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26. EFFECT OF SCIENCE LABORATORY CENTRIFUGE ON SPACE STATION ENVIRONMENT

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I represent a completely different user community, the life sciences. It has been a good opportunity to be here and listen to what life sciences often considers the other side of the fence, materials sciences. Hopefully, I can share a little of the life sciences rationale with regard to the centrifuge. One of the projects we are working on at Lockheed, as an independent development project, is a specimen research centrifuge. Consequently, this is proprietary data for Lockheed.

The National Commission on Space report, released recently, states the rationale for a specimen research centrifuge. It says that we really don't understand the life sciences aspects of the effects of gravity. Materials scientists are interested in the effects of residual gravity levels on the order of 10^{-4} to 10^{-7} g. The life sciences community is interested in slightly different levels, between 10^{-3} and 1 g, which are only obtainable in the Space Station or in a spacecraft environment using a centrifuge.

Several potential medical problems arise for spacecraft crew in space. The heart becomes deconditioned, the skeleton demineralized, and the muscles lose mass. The body stops reacting to the 1-g force that is always felt on the ground. The Russians found that after 237 days in space, their cosmonauts had many problems adapting to Earth's gravity again. In fact, it took them 45 days back in Earth's gravity before they could even play catch, because they had lost their coordination. Consequently, these microgravity effects pose a very serious problem. And, although it brings a variety of horrifying pictures to many people's minds to have this large rotating device up there, the centrifuge is essential if we're going to go further in manned space exploration.

In this presentation I will discuss the rationale for the research centrifuge, to give some background information about our need for it. I will also discuss the configurations that are currently being considered, and the dynamics of the centrifuge. I will then describe a system that we have developed, with the help of Sperry Corporation, that should ease the worries about the centrifuge.

The primary reason for the centrifuge is to identify gravity's role in biological, physical, and chemical processes. We must also evaluate the requirements for artificial gravity on long-duration manned missions. Some of the Russian cosmonauts have said that they don't know if the human body could withstand a round trip to Mars. We could go there, without a problem, but upon return to the Earth environment, it is not certain our bodies could re-adapt to 1-g. We also don't understand the effects of fractional g. The Moon has 1/6 Earth's gravity and Mars 1/3. It has always been a dream to colonize Mars, but we are not sure if we can tolerate that level.

We must provide a controlled acceleration environment for comparison with microgravity studies. One of the criticisms of biological experiments that have been conducted to date in the Shuttle, is that we can not be sure the effects we are seeing are from microgravity unless we have a control group. It is normal practice to have a control group, where we vary only that one parameter, microgravity. So if we have a centrifuge and a microgravity holding facility that use the same habitat configuration, we are able to vary that one parameter of gravity.

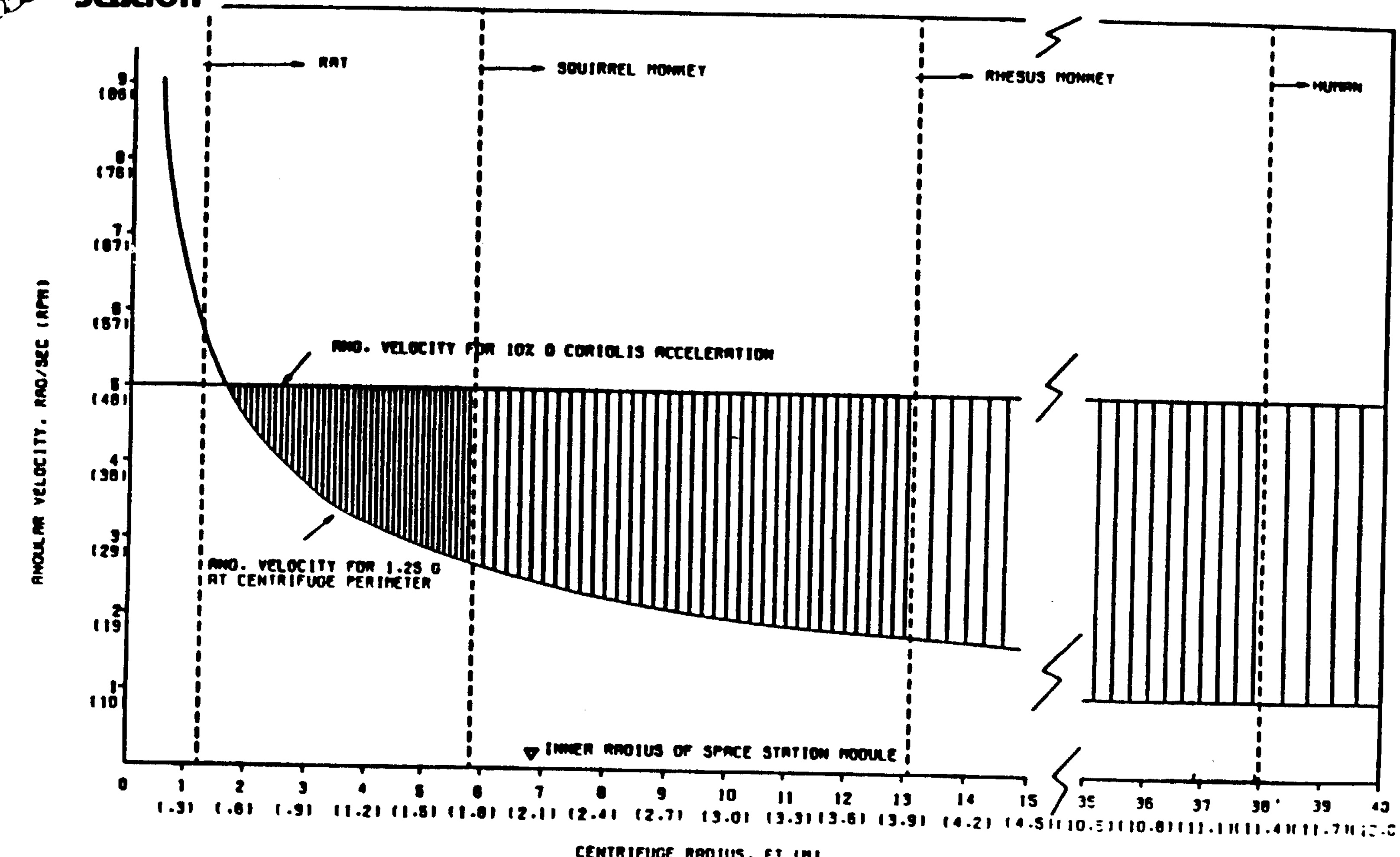
We also can use the centrifuge to provide a 1-g environment to supply specimens free of launch effects for long-term studies. After going through launch and into orbit, the specimens may already have adapted quite a bit to zero-g. If we had them on the centrifuge we could simulate a 1-g environment (as though they were on Earth), and we could immediately transfer them to microgravity. We could then detect any rapid changes as they occur.

