the problem Delucas was having. Being an experimentalist, he recruited Professor Antar, a theoretician who has worked with NASA for more than 20 years on microgravity fluid problems, to help investigate the problem after the flight.

What they found - and it took a high-speed movie camera working at 400 frames per second - was that the needle Delucas was using accidentally whipped open a small cavity in the water in microgravity and pulled in tiny air bubbles.

Air bubbles have long been a problem in experiments to grow high-quality crystals of proteins in space. Bubbles often get trapped in the corners of growth chambers, or get stuck to the walls, and stay there - until the experiment is under way, then the bubbles can wander and cause crystals to grow where you don't want them. And sometimes the crystals grow on the chamber walls where you don't want them.

So, Kornfeld and Antar expanded their experiments to look at the problems of injecting bubble-free liquids into containers. They built plexiglass cubes, 5.1 cm (2 in) on a side, and injected water and other fluids like those used in protein crystallization. In one series of tests they sprayed a water jet across the cube to hit the opposite wall and observe how it stuck and spread across the wall. In others, they gently injected liquid and watched as it formed a growing sphere held in place by surface tension.

And that led to a new idea. On his way home one day, Antar realized that the liquid was showing them a better way to contain itself in space - a container without walls!

"But, what you need is something to 'pin' the fluid in place," Kornfeld said.

Surface tension will hold the fluid together, but the fluid mass needs something on which to pin itself. Antar's idea was to build a container out of as little material as possible, a cage, that would act as an attach point for surface tension.

Screens have been used in rocket propellant tanks to capture enough fuel and oxidizer so they can restart rockets in orbit, but not to act as an experiment "container."

Operating on a low budget -- they built their hardware for less than $10,000 - Kornfeld and Antar devised a series of cages from chicken wire, window screen, fishing line, and hooked rug base. These were suspended in plastic splash boxes (to keep the water from floating out into the airplane) and water lines were attached to fill the cage during the weightless period of the KC-135. High-speed film cameras captured everything on 16mm film and showed that the idea worked just the way Antar and Kornfeld thought it would.

When replayed in slow motion, you can see water ooze in like the water creature in *The Abyss*, wobble around a bit, then latch onto the mesh as soon as the surface touches solid. It sits there, seemingly breathing in an out until the low-g period ends and everything drains out of the cage as free fall ends.

Kornfeld said that the new design offers an innovative way to contain and grow protein crystals in space. With their solutions caged in a mesh and suspended inside a clear plastic splash and vapor container, scientists could circulate air to change evaporation rates, or insert needles to remove air bubbles or insert seed crystals.

Kornfeld and Antar plan additional experiments aboard the KC-135 using sound waves and a mesh plunger as alternative means of driving out bubbles that might get into the cage from the injection line.

But because the liquid still could be shaken out by quick movements, don't look for astronauts to have coffee mugs built of chicken wire. Not even as a dribble glass.

