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THE RHESUS MEASUREMENT SYSTEM: A NEW INSTRUMENT FOR SPACE RESEARCH

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INTRODUCTION

The Rhesus Research Facility (RRF) is a research environment designed to study the effects of microgravity using rhesus primates as human surrogates. This experimental model allows investigators to study numerous aspects of microgravity exposure without compromising crew member activities. Currently, the RRF is slated for two missions to collect its data, the first mission is SLS-3, due to fly in late 1995. The RRF is a joint effort between the United States and France. The science and hardware portions of the project are being shared between the National Aeronautics and Space Administration (NASA) and France's Centre National D'Etudes Spatiales (CNES).

The RRF is composed of many different subsystems in order to acquire data, provide life support, environmental enrichment, computer facilities and measurement capabilities for two rhesus primates aboard a nominal sixteen day mission. One of these subsystems is the Rhesus Measurement System (RMS). The RMS is designed to obtain in-flight physiological measurements from sensors interfaced with the subject. The RMS will acquire, pre-process, and transfer the physiologic data to the Flight Data System (FDS) for relay to the ground during flight. The measurements which will be taken by the RMS during the first flight will be respiration, measured at two different sites; electromyogram (EMG) at three different sites; electroencephalogram (EEG); electrocardiogram (ECG); and body temperature. These measurements taken by the RMS will assist the research team in meeting the science objectives of the RRF project.

THE SCIENCE OBJECTIVES OF THE RRF

The science experiments of the project will be performed by a team of U.S. and French principal investigators (P.I.) studying the effects of microgravity in the following areas: behavior and motor performance; muscle and bone physiology; calcium homeostasis; immunology/microbiology; cardiopulmonary, regulatory, and neural physiology.

During the mission, the subject will occupy his daylight hours by performing tasks on the Psychomotor Test System (PTS). The PTS consists of a monitor, a joy stick, and a number of pre-programmed tasks that the subject performs. The tasks involve maneuvering a pellet through a maze, similar to that of several video games. Successful completion is rewarded with a food pellet. Behavior and motor performance will be evaluated through the use of the PTS and the Activity Video System (AVS). Basically, the AVS is a video camera and image processing system which will record the subject's actions during the flight. The scientists will integrate the data recorded from the PTS and the AVS to study the primate's eye-hand motor skill, reaction time, perception and discrimination, target prediction, attention, memory, and ability to learn. These results will be compared to pre- and post-flight testing to determine how exposure to microgravity affected these characteristics.

Several aspects of muscle physiology will be studied. The research team will examine pre- and post-flight EMG patterns, using the AVS system to coordinate EMG activity with muscle movement. Muscle biopsy samples will be extracted pre- and post-flight and evaluated for biochemical changes due to microgravity exposure. The research team will examine muscle contractile protein alteration, myosin changes in muscle fibers, and ultrastructural remodelling of the muscle-tendon and muscle-nerve interfaces. The investigators will characterize the physiological mechanisms responsible for any observed changes due to microgravity.

To aid the research team, the RRF will be a closed biological system: all inputs and outputs will be quantified and qualified; food and water intake, electrolyte intake, urine output, and feces volume. Utilizing this closed system, the investigators will gain insight into calcium regulation, fluid and electrolyte shifts, hormonal responses, and temperature regulation.

Bone morphology studies will include pre- and post-flight bone biopsy samples, bone density measurements, and bone marrow samples. These observations will help determine if changes in bone calcium regulation (release/resorption) occur upon exposure to microgravity, and if so, whether these changes lead to modified bone cell activity and/or bone synthesis.

Fluid, electrolyte, and hormonal shifts are known to occur in human subjects upon exposure to microgravity within the cardiopulmonary system. The RRF will collect data on heart rate, pulmonary gas exchange kinetics, respiration rate, tidal volume and fluid volume shifts via ECG and abdominal and thoracic respiration. This information will allow investigators to quantify the magnitude of regulatory changes within the cardiopulmonary system.