Finally, one of the objectives proposed by the National Commission in Space is to have a large-diameter, experiment-carrying capsule or module at the end of a tether or some very large rotational system where we could actually investigate the effects of varying artificial gravity on humans. The Space Station centrifuge allows you to test the necessary rotational systems.

Figure 1 shows the scientific bounds on centrifuge size. The most constraining bound on the size of the centrifuge, assuming we want it to be inside the Station, is the inner radius of the module. The upper limit of the angular velocity is set by the coriolis acceleration. It is bounded on the lower side by the need to create 1 1/4 g at the perimeter, which should make about 1 g at the specimen's heart. Figure 1 illustrates the relationship. The vertical lines indicate the radius an animal can handle with a ±10% gravity gradient across its body. If you were on a centrifuge, you wouldn't want the gravity at your feet to be completely different from the gravity at your head; that would not simulate Earth. Scientists think specimens can probably handle a plus or minus 10% or a 20% gradient across their bodies, thus determining the centrifuge size limits for a rat, a squirrel monkey, a rhesus monkey, and a human. To have a rat on a centrifuge and to simulate Earth gravity, we need a centrifuge diameter of at least a couple of feet. We can't fly squirrel monkeys on the centrifuge unless its radius is almost 6 ft, and we'll notice that for radially oriented humans to be on the centrifuge, we need a 38-ft-radius centrifuge, which would require a variable gravity research facility separate from any modules of the Station.

Another capability that scientists would like to have is various radii simultaneously available to provide different g-levels. They would like the centrifuge to have positions at 1 g, 0.8 g, and 0.6 g so that they can study the effects on the specimens of fractional gravity in the same experimental time frame.

SCIENTIFIC BOUNDS TO CENTRIFUGE SIZE



ASSUMES: ± 10% GRAVITY GRADIENT
- 0.3 KG RAT, 2.5" BACK TO BELLY
- 1.2 KG SQUIRREL MONKEY, 11" HEAD TO BUTTOCKS
- 14 KG RHESUS MONKEY, 26" HEAD TO BUTTOCKS
- 92 KG 95TH % MALE, 73" HEAD TO FOOT
- SPECIMEN MOTION OF .1 M/SEC

FIGURE 1

A controversial issue at this time is whether we need a servicing rotor. If we must create and maintain a continuous 1-g, Earth-like environment on the Station, we wouldn't want to stop the centrifuge and expose all the 1-g specimens to micro-g every time we need to take a sample or clean a cage. There are some scientists who believe we need to have a separate rotor that spins up, matches the spin rate of the centrifuge, engages with the centrifuge, removes two specimen packages, and spins back down again, so that we expose only that two specimen packages to microgravity (see Figure 2).

We also want to support samples ranging in size from cells all the way up to humans. Acceleration levels shown range from 0.001 to 2 g, and acceleration rates from 0.01 to 0.25 g/sec. The centrifuge should not create vibration for the Station. Also, the variation of the g-level on the centrifuge should not exceed 10^{-3} g.

Figure 3 shows a concept that would fit in the Station. The 6-ft-diameter centrifuge takes the space of two double racks on a Space Station module. On this centrifuge we can put rodents and small plants, but we can't do squirrel monkey research.

A full-module-diameter centrifuge which provides the scientists with the large radius that they want, but has a very large hub with a hole through the center, is shown in Figure 4. In fact, the hub has the same diameter as the diagonal dimension of the hatch. And it's stationary, so as far as the crew is concerned, it's just a tunnel that they go through. Another solution is an attached module containing both the centrifuge and the stationary specimen holding facilities. The centrifuge would have a small hub and therefore support more specimens. The specimens would be isolated from the material sciences and the other parts of the station.