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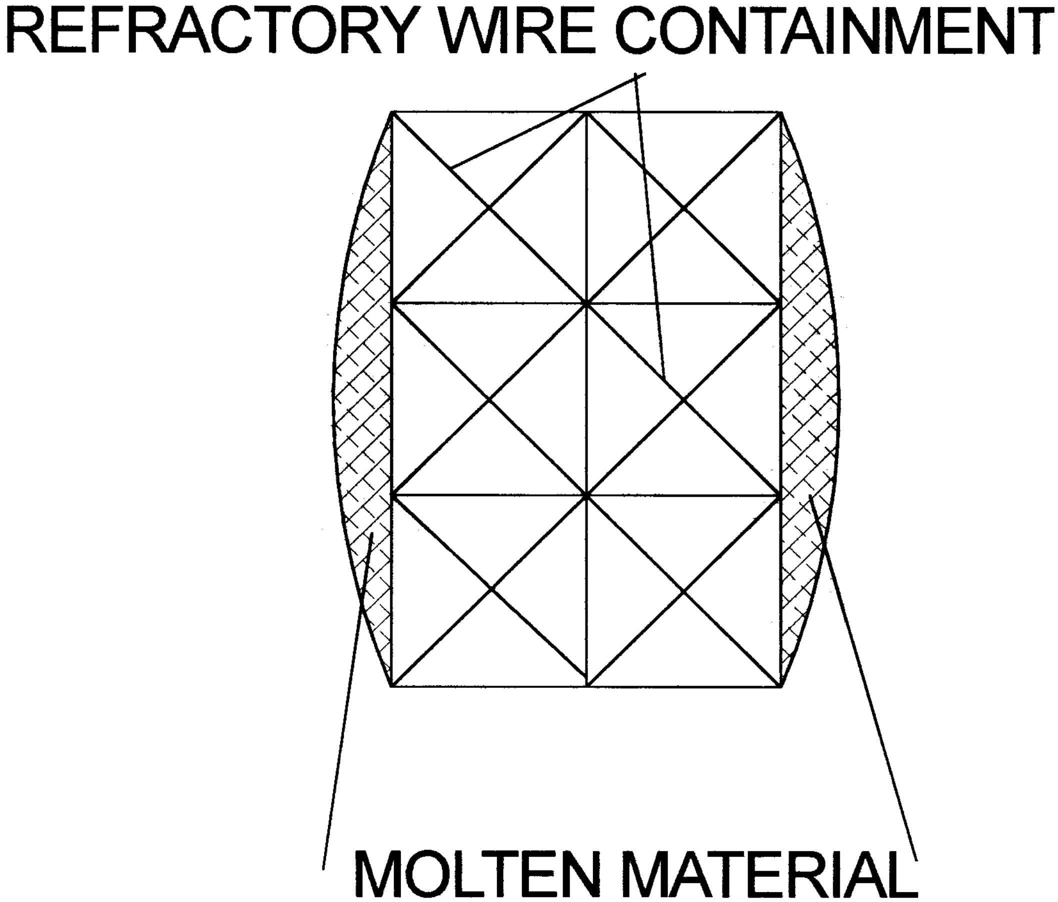
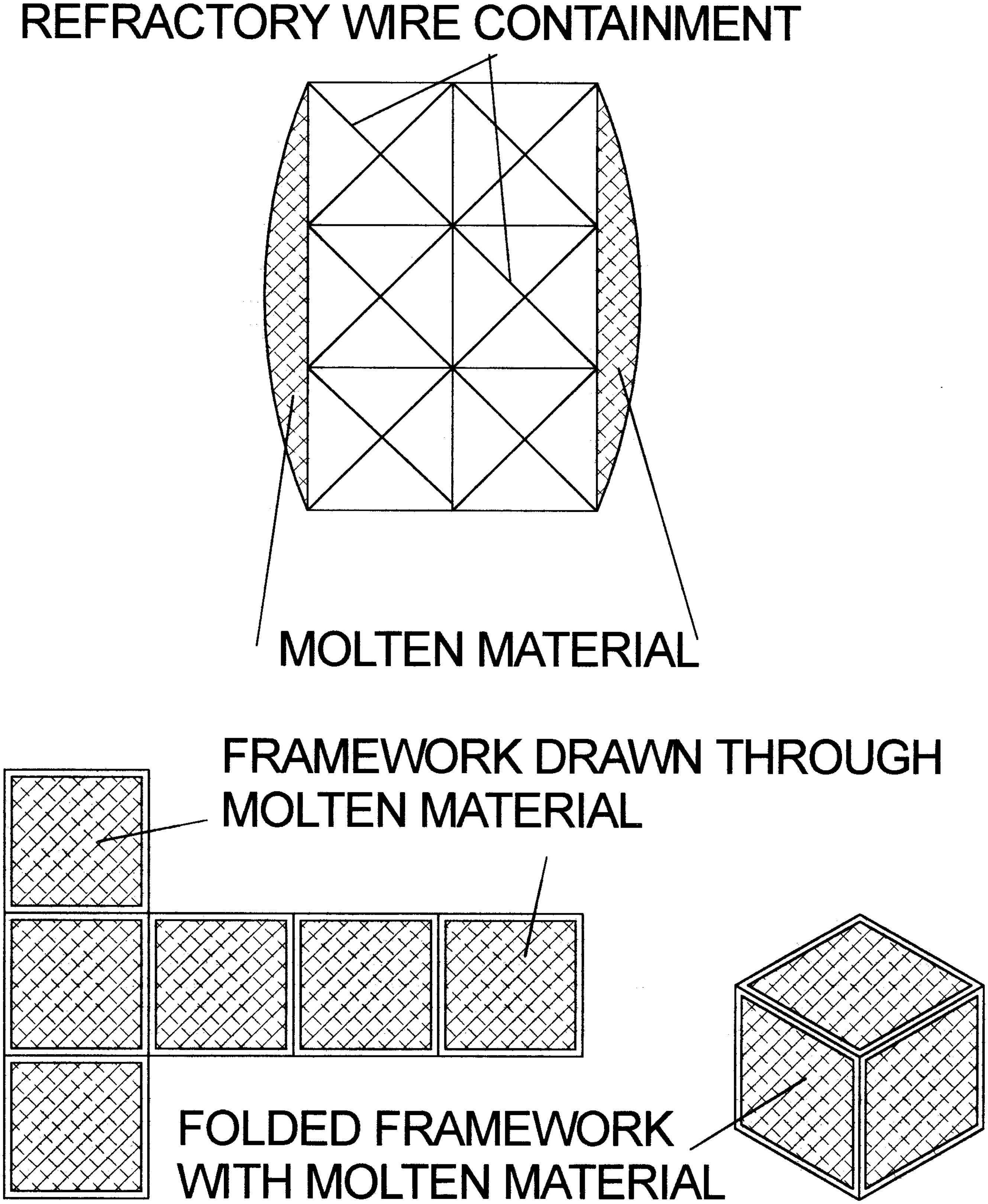