Within the environment on the space shuttle, it is not possible to completely separate the life support systems of the animals and the astronauts. Therefore, it is necessary to assess the cross contamination of micro-organisms between the humans and the animal subjects, and any subsequent immune response. Cultures will be collected from both groups and susceptibility to antibiotics will be assessed as well as lymphocyte proliferation. Modification of intestinal microflora and fermentation will also be studied as a part of the immunology-microbiology discipline.

Space Adaptation Syndrome (SAS) is a problem encountered by many astronauts and may affect the ability of man to inhabit space for any significant length of time. The RRF will examine ECG and EEG data, correlated with PTS and AVS activity, to study the neurophysiological responses and potential mechanisms associated with SAS.

THE RHESUS MEASUREMENT SYSTEM

The RMS has several different components. Functionally, the RMS is composed of sensors, which interface to the subject; the Respitrace subsystem, which interfaces directly with the respiration sensors; the biotelemetry subsystem; the signal conditioning unit, a digital sampling and memory storage unit, and a power supply module. The biotelemetry subsystem is a receiver for an implanted transmitter which measures ECG and deep body temperature. The biopotential signal sensors for EEG and EMG interface directly to the signal conditioners.

Physically, the system is comprised of four different units: the Biotelemetry subsystem, the Respitrace subsystem, the Animal Analog Signal Conditioner, and the Power Supply Module. The configuration of the RMS can be seen in figure 1.

The Biotelemetry subsystem, referred to as Experiment Unique Equipment-1 (EUE-1), is one unit. The subsystem consists of a receiver, EUE-1, and the implanted transmitter. This transmitter contains the sensors which measure ECG and body temperature. ECG is measured with bio-potential leads attached across the heart. Body temperature is measured with a thermocouple. These readings are then modulated on to bursts of a 455 KHz signal which is then demodulated into the different signals and passed on the AASC for final signal conditioning. Because of the low power implanted transmitter, the receiver must be located close to the subject. Therefore, EUE-1 is mounted under the primate's left armrest.

The Respitrace Subsystem consists of EUE-2, and the respiration sensors, called the Respibands. The Respitrace utilizes inductance plethysmography to measure volume shifts in different parts of the body. This is implemented by the two Respibands, which are used to measure the respiration rate of the primate, and additional circuitry. The two Respibands, one placed around the thoracic region and the other on the abdominal region, are composed of a wire sewn into an elastic band in a zig-zag fashion. The bands each act as a single turn inductor which, when expanded and contracted, cause a change in inductance proportional to the circumference changes caused by respiration. Each inductor completes a phase-lock-loop oscillator circuit, creating a frequency shift proportional to the inductance change. A frequency to voltage conversion circuit then produces a voltage output analogous to the inductance change. The outputs of the Respitrace are further conditioned by a card located within the AASC. EUE-2 must also be close to the subject because it is connected to the Respibands. The unit mounts underneath the right armrest of the primate's chair.

The AASC houses the signal conditioning cards, the digital system, and two power cards. This unit has been the most complicated piece of the RMS to develop. While the AASC will provide 8 channels of data during its first mission, it is designed to accommodate up to 16 channels. The AASC is configured into 7 signal conditioner cards, 3 digital system cards and 2 power cards mounted into a single backplane. Because of a 180 × 240 × 70 cm envelope enclosure restriction, surface mounted components have been used in the design. The AASC is mounted on the wall behind the rhesus compartment. The signal conditioners must be located fairly close to the low level signals it receives in order to reduce noise induced on the lines. Table 1 gives the characteristics of all the cards in the AASC.