The mass for the 6-ft-diameter centrifuge is about 270 kg, while for the 12-ft diameter it is approximately 1,000 kg. The moments of inertia are correspondingly larger on the large centrifuge. To create 1 g at the perimeter, the spin rate of the 6-ft centrifuge is 31.5 rpm,

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12 FOOT CENTRIFUGE WITH SERVICING ROTOR IN 14 FT MINIMODULE

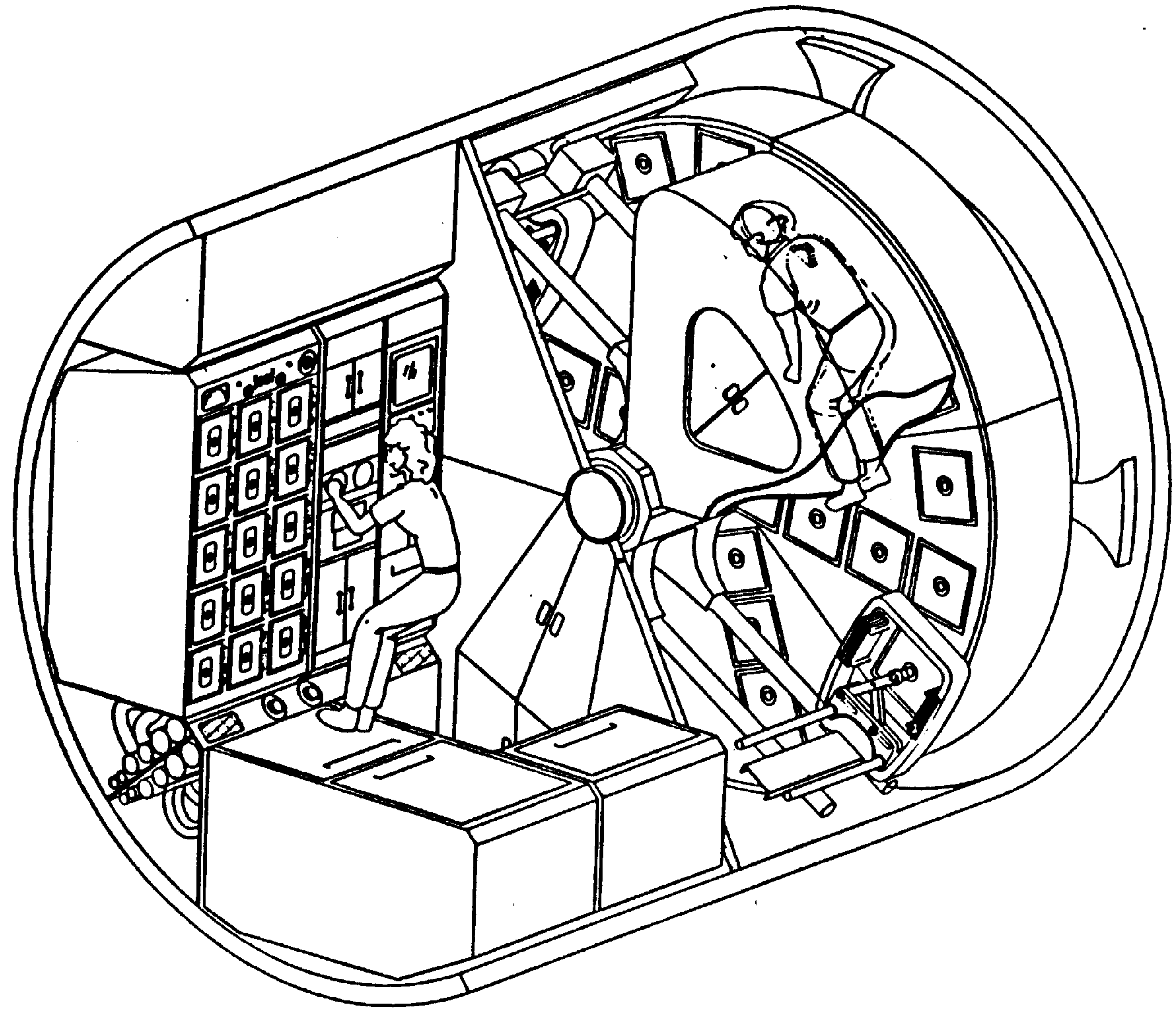

