BIOMECHANICS ON THE INTERNATIONAL SPACE STATION: THE PAST, PRESENT, AND FUTURE:

THE DYSON LECTURE

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This lecture presents a brief history of biomechanical studies in space and contrasts their relative recency compared to physiological studies. Bone loss during long duration space flight is identified as an extremely important problem which remains in search of a solution. The present process of planning and implementing a flight experiment is briefly outlined and current funding opportunities are identified. The biomechanical equipment available to investigators in the Human Research Facility on the International Space Station (ISS) is discussed. Finally, an experiment which the author will conduct on the International Space Station in 2002 is described.

KEYWORDS: space exploration, biomechanics, NASA funding opportunities, bone mineral loss.

INTRODUCTION – THE DYSON LEGACY: I find it particularly nostalgic to present a lecture named for Geoffrey Dyson because during my days as an undergraduate at Loughborough College in England (1965-1969), Dyson's book *The Mechanics of Athletics* (1964) was an important reference in our coursework. I still have this book on my shelves. Dyson was a pioneer in human movement science and those of us in this field owe him a considerable debt. It is interesting to note that Dyson's name is alive and well in Cyberspace. While recently browsing the web , I found him referred to as "Britain's first seminal National Athletics Coach" (at http://users.ox.ac.uk/~ouac/Coaches.html); and saw the above mentioned book described as still "The best reference book for throwing physics" (at http://www.geocities.com/Colosseum/8682/physics.htm); and found the U.S. National Council of Teachers of Mathematics (at http:www.nctm.org/mt/indexes/authors/d-authors.html) referenced his book in their online mathematics teaching index. We should all hope that some of our work will still be revered 40 years after its publication!

BIOMECHANICS IN SPACE – A BRIEF HISTORY: Compared to the strong interest in physiological changes as a result of spaceflight that has always pervaded the US and former Soviet space programs, biomechanics has been somewhat ignored until the last decade or so. This is understandable since there were real questions in the early days of space exploration as to whether the human body would survive the accelerations of launch and reentry and how various organ systems would respond to the increased exposure to cosmic radiation (McCormack & Nachtwey, 1989). Once survivability had been assured (principally by animal experiments), the issue of space motion sickness held a dominant position since it was almost universal among crew members and resulted in a major loss of productivity on short flights (Homick & Vanderploeg, 1989). Later, interest shifted from the acute to the chronic problems and more biomechanically accessible issues such as bone mineral loss, muscle atrophy, and post-flight alterations in gait and motor control were explored (LeBlanc et al., 1995; Reschke et al., 1998). The term "exercise countermeasure" became current as a term for exercise programs designed to reverse adaptations to microgravity. However, for a number of years exercise was still seen in physiological terms although it was becoming increasingly clear that simply increasing heart rate to a given level was no guarantee of having a positive effect on bone and muscle (Cavanagh et al., 1992). The important studies of LeBlanc and colleagues (1998) have shown that despite extensive exercise countermeasures, 18 cosmonauts and astronauts who flew on the MIR station for between 4 and 14.4 months lost, on average, 1.5% of the bone mineral in the proximal femur per month. Importantly, there was no significant loss of bone in the upper extremities. These findings have been taken by some to indicate that exercise is not effective in preventing bone loss, but I feel strongly that this is the wrong conclusion. What these studies do show is that the magnitude, frequency, and duration of the exercises performed on MIR were not effective in preventing bone loss. What is now required is a controlled study with an adequate number of subjects adhering to a carefully monitored exercise program which has been designed to optimize loading on the lower extremity. Hopefully such an experiment will be possible in the future although there is no present plan for such a study.