The signal conditioner cards in the AASC filter the signals into appropriate bandwidths and scale them to a 0-5 Volt signal. There is one signal conditioner card for each physiological signal except the respiration measurement, which has a dual respiration signal conditioning card. The signal conditioner cards also contain calibration circuitry to allow for in-flight calibration of the circuits and to optimize measurements for each particular subject. The AASC has been designed as a modular system. Signal conditioner cards are interchangeable. The modular design allows new signal

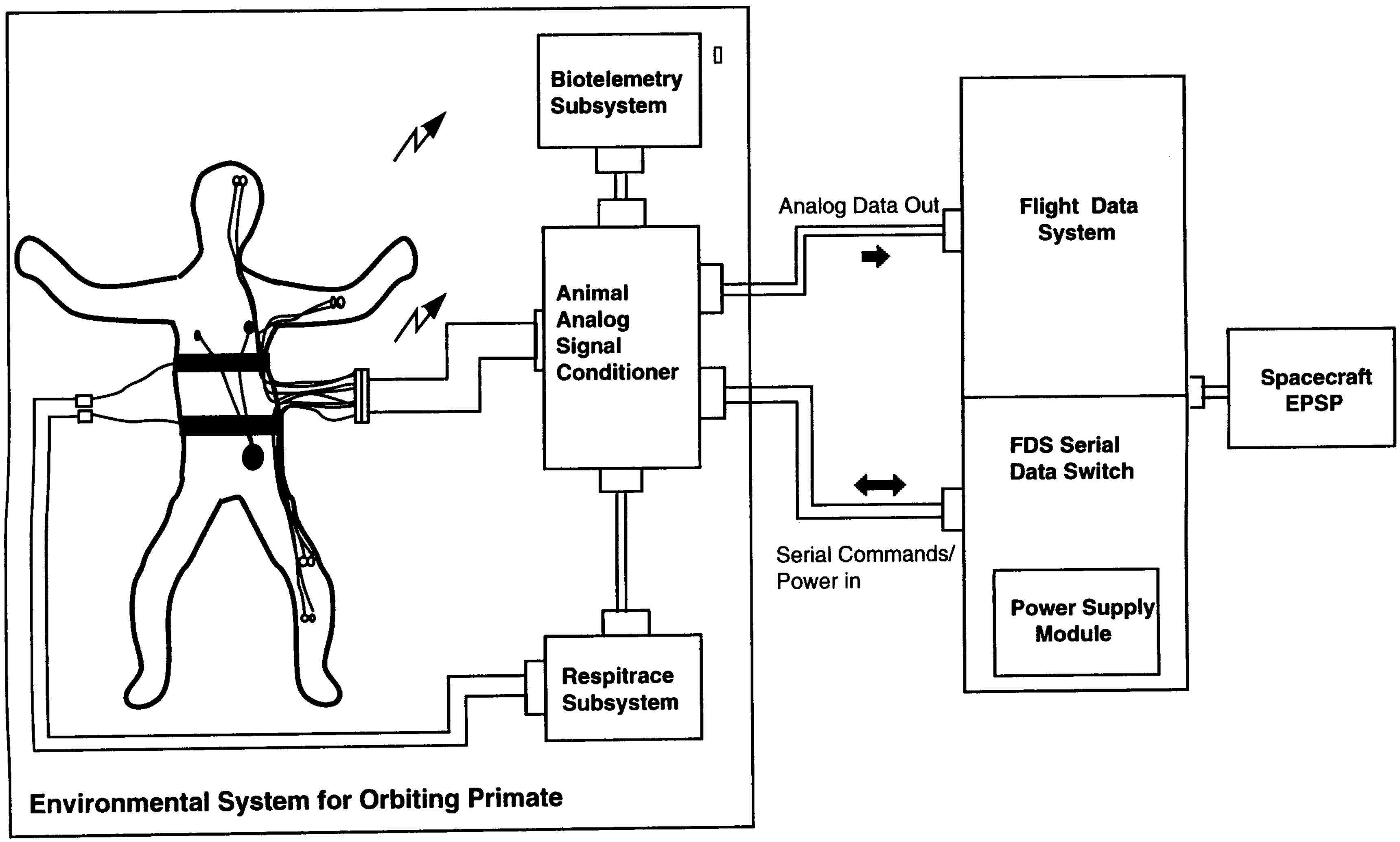

Figure 1. RMS Block and Interconnect Diagram.

