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2 Universal Test Facility

2.1 Summary

2.1.1 Design Objective

To develop a highly marketable, automated test facility capable of performing diverse microgravity experiments according to NASA space station constraints.

2.1.2 Abstract

A universal test facility for Space Station Freedom is developed. In this context, universal means that the experimental rack design must be: automated, highly marketable, and able to perform diverse microgravity experiments according to NASA space station requirements. In order to fulfill these broad objectives, the facility's customers, and their respective requirements, are first defined. From these definitions, specific design goals and the scope of the first phase of this project are determined.

An examination is first made into what types of research are most likely to make the UTF marketable. Based on our findings, the experiments for which the UTF would most likely be used include: protein crystal growth, hydroponics food growth, gas combustion, gallium arsenide crystal growth, microorganism development, and cell encapsulation. Therefore, the UTF is designed to fulfill all of the major requirements for the experiments listed above. The versatility of the design is achieved by taking advantage of the many overlapping requirements presented by these experiments.

The UTF centers around eight, self-contained experimental canisters. The UTF supplies these canisters with the resources their respective experiments require (power, electricity, etc.), and is able to monitor them with two video cameras. The canister's rectangular shape is chosen to optimize volume and space within the rack system. Its features include: an ergonomic handle for easy transport and installation, an effective clamping system designed to keep the canister locked into place, an LED indicator which lights when the canister is properly inserted, and a single, universal interface for exchanging raw materials and data with the UTF.

The universal interfaces, attached to the back wall of the experimental rack, add versatility to the overall design. Consisting of a data acquisition linkage, power source, and six input / output portals for transport of vital resources, the universal interface is responsible for sustaining all microgravity experiments in the rack. More importantly, it becomes the experimenter's direct link to an experiment and all data acquisition involved.

The rack system is broken into three sections. On the top of the facility, the computer system for data acquisition is positioned and insulated from possibly harmful heat transfer derived from the experimental section. The experimental canisters, universal interfaces, and visual monitoring systems are located in the central portion of the rack. Specifically, a total of eight canisters (four on each side of the rack) are separated by two small video cameras which monitor the experiments. The bottom portion of the rack consists of two storage tanks for either the recirculation or disposal of resources, the HVAC system, and a utility section for containment of the motor and pump.

It is important to note that the facility design is, for the most part, conceptual. Specific hardware definition is reserved for our successors. We believe, however, that the design objective is entirely satisfied. The design process is made significantly less burdensome by giving our

customers the responsibility of designing the internal components of the experimental canisters which they purchase.

2.2 Glossary

camera system	- visual monitoring system for the UTF which utilizes two, independently operating, video cameras.
canister	-a self-contained unit which houses a microgravity experiment.
LED	-Light Emitting Diode
rack	-the entire unit containing the experimental facility (including the canisters).
telerobotics	-a vital link enabling the experimenter to communicate with and monitor the experiment's progress while in the test facility.
Universal Interface (UI)	-a versatile interface which provides for all the input and output of all the Space Station supplied resources.
Universal Test Facility (UTF)	-the entire unit containing the experimental facility (including the canisters, universal interfaces, optical system, storage facility, HVAC, and utility containment of the pump and motor).

2.3 Background

In order to satisfy the "highly marketable" aspect of the design objective, several microgravity experiments are researched and identified. Based on our findings, the experiments for which the UTF would most likely be used include: protein crystal growth, hydroponics food growth, gas combustion, gallium arsenide crystal growth, microorganism development, and cell encapsulation. This evaluation is made assuming the experimenter reserves space in the rack and financially supports an experiment from beginning to end.

2.3.1 Protein Crystal Growth

The study of protein crystal growth is necessary in developing a complete understanding of the purpose and function of proteins. Because proteins play a key role in life, a comprehension of their function can elicit breakthroughs in medical research. Other fields such as biochemistry and agriculture can also benefit from a thorough understanding of proteins. Protein molecules are too small to study individually, therefore protein crystals, which are large enough to be tested, are grown. The difference between a protein crystal grown on Earth and one grown in a microgravity is illustrated in Figure 2.1. As shown in this figure, techniques used to analyze

Figure 2.1.
Comparison of a terrestrially grown protein crystal (l) with a protein crystal grown in microgravity (r).

crystalline structure, such as x-ray diffraction, are significantly more effective on three-dimensional crystals grown in microgravity. On Earth, crystals tend to grow in two dimensional patterns.