CONDUCTING EXPERIMENTS IN SPACE – THE PLANNING AND THE PITFALLS: Dyson is reputed to have said that, “Athletes are made in the winter, polished in the spring and displayed in the summer.” This notion of perseverance is highly appropriate for a discussion of spaceflight experiments which are often planned in one decade, executed in the next, and perhaps published in a third! While this is somewhat of an exaggeration, I have never before experienced in my research career a process which requires so much advance planning. NASA, and more recently the National Space Biomedical Research Institute (http://www.nsbri.org/), have developed a carefully choreographed process which begins with the announcement of research opportunities and often a statement of research priorities. These are posted on the web at http://dstreet.idi.usra.edu:88/peer_review/nra/nra.html (See Figure 1). Scientists may respond by submission of a formal research proposal which is then peer reviewed. A small subset of the proposals are identified for further feasibility study which NASA calls “definition”. If the experiment fits with operational constraints and institutional priorities, the definition phase leads to funding. A team of administrators and engineers from NASA and its life science contractors are assigned to the experiment at this point to work with the principal investigator (PI) in order to assure that the science requirements of the project are met and matched by operational knowledge. This team of talented, motivated individuals who know what it takes to make an experiment fly successfully is a tremendous resource for the PI.

From this point on a series of clearly defined milestones must be accomplished. Experiment unique hardware must be designed, built, and tested to meet rigorous standards. Major design reviews (Preliminary Design Review, PDR, and Critical Design Review CDR) are held at which the status of the experiment and its hardware are presented to teams of NASA specialists with a broad spectrum of expertise. Informed consent must be obtained after briefings to astronauts and cosmonauts who are entirely free to decline or accept participation in any experiment. Crew training is a detailed process with many preliminary steps including the approval of lesson plans and presentations well in advance of their delivery. Custom devices to be used by crew members must be individually fitted and manufactured. Baseline data collection sessions need to be scheduled many months in advance since crew time is at a premium, and in the current arrangement crew members share their time between Russia and the US. Approximately 6 months before launch, flight equipment needs to be delivered to the Kennedy Space Center and is inaccessible in bond from that point onwards. Pre-and post flight data collection is complicated by the fact that launch and return of space station crew members always occurs on different continents. Detailed data archive agreements are worked out in advance and this has resulted in a major scientific resource being publicly available at the NASA Life Science Archive on the web (http://lsda.jsc.nasa.gov/). On days when experiments are being performed, principal investigators are in indirect contact with crew members via mission control, ready to troubleshoot any problems and to answer questions that the crew may have. Data return can be remarkably rapid; data streams downlinked from the Space Station can be in the hands of investigators within 24 hours.

Given the multifaceted nature of crew responsibility and the complexity of the systems involved, the investigator needs to be prepared to meet postponements and delays. The present plan is for each expedition (termed an "increment") to the ISS to last for approximately 120 days and scheduled changes of experiments from one increment to another are common. Sometimes experiments are discontinued after many of the stages described above have already been completed.

THE HUMAN RESEARCH FACILITY ON THE INTERNATIONAL SPACE STATION: The Human Research Facility (HRF) includes sets of equipment specially designed to provide investigators with tools to study human responses to space flight over the next 10 years. The first rack was launched in February 2001. Investigators who are planning to submit proposals for human research in Space would be well advised to become familiar with the equipment that is already available, since this minimizes the need to develop new experiment-unique hardware. Among the HRF equipment that is of interest to biomechanical researchers is the foot-ground interface device (FGI) - a modified Novel Pedar (http://www.novel.de), Joint Excursion Sensors (JES) - a modified Biometrics goniometer set (http://www.biometricsltd.com/), multichannel electromyography through an ambulatory data acquisition system (ADAS) - an off-the-shelf system from Temec (http://www.cuci.nl/~temec/), a head and body tracking device, and a device to measure body mass (not a straightforward problem in zero g). In the future, there may also be the capability to measure ground reaction forces and bone density.