CONTAINMENT OF MOLTEN MATERIAL BY SURFACE TENSION FORCES

Refractory Wire	
Louis P. Quinn	The Martian Embassy, LLC
louis@marsemb.com	SSR3 24-26 Oct 2001



Folded Frame Molten	
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Electrostaic Molten	
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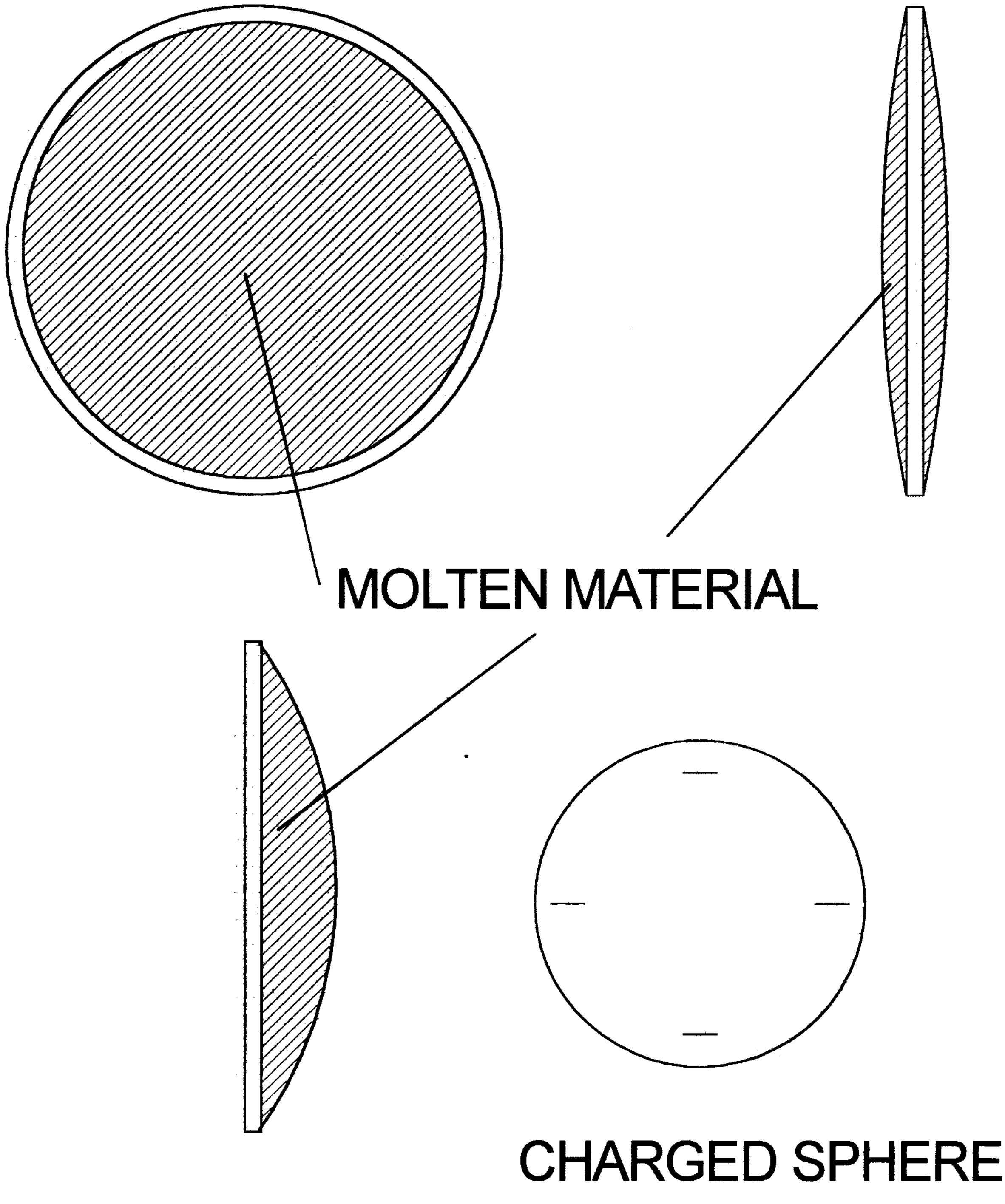
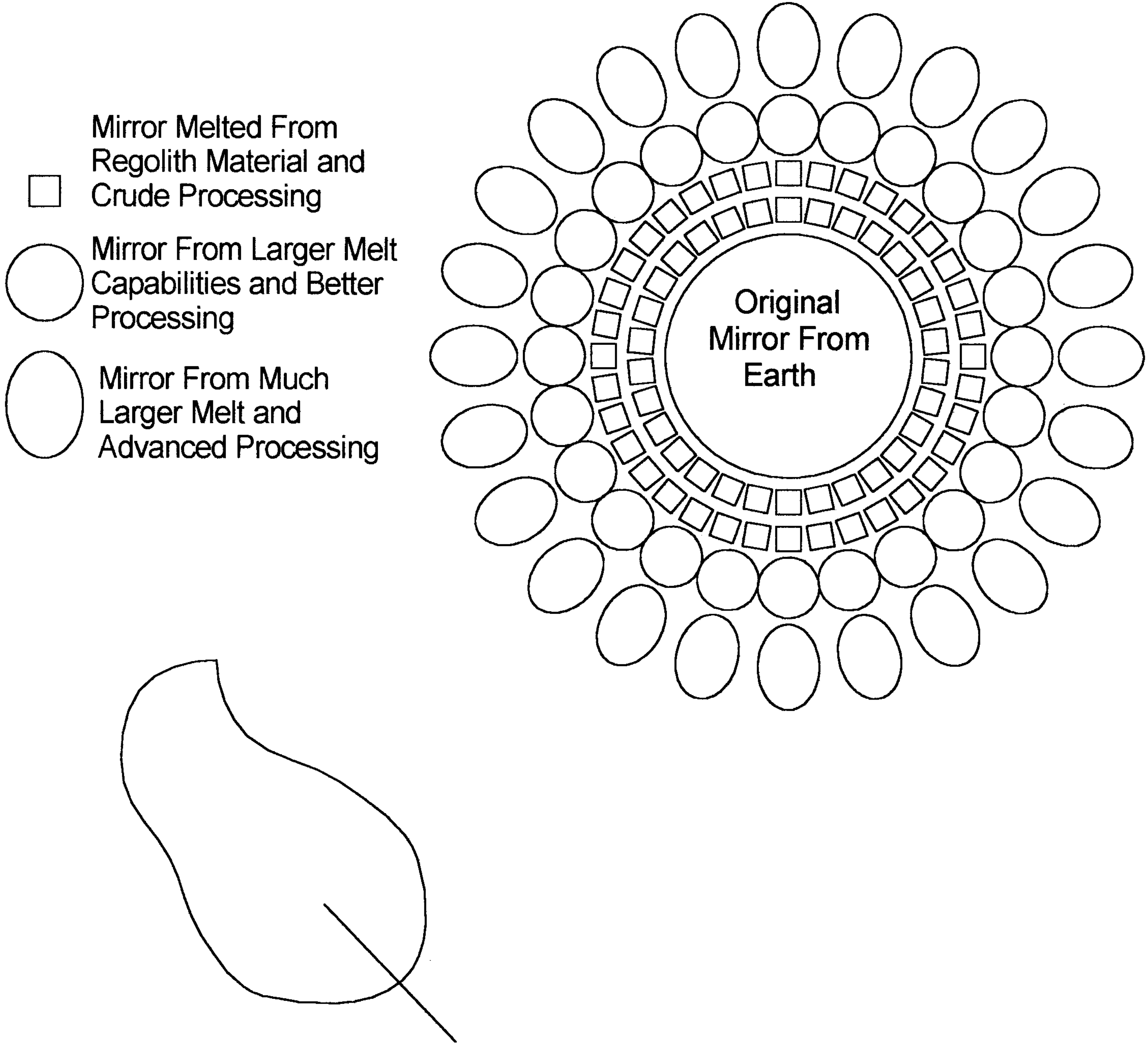