FIGURE 2

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6 FOOT DIA RACK MOUNTED CENTRIFUGE WITH AUTOMATED SERVICING

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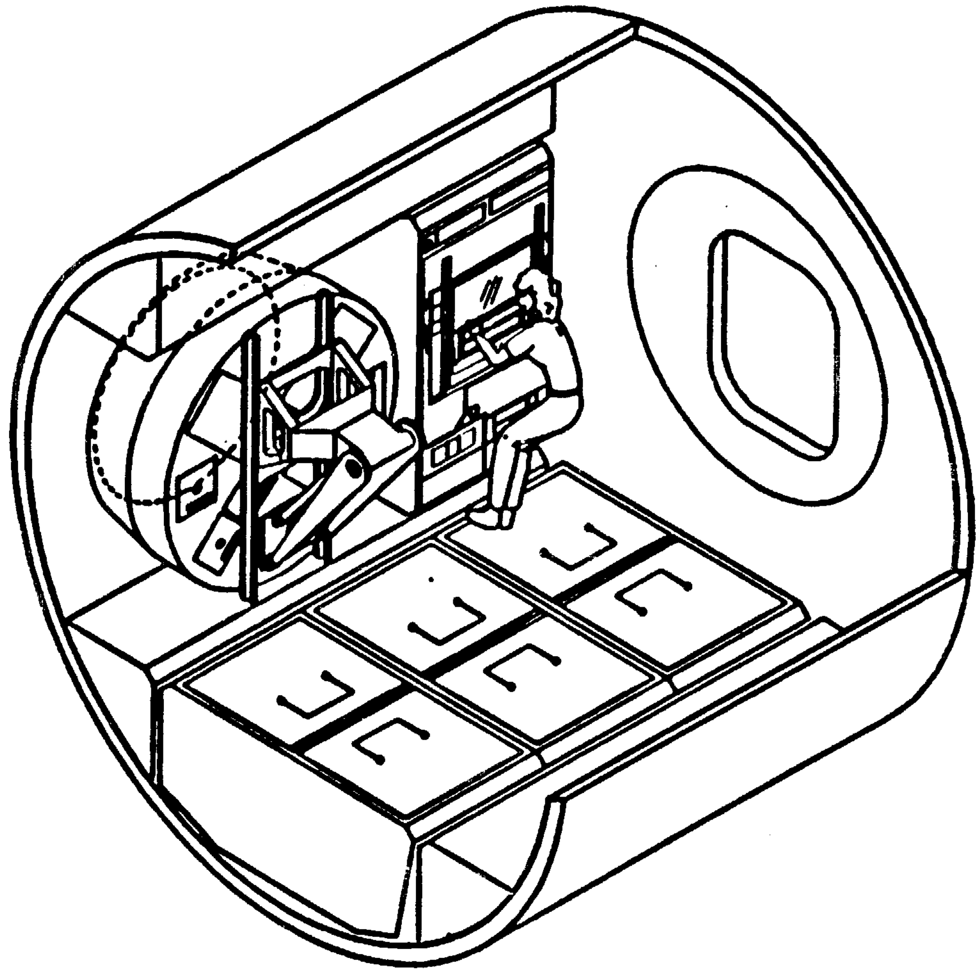

FIGURE 3

12 FOOT CENTRIFUGE WITH SERVICING ROTOR IN MODULE END OR 14 FT MINIMODULE

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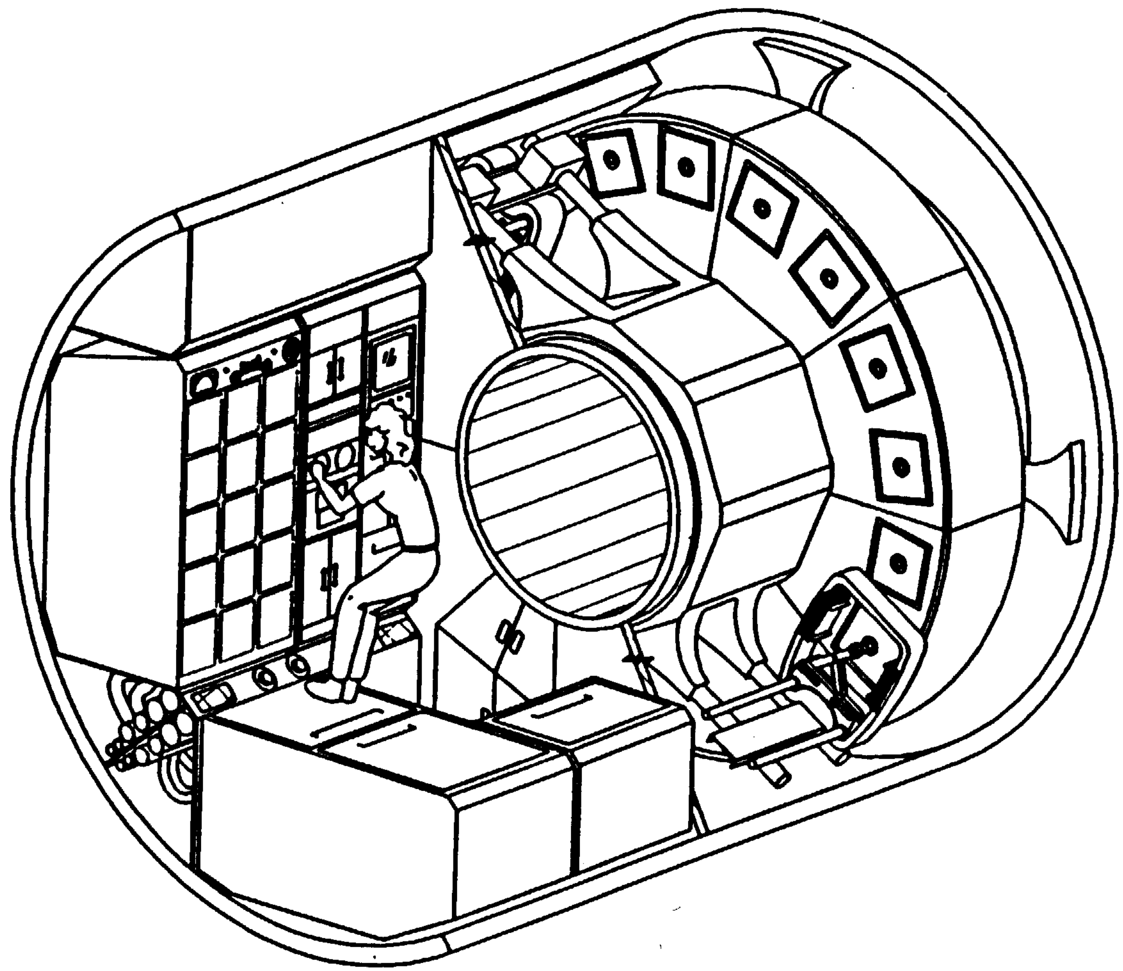