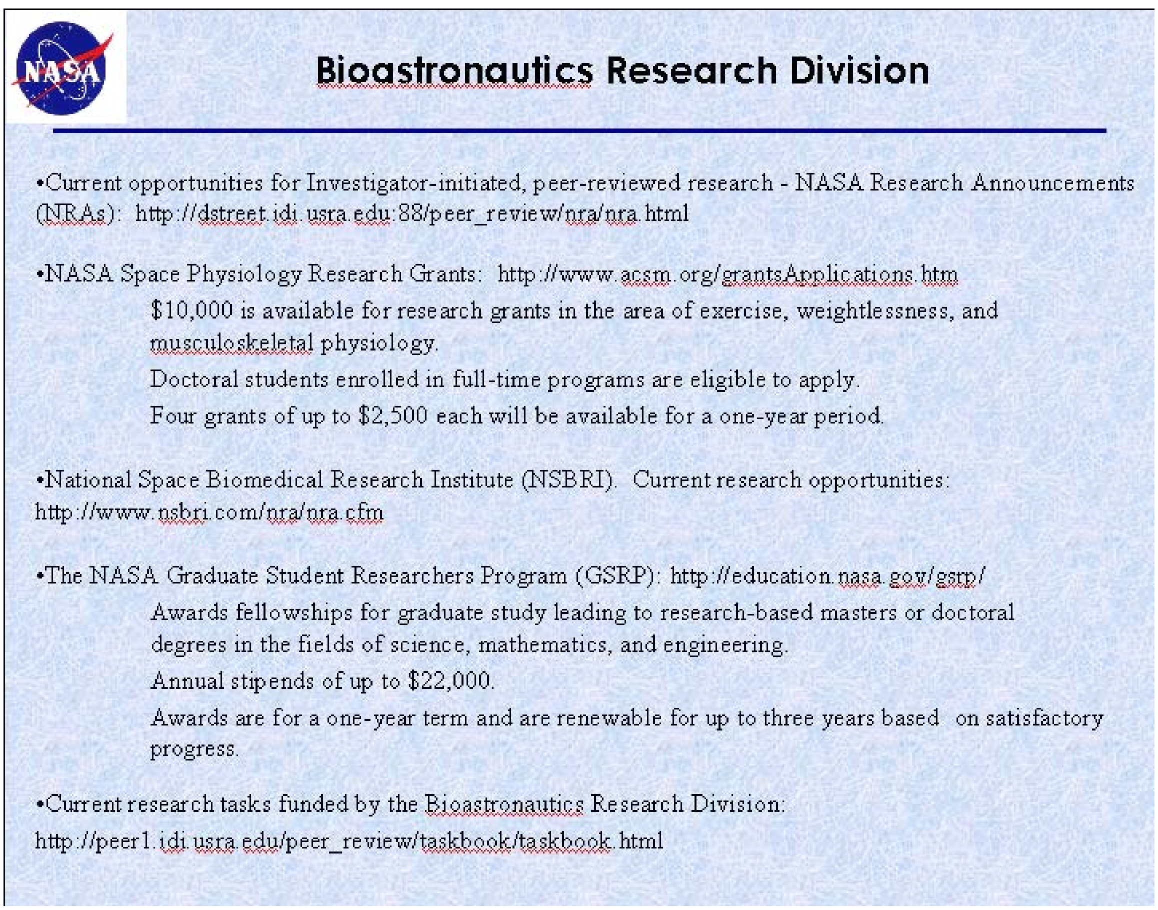

Figure 1 - Current NASA Funding Opportunities for Students and Researchers

EXPERIMENT 318 –THE BIOMECHANICS OF DAILY LIFE ON THE SPACE STATION: In the spring and summer of 2002, an experiment designed by the author (identified as ISS experiment 318 by NASA) will be conducted on the ISS. This experiment will compare upper and lower extremity function in 1g with that in 0g. Data on foot reaction forces, lower extremity joint excursions, and upper and lower extremity muscle activity will be collected on 3-5 subjects for 4 complete working days in both environments. In order to allow this to occur as a "background" experiment, all of the instrumentation has been built into a suit called the Lower Extremity Monitoring Suit (LEMS) which is shown in Figure 2. An armband containing EMG electrodes for the biceps and triceps will also be worn. The data will be stored on a 440 Mb flash card for subsequent downloading and returned to earth. We will be able to identify the duration and type of the lower extremity muscle actions that occur in the target muscles as isometric, concentric, and eccentric. The daily load on the surface of the feet will also be determined. Pre and post flight DXA and MRI will provide evidence of changes in bone and muscle during the 4 month stay in space. We hypothesize that the pattern of muscle action will be quite different in Space with a preponderance of concentric actions. We also anticipate that the amount of loss of bone mineral and muscle volume will be a function of the loading measured at the feet. In addition, we expect to see a considerable increase in upper extremity muscle activity in Space compared to that in 1 g.