This experiment is chosen for two reasons. First, protein crystal growth was the primary emphasis of the 1993 design effort, thus it seems a logical place to start. Secondly, the growth of protein crystals involves several unique processes. That is, protein crystal growth rounds out a list of experiments which have very diverse input and output requirements. However, since the design of components tailored to specific experiments are left to the individual scientists, the processes involved with protein crystal growth are not discussed here. It is sufficient to list the necessary inputs and outputs to and from Space Station Freedom. These include power and data transfer for the sensing and control systems.

2.3.2 Hydroponics Food Growth

NASA space exploration has reached a level where the idea of a permanent space station and/or a space colony is feasible. To make the space station self-sufficient is important to the feasibility of this mission. Part of the process of making the space station self-sufficient lies in the ability to provide its own life support. One solution to this problem is a system under development called the Controlled Ecological Life Support System (CELSS). The CELSS system is dependent on the use of higher plant species such as wheat and beans to regenerate oxygen, water, and food supplies, from different forms of wastes produced in the station. The key in developing the system lies in hydroponics. Use of hydroponics on earth is now common, but the use of hydroponics in space is a relatively new science. Since the use of hydroponics in space is untried, researchers need ways to experiment with different types of hydroponics systems in space. The proposed Universal Test Facility is able to accommodate such experiments, and thus advance the body of knowledge on this subject.

The term hydroponics describes any of several methods for growing plants without soil. In general, a hydroponics system works by utilizing a rich nutrient solution that flows through a containment structure where the plant roots have attached themselves. As the solution passes through the apparatus, the root draws from the solution the essential nutrients it needs to grow. The solution, depleted of some of its nutrients, returns to a reservoir to be stored or have its nutrients replenished.

One of the main advantages of a hydroponics system is the ability to control the growth environment. The researcher is able to control the concentration levels of: water, nutrient, pH, electroconductivity, and oxygen. Controlling these factors allows the researcher to maximize plant growth. This control also allows the researcher to alter the type of growth desired. For example, alteration of light patterns between night and day as well as modification of the light wavelength affect the amount of root and shoot growth. Experimenting with these levels will provide the best method to produce crops in space. Another advantage to hydroponics is its sanitary conditions. Since there is no soil, there is no sand or grit to cling to the roots. Also, sanitation of the entire system is simple because the containment structures and solution piping are all plastic. This feature allows the use of a cleansing solution to clean all parts of the hydroponics system. Another important advantage to researchers is the flexibility that a hydroponics system offers. Planting and interchanging of the crops is quick and simple. The ease of changing the types of plants allows the researcher to study the growth patterns of many different species. Finally, the most important advantage of hydroponics is that it is conducive to automation. It is relatively simple to program a computer to control the environment in which a plant grows. This factor makes hydroponics experiments excellent candidates for execution in the universal test facility.

The hydroponics process can be generalized to have certain requirements that are necessary in order for the system to function. These requirements are that: the system must have the ability to monitor and adjust the nutrient levels in the solution, the ability to efficiently distribute the solution, the capability of effectively transferring nutrients to the roots, and the capacity to store or recycle the used solution. The design of the UTF meets all these requirements. The facility provides the hydroponics experiment with: power, water, air, and nutrients through the universal interface. The facility's computer, utilizing researcher-written hydroponics software specific to the experiment, then monitors and adjusts the growth process. The facility can then store the used nutrient solution before it is recycled.

Figure 2.2 shows a simplified version of a possible hydroponics system for use in space racks. The original concept work was done by Steven H. Schwartzkopf at Lockheed Missiles and Space Company (reference MSC-2165). The system is internalized into one of the facility canisters. The system operates in a cycle starting from solution bladder 1 passing through the system to solution bladder 2. An air compressor forces the solution out of bladder 1 by increasing the pressure. As the solution passes through the system, sensors monitor many elements including flow, temperature, pH, and nutrient level. The solution then passes through a control manifold where the computer adjusts the levels of concentration for all the components using supplements stored internally or in the optional storage canister The adjusted flow now enters the test chamber where it feeds the roots of the plants. Video monitoring is available to record the patterns of growth of each plant. The depleted solution returns to bladder 2 for temporary storage. When bladder 2 reaches its capacity, valves shut off the pressure to bladder 1. After bladder 1 is filled, the valve switches back to their initial positions and the process starts over again.