ELECTROSTATIC MANIPULATION
OF MOLTEN MATERIAL



The Asteroid the Processing Station is Orbiting. Source of Regolith for Both the Early Mirrors and Impulse Sand for Maintaining Orbit and Position.

Orbital Processing Station	
Louis P. Quinn	The Martian Embassy, LLC
louis@marsemb.com	SSR3 24-26 Oct 2001

Asteroid Material Catapult

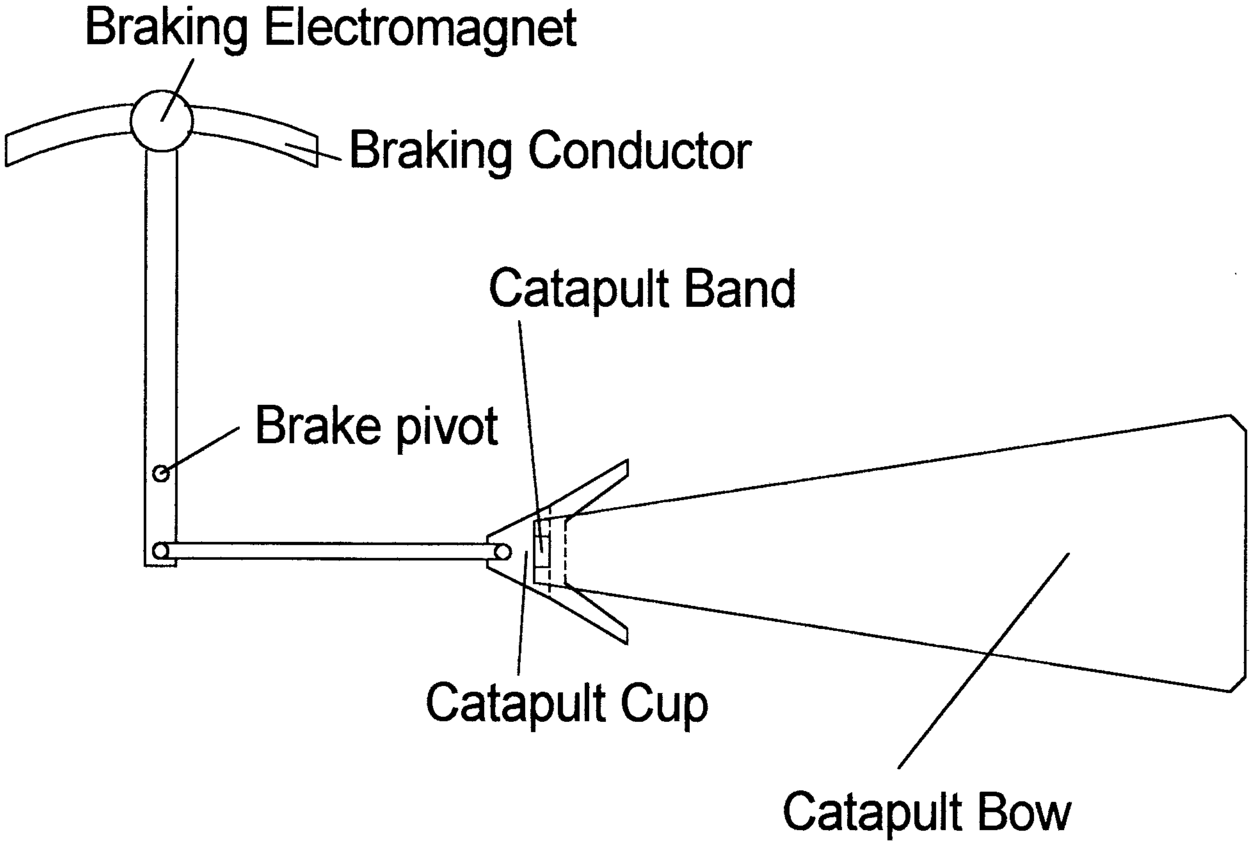
For precise injection of material to the orbital processing facility, a catapult with relatively precise velocity control will be necessary. Unlike the trebouchet type of catapult with it's rotational flinging of the projectile, a translational design similar to a large crossbow would be a better basis for the design of a material catapult. Since each material load will vary in mass, sometimes significantly, the velocity will be the variable of interest in the control loop for a catapult.