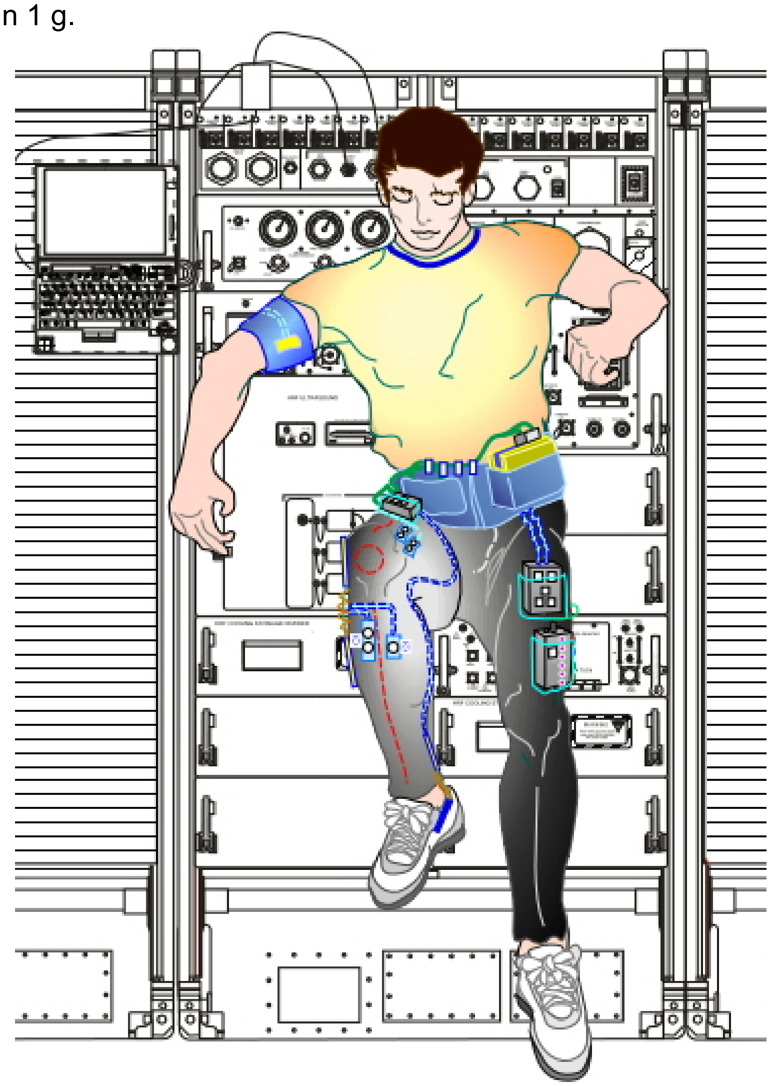

Figure 2 - An artist's impression of the Lower Extremity Monitoring Suit (LEMS) in which data from EMG, in-shoe force, and joint angle excursion is collected on the waist-mounted Ambulatory Data Acquisition System (ADAS).

CONCLUDING REMARKS: The author hopes that this lecture will stimulate young biomechanists to take on the challenge of performing experiments in Space. There are biomechanical problems of major concern to future inter-planetary missions that remain to be solved and much of the equipment for study of these problems is already in orbit. As Geoffrey Dyson might have said: " Reaching for the stars is possible with the right equipment, a good team, and a great deal of hard work".

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