Table 1. AASC board characteristics

Board	Input level (V)	Gain range	Offset range (V)	Filter range (Hz)
EMG	.1 - 10 mV	400 to 40,000	2.5 nominal	2 to 1000
EEG	.01 - 10 mV	400 to 40,000	2.5 nominal	1 to 100
TEMP	0 - 1 V	0 to 100	2.5 nominal	Low pass 1 Hz
ECG	1 V P-P	1,2,5,10,20, 50, 100	2.5 nominal	0.05 to 100
Dual RESP	1 V P-P	1,2,5,10,20,50, 100	2.5 nominal	Low pass 10 Hz
PWR Cond	± 8.5 V	N/A	N/A	N/A
PWR ISO	± 8.5 V	N/A	N/A	N/A
Micro-controller	68HC11 Microcontroller, provides parallel control ports to cards: 8 ch., 8 bit A/D converter, RS-232 Serial Communications Port			
Micro-peripheral	Provides control for the memory plus battery backup for memory			
Memory	≥ 2 Mbytes 8 bit SRAM Memory			

conditioner cards to replace the originals so that new measurements can be collected in future flights without a complete redesign of the instrument. Also, this allows the hardware to be used for ground-based research.

The power cards and the digital system cards are fixed in the AASC. The first power conditioner card further regulates the output of the Power Supply Module and routes it to the power isolation card. The power isolation card prevents a shock hazard to the subject by generating a floating power supply for the biopotential signals (EEG and EMG) which are directly connected to the biopotential signal conditioning cards. To prevent shock originating from direct short circuits to the isolation power card, there is a high input impedance between the probes and the signal conditioning card, which severely restricts current flow.

The digital system provides the AASC with the ability to acquire and store data during the ascent and descent phase of the flight. During that time, power supplied to non-critical hardware in the shuttle must be kept to a minimum. The Flight Data System requires much more power than the RMS alone; therefore, during those phases the RMS must store the data. The data will be down-loaded to the FDS in flight when it comes on line. The digital system consists of a microcontroller card, a memory card containing at least 2 megabytes of memory, and a memory controller card.

The digital system gives the AASC considerable flexibility. Through the software stored in the microcontroller card, the system has the capability to adjust gains, offsets, and sample rates and provide a calibration and operate mode for each different signal. Because of the limited memory due to size constraints, different sampling scenarios have been developed. These scenarios are outlined in table 2. These scenarios allow the research team to optimize the data available to them during ascent and descent. In EEG and EMG, with a bandwidth of 1000 Hz, there is much information to be gained at a high sampling rate. However, to do so would require large chunks of memory. The compromise is to sample high fidelity data for 10 seconds of each minute on two channels of EMG, and 1 minute out of every 2 hours on the other EMG channel.

Table 2. RMS Digital System Sampling Scenario

Parameter	Ascent Duty cycle sample rate (Hz)		Descent Duty cycle sample rate (Hz)	
ECG	N/A		N/A	
Heart rate	60 sec		.2	
Body temp	60 sec		.2	
EMG1	50 sec/6 min	50	50 sec/8 min	50
	10 sec/6 min	1000	10 sec/8 min	1000
EMG2	50 sec/6 min	50	50 sec/8 min	50
	10 sec/6 min	1000	10 sec/8 min	1000
EMG3	N/A		1 min/2 min	50
	1 min/2 hr	2000	1 min/2 hr	2000
EEG	(Undecided)			
Respiration (abdominal)	1 min/3 min	20	1 min/2 min	20
Respiration (thoracic)	1 min/3 min	20	1 min/2 min	20

The Power Supply Module (PSM) is the fourth element of the RMS. The PSM receives power in the form of +28 Volts from the Shuttle's Experimental Power Switching Panel (EPSP). Utilizing DC to DC converters, it then converts it to the ±8.5 volts necessary to power the AASC. As required by Shuttle, the PSM has a large inductor on the front end to smooth voltage transients up to twice the nominal value of the supply. The Power Supply Module, which does not require close proximity to the AASC, is mounted in a separate rack.