FIGURE 4

while it is almost 22 rpm on the large-diameter centrifuge. The spin-up time for nominal 1-g operations is about 2 min for the principal rotor. That doesn't require a lot of torque. The angular momentum for this case is 363 N m sec for the 6-ft, and about 4,800 N m sec for the 12-ft centrifuge. Our assumption has been that uncompensated momentum and torque should not exceed 1 to 3%, and that the Station control system can handle that much residual.

Figure 5 was put together to eliminate some misconceptions about the centrifuge and illustrate how we have eliminated or solved many potential problems. The first misconception is that the centrifuge will create an unacceptable disturbance of the microgravity environment. The system that we have designed is a magnetically suspended and dynamically balanced centrifuge. That eliminates the majority of the problems of vibration disturbance. Another concern was that the centrifuge would cause a torque on the Space Station and cause it to precess. We've designed the centrifuge with a counter-rotating inertia wheel, which absorbs both the gyroscopic effects and the starting and stopping torques of the centrifuge. Another concern is that such a large centrifuge will be dangerous, but the centrifuge really rotates slowly, only at about 22 rpm. Also, we plan on enclosing it in a structural honeycomb absorption barrier system so there won't be any problems if something should come loose. We also have touchdown bearings to contain the centrifuge in case of power loss. Other concerns were that the magnetic suspension system would generate electromagnetic interference and that the magnetic suspension system presents a big development risk. In response, the system is designed so that magnetic flux cannot escape. This suspension technology has been used before on momentum control gyros and on vibration-isolated pointing systems.

Another major design driver is that the centrifuge must be assembled on orbit. The hatches are 50 in. square with a 12-in.-radius corner which gives a 60-in. diagonal. Even the 6-ft centrifuge would not fit through the hatches. Consequently, we have designed both centrifuges to break into separate components which can be passed through the hatches. The drive motor is an ironless armature, dc-drive, brushless, noncontacting system.

SPACE STATION

CENTRIFUGE FACT SHEET

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MYTH	FACT
THE CENTRIFUGE WILL CAUSE UNACCEPTABLE DISTURBANCE OF THE MICROGRAVITY ENVIRONMENT	THE CENTRIFUGE DOES NOT MAKE PHYSICAL CONTACT WITH THE SPACE STATION. IT IS MAGNETICALLY SUSPENDED AND AUTOMATICALLY BALANCED
THE CENTRIFUGE WILL EXERT A TORQUE ON THE SPACE STATION, CAUSING THE STATION TO PRECESS	A COUNTER-ROTATING INERTIA WHEEL ABSORBS GYROSCOPIC, STARTING, AND STOPPING TORQUES
SUCH A LARGE ROTATING SYSTEM IS DANGEROUS TO THE CREW AND STATION	THE CENTRIFUGE ROTATES SLOWLY (~22 RPM). AN INTERLOCKED PHYSICAL BARRIER IS PROVIDED BETWEEN THE CREW AND THE ROTATING CENTRIFUGE. AN ENERGY-ABSORBING HONEYCOMB SHIELD ENCLOSES THE CENTRIFUGE. DESIGN IS FAIL-SAFE AND INCLUDES TOUCH-DOWN BEARINGS TO PROVIDE CONTAINMENT IF POWER FAILS
THERE WILL BE ELECTROMAGNETIC INTERFERENCE FROM THE MAGNETIC SUSPENSION AND MOTOR	SIMILAR MAGNETIC BEARINGS ARE USED ON THE MAGNETIC ISOLATOR DEVELOPED TO FLY IN A SHUTTLE MID-DECK LOCKER, DESIGNED TO SHUTTLE EMI REQUIREMENTS
THERE WILL BE MAGNETIC FIELD INTERFERENCE BETWEEN THE MOTOR, SUSPENSION, AND ROTARY DATA AND POWER TRANSFER DEVICES	DESIGN IS BASED ON MAGNETIC ATTRACTION. FLUX IS CONFINED TO THE AIR GAP AND DIES OUT TO BELOW EARTH'S MAGNETIC FIELD WITHIN ONE FOOT
MAGNETIC SUSPENSION AND PROPULSION REPRESENTS A SIGNIFICANT HARDWARE DEVELOPMENT RISK	TECHNOLOGY IS SIMILAR TO THAT USED IN SATELLITE CONTROL MOMENT GYROS, TALON GOLD VIBRATION ISOLATION POINTING SYSTEM, AND HIGH RATE GAMMA SCANNER FOR SANDIA

FIGURE 5

To determine how the centrifuge will perform on the Station -- because we not only have to isolate the Station from the centrifuge, but also the centrifuge from the Station -- we modeled the Space Station for manned push-off, treadmill, and control moment gyro forces. We obtained an environment for the Space Station as shown in Figure 6. Then we did a similar analysis for the centrifuge, also shown in Figure 6. It is obvious that the centrifuge is really not the major driver for micro-gravity concerns; there are more problems with the crew push-offs, treadmill, man movements, pumps, fans, and other forces.

