and perform tests. Electric motors are to be controlled by software, based on the control algorithm developed in Objective 3. Proposed software developments are divided into three parts: (a) A database to store relevant parameters for a healthy person with no physical limitations, (b) Background processing which includes data collection and analysis and generation of control signals to control the EVRA, and (c) A Graphical-User-Interface (GUI) which provides the Man-Machine-Interface (MMI).

Exercise Physiology Laboratory at NASA-JSC

Areas of research interest include cardio-respiratory functional capacity, musculoskeletal strength development and maintenance, orthostatic intolerance, biomechanics of movement, bone metabolism, and thermoregulation. The JSC Laboratory also evaluates in-flight exercise responses and activity patterns as a way of evaluating and validating exercise countermeasure concepts. Basic research investigations are conducted through the NRA, NSBRI, and CEVP peer-review processes.

Current, projects include: biomechanical analysis of treadmill locomotion in weightlessness using the KC-135, evaluation of eccentric and concentric muscle strength using the Agaton system, evaluation of the Muscle Lab measurement device, and preliminary investigations of the use of near-infrared spectroscopy in the evaluation of muscle and skin blood flow during dynamic exercise of the arms and legs. Hardware used in the Exercise Physiology Laboratory (EPL) is both traditional and innovative. Equipment is upgraded on the basis of ongoing research:

Metabolic Gas Analysis Systems
Heart Rate and Blood Pressure Systems
Treadmills
Cycle Ergometers
Rowing Machines
Resistance Exercise Dynamometers
Electromyography Recording System
Hardware for Thermoregulatory Studies
Hardware to assess Orthostatic Responses
Computers and cameras to conduct motion analysis studies
Underwater Weighing Tank Launch and Entry Suit
Advanced Crew Escape Suit
IBM and Macintosh computers

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Development of Micro-Column Arrays (MCA) for Thermal Management Applications

Thermal management of spacecraft and space station environments is an important issue in both the manned and unmanned exploration of space. Transporting heat away from spacecraft components and bringing heat to other systems often rely on large, liquid-based heat exchange systems. Such active systems add extra weight to the spacecraft and comprise additional mechanical components which can malfunction, thus affecting maximum payload and mission lifetime. A possible alternative is a passive cooling system in which thin coatings or foils would collect or remove heat by radiative absorption or emission.

A technology for the successful fabrication of Micro Column Arrays (MCAs) on thin metal foils has recently been developed in conjunction with Integrated Micro Sensors, Inc. (IMS) of Houston, TX. MCAs consist of densely packed micro cones separated by cone-shaped micro cavities. They exhibit low reflectance (< 0.171) and high absorptance (> 0.978) over a wide spectral range in a very close approximation of blackbody behavior. The goal of this project is to explore the use of MCA structures on metal foils for heat acquisition and/or heat rejection through their near-blackbody nature.

In-depth simulation of their heat transport properties will be undertaken using a newly developed Transmission Line Matrix (TLM) methodology. In this approach, a novel TLM link line is introduced to account for the enthalpy heat transport in a fluid or gas. Incorporation of an electrical diode in the new enthalpy link has proven to be an excellent way of accounting for the heat convection without altering the classical TLM algorithm arrangement. Full extension of this model to radiative heat dissipation and collection will be undertaken.

Technical Approach

MCAs are produced by pulsed laser ablation combined with mechanical translation of the substrate material to create cone-shaped micro tips interdigitated with cone-shaped micro cavities[1,2] (Fig. 1). The tips are on the order of 10-20 μm in base diameter and 20-30 μm tall. MCA surfaces feature large (more than 10X) specific areas, low-threshold electron field emission, and unique optical properties.[3] To date, MCA fabrication has been realized on a variety of metal foils including stainless steels and refractory metals (Fig. 2).

Measurements on various MCA samples have been performed at NASA-JSC. Measurements of reflectance from 250 nm to 2.8 μm to calculate an integrated absorbance α over that range and single average reflectance ρ over the spectral range of 2.5-30 μm were undertaken. In both cases, the front (MCA processed) and back (unprocessed) of each metal foil was measured. The results clearly demonstrate the drastic reduction in reflectance with corresponding increase in absorbtance on the MCA-processed side. For the MCA metal foils studied, the average α over the range 250 nm-2.8 μm varied between 0.97 and 0.985 while the average reflectance ρ over the long-wavelength range 2.5-30 μm varied between 0.12 and 0.155.

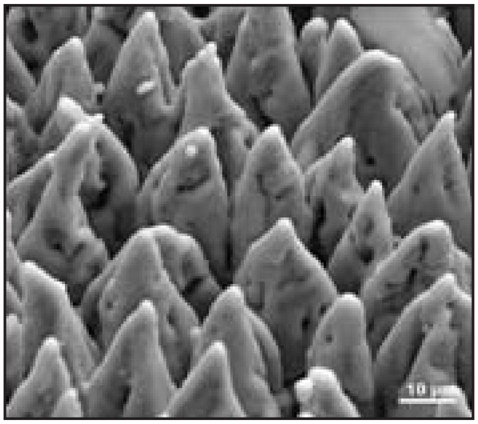

Figure 1. SEM Image of Micro Column Arrays Generated on Stainless Steel Foil

Previous research has demonstrated that MCAs act as micro cavities to efficiently trap and absorb light similarly to blackbody emitters.[4] Metal strip samples were resistively headed in vacuum to temperatures up to 1360ºC (for the tantalum). The resulting optical emission was recorded. These spectra were compared to that of a large, cavity-type blackbody simulator. Results indicate that the emission from the MCA structures closely follows that from a blackbody source. In cases where heat acquisition is desired, the high absorbtance of the MCAs over a wide wavelength range could provide efficient heating through the conversion of incident solar energy.