The catapult will incorporate a transducer for determining the material bucket's speed. The catapult will also incorporate a magnetic brake to retard the motion of the catapult bucket to the desired velocity. A magnetic brake is an electrically conductive sheet that travels between the poles of a magnet(s).

As the sheet moves between the poles of a magnet it induces a current in the electrically conductive sheet. These currents create a magnetic field, which opposes the applied field and opposes the motion of the sheet through the magnets. The stronger the magnets, the stronger the opposing magnetic currents and the more resistance to movement the conductive sheet encounters. The amount of mechanical resistance is dependent on the velocity of the conductive sheet and the strength of the magnetic field it is moving through. Using an electromagnet to supply the magnetic field allows the mechanical resistance to be varied by varying the current through the electromagnet. By monitoring the buckets velocity profile and adjusting the current in the braking electromagnet, a controllable and precise velocity for the launched package is possible.

The design would maximize the velocity of the braking conductive sheet just before material release, to give maximum effect to the braking electromagnets. This could be a robust design of simple mechanical components and electronic elements, which could open up another aspect of asteroid usage.

PRECISION VELOCITY CATAPULT



Catapult #1	
Louis P. Quinn	The Martian Embassy, LLC
louis@marsemb.com	SSR3 24-26 Oct 2001

Acknowledgements

Gregory Benford and David Brin, Heart of the Comet, The Hot. A term referring to a distance from the sun when heating begins to affect the surface of a comet. I modified it to mean within the orbit of Mars where the temperature difference between sunlight and shadow is enough to efficiently operate heat-powered machines. The impulse sand-rocket idea for orbiting a processing station was synthesized from scenes in this book.

Wile E. Coyote, Super Genius. Patron Saint of unlucky, but persistent Inventors. Looney Tunes Warner Brothers

Leonardo Da Vinci drawings on catapults and giant crossbows brought clarity of vision and whose spirit lives on.

Michael Duke for allowing me the opportunity to present these musings to my peers.

Roger G. Gilbertson, Muscle Wire Project Book 3rd Edition. Useful Information and data on Nitinol

Larry C. Hoffman, The Rock Drill and Civilization Summer 1999 pages 56-63 American Heritage of Invention & Technology. A history of rock drills and potentially useful anachronisms. A look at a time when 50 ton machines was not doing the mining.

Nitinol Devices & Components for information and a sample of the memory metal Nitinol.

World Wide Web. Allowing research and information to be found without leaving my apartment. Although the wheat to chaff ratio is a bit high, the Copernic meta-search engine helped.

And my apologies to anyone whose ideas may have entered my consciousness and writings without my noting their source.

Sincerely
Louis P. Quinn
Given at the Colorado Scholl of Mines Space Resources Roundtable III 25 October 2001
Earth