In Figure 7, the centrifuge characteristics were superimposed on a chart showing representative disturbances. The centrifuge comes in below many of the transient responses, but above the steady-state accelerations.

You will recognize the chart taken from a Teledyne Brown Engineering study, shown in Figure 8; it has been discussed repeatedly in the past few days. The centrifuge data are plotted with the requirements that are postulated by the material sciences. The centrifuge data are located far enough to the right in frequency so that the centrifuge would not disrupt even the lower than 10^{-5} g requirements of the materials sciences in the lower frequency regime.

This is our first cut at the large centrifuge. We continue our analyses, and as the Station configuration is defined more closely, we will be able to do more work on the design to ensure we don't adversely impact experiments. One of the challenges that faces the centrifuge program is to determine if we need the service rotor. We are already facing a complex dynamic problem by having two wheels rotating, the counter-rotating inertia wheel and the centrifuge. An independent service rotor will add complexity because the counter-rotating inertia wheel has to compensate for that additional rotation. If we don't have a service rotor the centrifuge must be stopped for servicing, and all the specimens must be serviced at once.

CENTRIFUGE DISTURBANCE
COMPARED TO SPACE STATION ENVIRONMENT

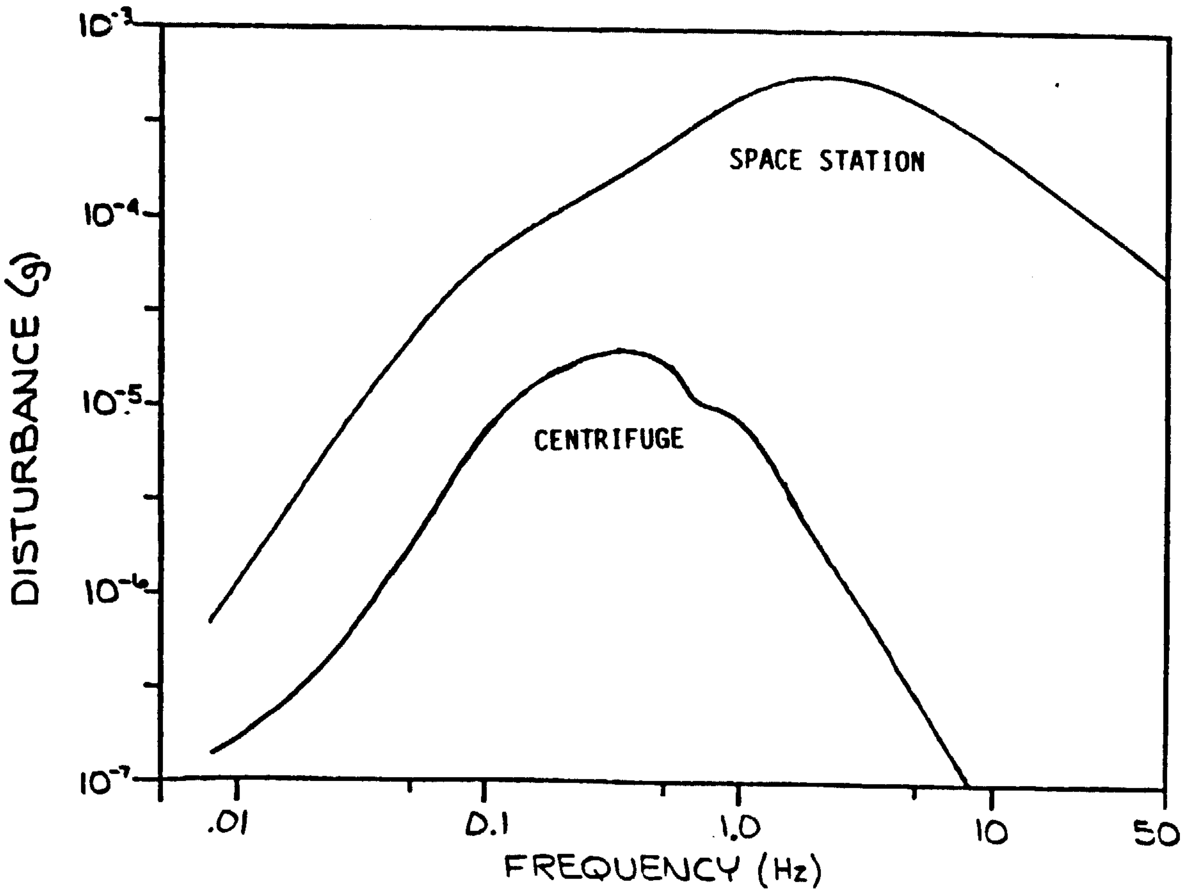
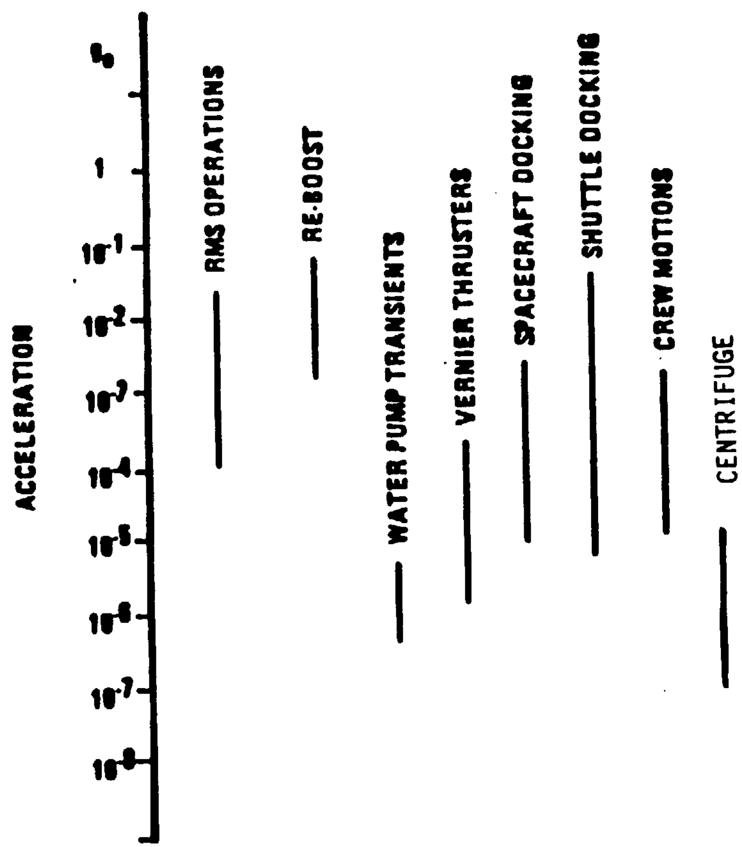
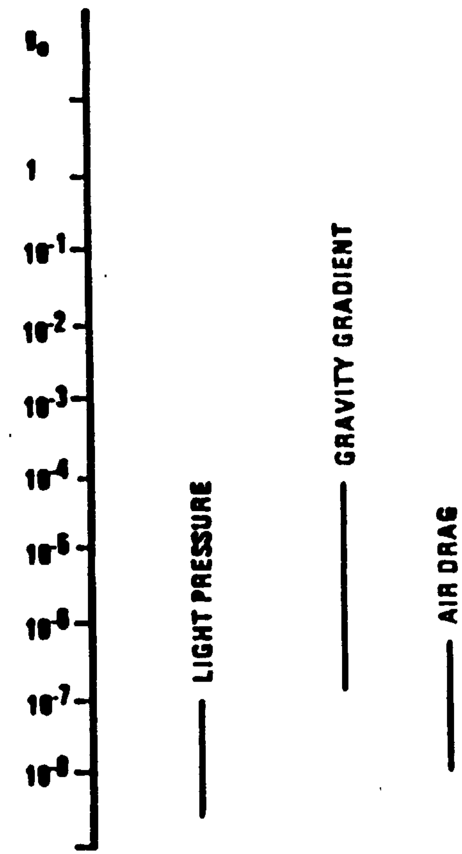


FIGURE 6

SPACE STATION ACCELERATION ENVIRONMENT



TRANSIENTS
COVERING A FREQUENCY SPECTRUM
FROM ABOUT 10^{-3} TO 10 Hz



STEADY STATE ACCELERATIONS
(0 TO 10^{-3} Hz)