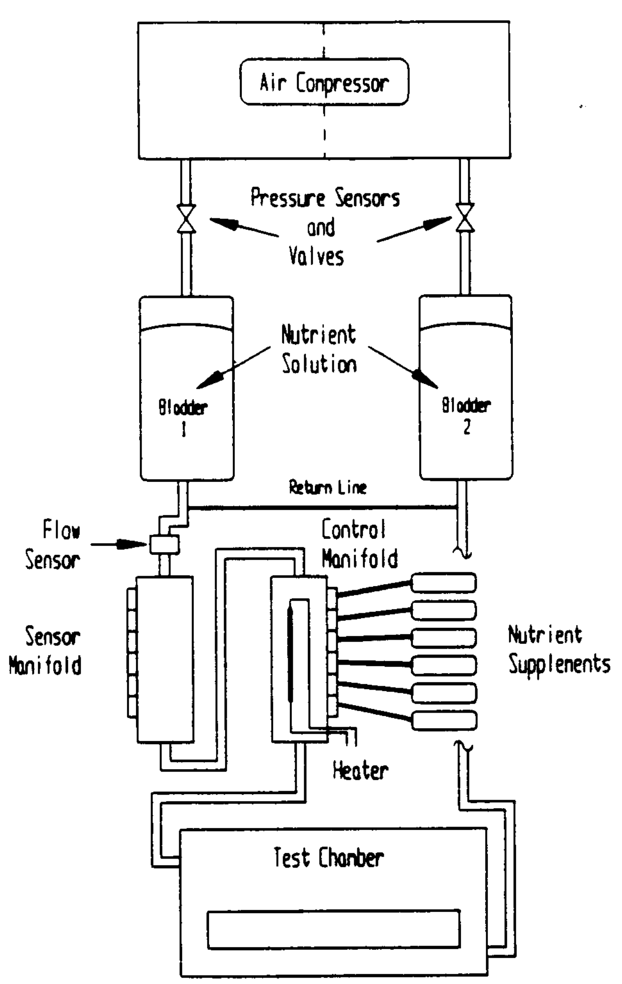

Figure 2.2. Hydroponics system schematic.

2.3.3 Gas Combustion

Gases and other substances behave very differently in microgravity than on Earth. Combustion is no exception to this principle. Microgravity causes differences in the manner by which a gas is excited. The understanding of how gases combust in microgravity is important to the development of alternative fuels for space exploration. Thus, research is ongoing on how gases and other substances combust in microgravity. The Universal test facility offers the ability to perform combustion experiments efficiently.

In general, the combustion experiment utilizes an experimental canister that can withstand the high pressure generated by combustion. The test specimen rests on a pedestal as oxygen fills the canister. The test facility's computer then prompts a pyrotechnic wire fuse attached to the specimen to ignite. During ignition and combustion, the facility monitors the entire process for later viewing by researchers. The researcher quenches the experiment by introducing argon and nitrogen gases into the chamber. The canister then releases the exhaust gases to a storage container for later disposal.

The requirements of the combustion process are that the system have: the ability to monitor the combustion process, the ability to supply and control the introduction of the igniting and quenching gases, and the capability to store the combustion reactants and products. The facility supplies the necessary video monitoring and data acquisition, thus allowing the researchers to view and document the process at a later time. The facility, through the universal interface, can control the supply of the ignition and quench gases available from the combustion canister or from the optional storage canister of the test facility. In addition, the facility provides an exhaust outlet to a storage container for future disposal.

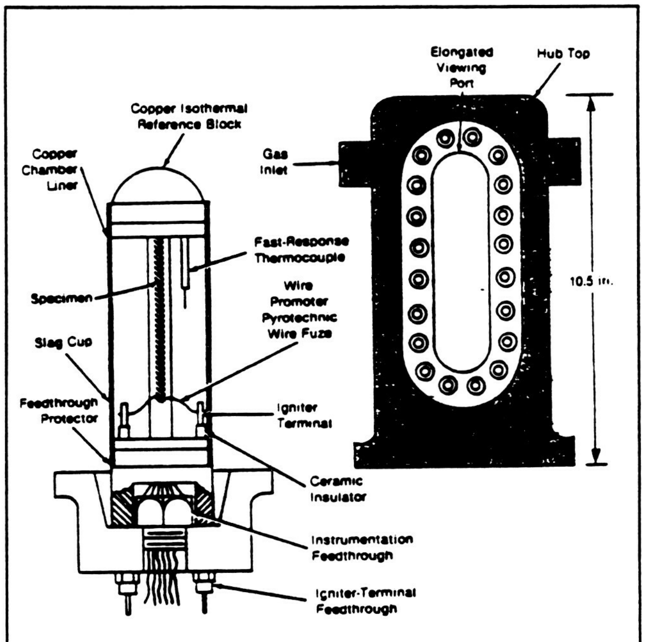

Figure 2.3. Gas Combustion Experiment Chamber.