Likewise, the high emissivity of the MCA structures means that they could be used as efficient radiative emission sources. For example, MCAs can be used as passive cooling elements for mechanical or electronic systems by radiating away the excess heat in the IR wavelengths. Blackbody temperatures between 50-100ºC have corresponding peak emission wavelengths from 9.25-7.77 μm, respectively, which match up well with the absorbtance of MCAs (0.88 as averaged over the entire 2.5-30 μm range). The 10X increased surface area from the MCA structures would also provide improved convective cooling in an atmospheric environment in comparison with smooth, unprocessed materials. For temperatures in the 1000-1600°C range, applicable to the leading edges of vehicles upon atmospheric re-entry, the corresponding peak emission wavelengths range from 2.28-1.55 μm, respectively, which also match up well to the spectral regions of high absorbtance of MCA structures.

Heat transfer from one medium to another depends critically on both the thermal properties of the media and the interfacial region area and geometry. While both parameters can be tailored to satisfy a particular application, the media (i.e., the substrate material to heat or cool and the heat dissipater/source are sometimes dictated by other considerations and properties (optical, mechanical, etc.). Their modification/substitution is thus either impractical or expensive. On the other hand, engineering of the existing interface to enhance the heat management characteristics of a system might be realized without significantly perturbing the traditional set up; thus, such an approach is highly desirable.

The use of MCA materials as passive heating or cooling elements could potentially reduce the size, complexity, and weight of thermal management solutions currently used in space. The fact that MCA structuring can be accomplished on most metals means that application-specific choices of materials can be made to balance the issues of weight, thermal stability, and/or thermal conductivity.

Project Work Plan

The project will be divided into the following five tasks:

1. Determine material/thermal requirements for NASA applications. Task leaders: A. Bensaoula and B. Mayeaux.
2. MCA fabrication processing and optical properties measurements. Task leaders: C. Boney and D. Starikov.
3. TLM Simulation. Task leaders: A. Bensaoula and Post-Doctoral Fellow (to be named).
4. Thermal/environmental stability testing. Task leaders: Post-Doctoral Fellow and B. Mayeaux.
5. Prototype fabrication and testing. Task leaders: A. Bensaoula and Post-Doctoral Fellow.

Figure 2. MCA Samples Fabricated Using Hastelloy, Alloy 321, *Ta*, *Ti*, and *Mo* Foils

NASA-JSC Resources

Facilities for the measurement of optical emission from MCA samples in the UV-Vis-near IR (up to ~3.0 μm) are available in the UH laboratory. UH investigators would require access to the NASA-JSC spectroreflectrometers mentioned earlier in this proposal in order to measure the absorbtance and reflectance of the MCA materials produced during this project. Additional facilities for the measurement of longer IR wavelength emission would be helpful, if available at NASA-JSC. Potential collaboration with Marshall Flight Center has been discussed with the JCS Project Manager.

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Thrust Measurement and Plasma Detachment Characterization in a Magnetic Nozzle

UH FACULTY HAVE FORMED a team with investigators from NASA-JSC on the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) in the Advanced Space Propulsion Laboratory. The opportunity exists for a Post-Doctoral Aerospace Fellow (PDAF) to join the project. The post-doctoral fellow will be responsible for two major tasks. First, the PDAF will begin the process of making force measurements with the recently installed Marshall Space Flight Center (MSFC) momentum flux probe. In this process, efforts will characterize and understand plasma and facility effects on the momentum flux probe. Second, the fellow will be expected to take the lead in designing and conducting a series of experiments to demonstrate the occurrence of plasma detachment in the VASIMR prototype.

A fundamental problem in human and robotic planetary exploration is the intrinsic limitation of today's chemical rocket. Developing a high power electric propulsion system suitable for use as the sustainer engines for manned missions beyond Earth orbit is directly relevant to JSC's mission to enable human space flight. One candidate system, the plasma rocket, opens up new and imaginative possibilities for fast space transportation. Utilizing ionized gases accelerated by electric and magnetic fields, these devices expand the performance envelope of rocket propulsion far beyond the limits of the chemical rocket. With a properly shaped magnetic duct, the internal energy of plasma could be extracted in the form of rocket thrust. The duct becomes a magnetic nozzle, the magnetic equivalent of a conventional nozzle.

At present, the VX-10 experimental device at the NASA Johnson Space Center in Houston is exploring the physics and engineering of the VASIMR. The VASIMR consists of three main sections: a helicon plasma source, a radio frequency (RF) power booster, and a magnetic nozzle. One key aspect of this concept is its electrode-less design, which makes it suitable for high power density and long component life by reducing plasma erosion and other materials complications. The magnetic field ties the three stages together and, through the magnet assemblies, transmits the exhaust reaction forces that ultimately propel the ship.

In many respects, the magnetic nozzle is the most controversial and speculative aspect of the VASIMR concept. If one considers only first order plasma physics, one naively expects the plasma produced in a magnetic bottle configuration to remain in a magnetic flux tube attached to the rocket, thus producing no thrust. In fact, detailed consideration of the expected plasma dynamics indicates that one should expect the exhaust plasma to detach from the engine magnetic field and become a true exhaust plume when one reaches an axial distance where the plasma pressure exceeds the effective pressure of the magnetic field. The principal goal of this project is to demonstrate that plasma detachment is occurring in the VASIMR engine.

The next two years will provide an ideal opportunity to show that plasma detachment occurs. Three recent or planned improvements to the laboratory version of the VASIMR engine will facilitate this research. First, the power level in the system is being increased from the present 10 kW to 50 kW. This increase will be completed by the end of the summer of 2004. Second, a powered axial translation stage for