FIGURE 7

ACCELERATION SENSITIVITIY OF MATERIALS PROCESSING

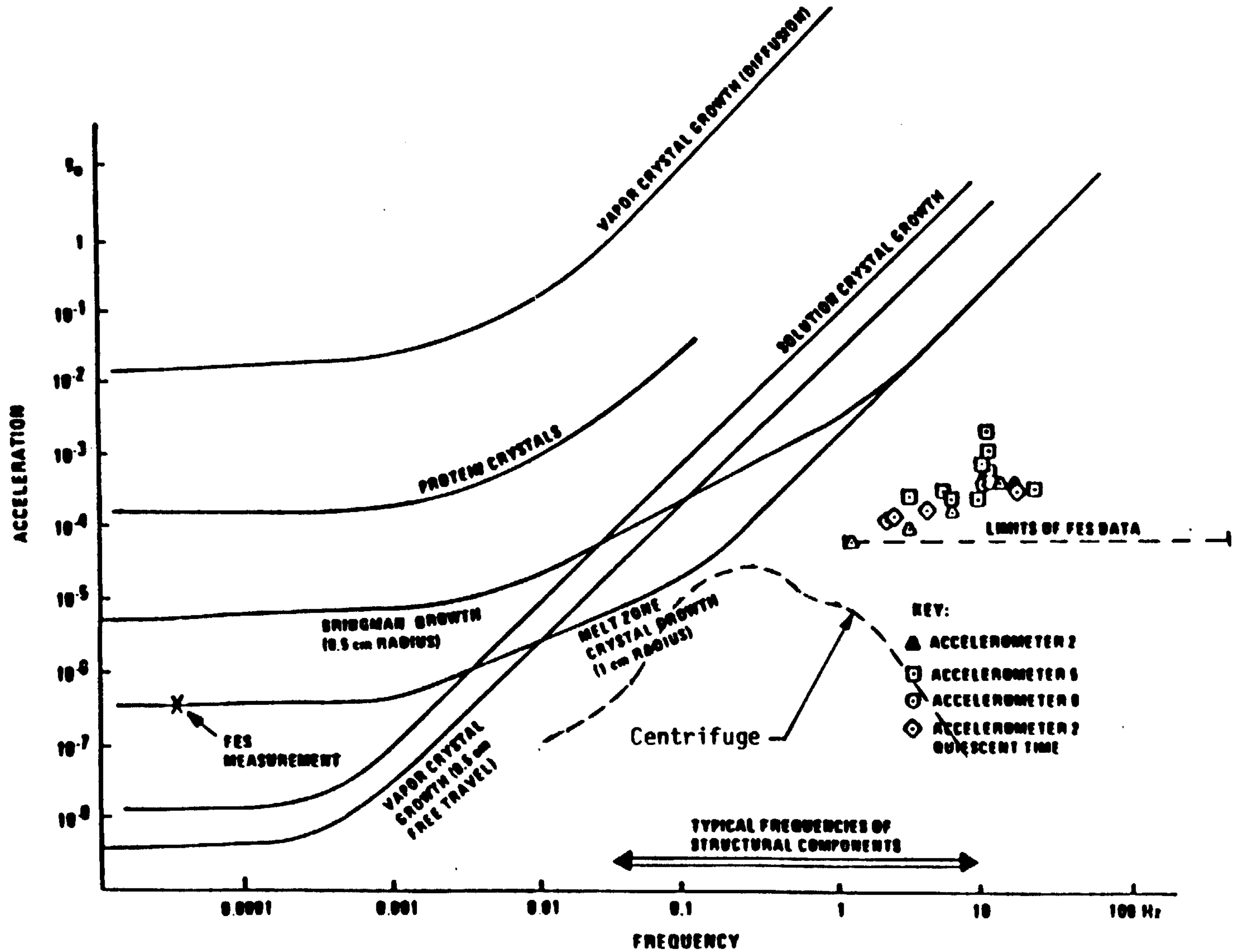


FIGURE 8

Another study that needs to be undertaken is the analysis of the dynamic interactions between the Station and the centrifuge to make sure the centrifuge doesn't excite any structural resonances. A further, important step will be the integration of all the dynamic disturbances, and the verification that they do not exceed the allowable limits.

In summary, as shown on Figure 9, the life sciences community and the Space Station program need the centrifuge. Lockheed has been working on centrifuge designs that satisfy the science objectives as much as possible, while also keeping in mind that the centrifuge must be designed to have the smallest possible dynamic impact on the Space Station.

Question: For all the dynamicists present, I will tell you that you will save yourself a ton of grief if you will bring that compensating rotor a lot closer to your main rotor.

Question: Is there a mechanism for taking into account animal movement back and forth in there, and how that might drive resonances in the Station?

Douglas Havenhill, Sperry Corporation: The balancing system was designed only to take out static imbalance. However, the magnetic isolation, or the magnetic suspension system, also provides a certain amount of isolation. Although we have not looked at it in any detail, we certainly think that animal motions are going to be much less than any kind of crew motion.

Searby: The philosophy was that you isolate against the dynamic imbalances, and you compensate for the static.

Question: The issue still is, will you drive the resonant frequencies of the Station?

Havenhill: There is a certain amount of isolation that's built into the suspension system. Whether there will still be an excitation of resonances, we don't know.

SPACE STATION

SUMMARY

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- WE NEED A CENTRIFUGE

- WE HAVE CENTRIFUGE DESIGNS WHICH SATISFY SCIENCE OBJECTIVES

- THE CENTRIFUGE IS BEING DESIGNED TO HAVE THE SMALLEST POSSIBLE DYNAMIC IMPACT ON THE SPACE STATION

FIGURE 9

Searby: I pointed out how important that integration aspect is. Hopefully, it will be an iterative process where we'll have a first cut, analyze it, and then go back and forth until we reach a situation where we don't excite those structural resonances.

Question: I'm having a little trouble with your first step, which seems to be Newton's law of reaction. If an animal moves in the centrifuge, giving an unbalanced situation, how does the fact that you have magnetic rather than mechanical suspension prevent you from coupling the reaction of that unbalance into the Space Station?

Havenhill: It does not prevent the forces from being transmitted across the magnetic gap. But, if there is a spike of the force, for instance an animal jumping, the magnetic suspension will tend to smooth out that spike because it represents an isolation system.

Question: So if an animal moves a matter of a meter or so, you get maybe a kg-m unbalance in the system....

Answer: An animal cage is really small. These cages are only on the order of 20 cm square, so the animals are not going very far. If they jump, they jump only a little, and come down very quickly.