FLIGHT HARDWARE REQUIREMENTS

In addition to the electrical requirements, the hardware must prove to be rugged and safe in order to be certified for flight on the Shuttle. The primary requirement is that the hardware must not compromise the safety of the crew or the study subjects. Further, the hardware must be able to withstand moderate vibration, possible pressurization and depressurization, and temperature fluctuations without flying apart or exploding. Materials used in the instrument must not offgas chemicals into the shuttle environment and must not be flammable. The system must not radiate electromagnetic interference (EMI) which might disrupt Shuttle systems. A secondary requirement is that, subject to all these conditions, the hardware must function properly. Electrical components must have the highest reliability available and mechanical components must maintain their integrity.

The system, therefore, is subject to rigorous analysis and testing regimes to verify it is qualified for flight on Shuttle. Analyses are performed to show it will withstand pressurization and to show a sufficient number and size of fasteners are used to mount components. The vibration and EMI tests performed on the hardware demonstrate that the RMS will not come apart and it will not interfere with other Shuttle systems. Materials used in the system must have been individually evaluated for suitability in space are rated non-toxic, particularly with regards to flammability and offgassing in non-metallic parts. Since the RMS utilizes surface mounted components, a relatively new flight hardware technology, the electrical components will face card level testing before flight. The cards will be subject to temperature cycling and vibration tests. This is in addition to the normal qualification testing sequence.

Another important requirement of the RRF is that it not contaminate the crew cabin with animal odors or particles. The RMS fulfills this requirement, because the AASC mounts on a surface which is an interface between the animal's chamber, the Environmental System for Orbiting Primate (ESOP), and the crew cabin. Thus, the AASC is attached with a gasket that provides an airtight seal. The integrity of the seal is tested for a specific leak rate. The interface gasket on the AASC also supplies a continuous electrical connection to the ESOP thereby providing a complete EMI shield.

The RRF has also developed a "power contract" with the shuttle limiting the maximum power the RRF may consume at all times during the mission. Power on the shuttle is limited and therefore, is doled out carefully, particularly during ascent and descent. The RMS has been allocated 20 Watts for the duration of the mission. The use of low power and CMOS surface mounted circuitry provides the RMS with a tremendous advantage in being able to accomplish the science objectives of the RRF well under this power restriction.

THE FUTURE

The RMS was designed to support the science objectives of the Rhesus Research Facility, but the system's capabilities extend beyond this mission. The surface mounted components utilized in the RMS will continue to pave the way for future flight hardware design, especially given the size and power restrictions on the Shuttle. The configuration of the RMS also allows the incorporation of hybrid technology which would further expand its capabilities. With instrumentation being so costly to develop, it is well worth our efforts to design hardware which can be used over again. With its versatile design, the RMS can implement new measurements accommodating many different kinds of science research, both ground-based as well as in space.

BIOGRAPHIES

Julie Schonfeld has been at Ames Research Center for one year in the Electronic Systems Branch. She is currently serving as the Deputy Project Manager, Systems Engineer for the Rhesus Measurement System project. Previously, Ms. Schonfeld worked at Kennedy Space Center in the Design Engineering, Instrumentation Section. There, her projects included the Hazardous Gas Detection System, both primary and back-up, and the Solid Rocket Booster Inadvertent Ignition Detection System. Ms. Schonfeld received a B.S. in Electrical Engineering from the University of Central Florida is currently working on an M.S. in Electrical Engineering at Santa Clara University.

John Hines is manager of the Sensors 2000! (S2K!) Program, an Advanced Biosensor Technology Development initiative within the Electronic Systems Branch at Ames Research Center. In addition to the S2k! Program, Mr. Hines is Project Manager for the Rhesus Measurement System, the Cosmos '92 US/Russian Bioinstrumentation System, and several ground-based sensor and instrumentation projects. Prior to those activities, Mr. Hines was a Major in the US Air Force assigned as Deputy Chief of the Information Processing Technology Branch in the Avionics Laboratory at Wright-Patterson AFB, Ohio. Previously to that, he was Manager of the NASA-Ames Cardiovascular Research Laboratory. Mr. Hines has a B.S. in Electrical Engineering from Tuskegee University and a M.S. in EE/Biomedical Engineering from Stanford University. Mr. Hines has over 17 years of combined NASA/Air Force service.