Figure 2.3 shows the combustion process configuration. The original concept was created by Theodore A. Steinberg of Lockheed Engineering and Science Company (reference MSC-21777). The canister mounts a rod specimen from the top of the chamber. The command control system sends a signal to ignite the pyrotechnic fuse located at the bottom of the chamber. The chamber has its own data acquisition system to record the readings from various thermocouple and pressure gauges. The universal interface provides the link for the transmittal of the control signals and the recorded data. Also, a viewing port allows the facility to video record the entire combustion process. If the pressure inside the canister reaches the high pressure limit (in this case 10 MPa), a valve opens and the gases are released from the chamber. The researchers retrieve the data and the canister is ready for reuse.

2.3.4 Gallium Arsenide

Gallium arsenide is a group III-V semiconductor characterized by a relatively high electron mobility and larger energy band gap. This makes gallium arsenide crystals perfect for high frequency applications. High frequency GaAs has applications for: high speed computing, military hardware, biomedical research, and communications. A small brassboard circuit constructed from GaAs was operated at a frequency in excess of 2 GHz, thus demonstrating the potential of research in this field.

Because crystal impurities move along the solidification front when grown in space, and do not contaminate the crystal, the growth of gallium arsenide crystals in a microgravity environment is desirable.

Gallium arsenide crystals have already been grown in space in a "gas can" type experimental set-up. This same type of gallium arsenide growing technique can be incorporated into the Universal Test Facility.

2.3.5 Cell Encapsulation

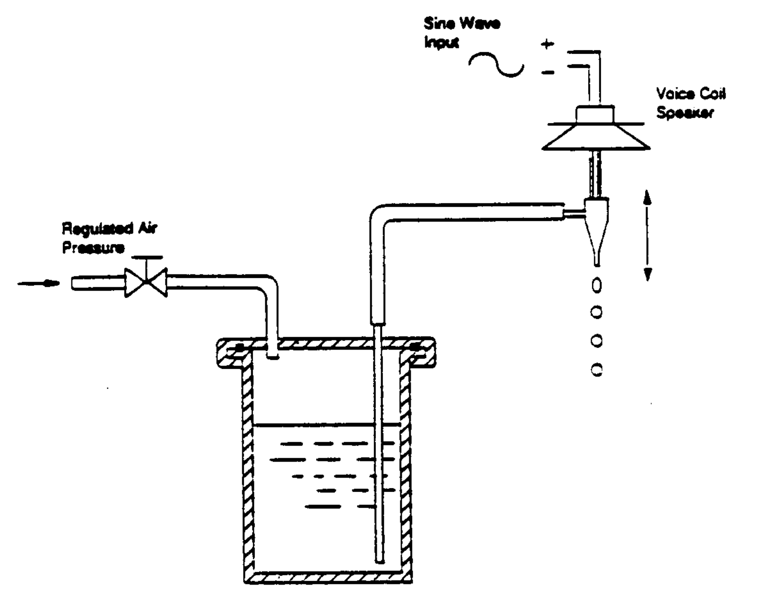

Figure 2.4. Cell encapsulation drop generator.

The purpose of cell encapsulation experiments is to protect islet cells so that, when injected into the human body, the cells will not be killed by antibodies. The islet cells, which produce insulin, are being studied to develop a treatment for diabetes. Experiments done on rats using encapsulated cells on earth have achieved favorable results. Unfortunately, due to the effects of gravity, it is very difficult to encapsulate cells consistently on earth. Therefore, the production of encapsulated cells needs to be investigated in space and is a perfect candidate for use within the UTF design.

Currently, cells are suspended in a nutrient solution to keep them alive. This nutrient solution is also the base for the polyanionic encapsulation process. The solution is then run through a drop generator (See Figure 2.4), and the droplets are immediately immersed in a polycationic solution. The chemical reaction between the two solutions creates the polymer encapsulation shell. Therefore, the islet cells are encapsulated in a semi-permeable membrane which allows nutrients and insulin, but not antibodies, to pass through. This experiment requires strict environmental control, therefore the entire process is controlled by computer.

It is possible to put the cell encapsulation experiment into one or more of the UTF containers. The experiment will utilize the storage sites at the bottom of the UTF. For this reason, the experimenter would probably purchase a whole rack.

2.3.6 Microorganism Development

The constant gravitational force which has influenced life on earth for the past 3.5 billion years leads biologists to speculate that many organisms utilize gravity in their normal developmental cycles. In particular, the belief that gravity plays an instrumental role in the evolution of many present-day organisms in terms of their structure and function prevails. Thus, studying the effects a microgravity environment has on these organisms, might provide insight into possible human reproduction in space.

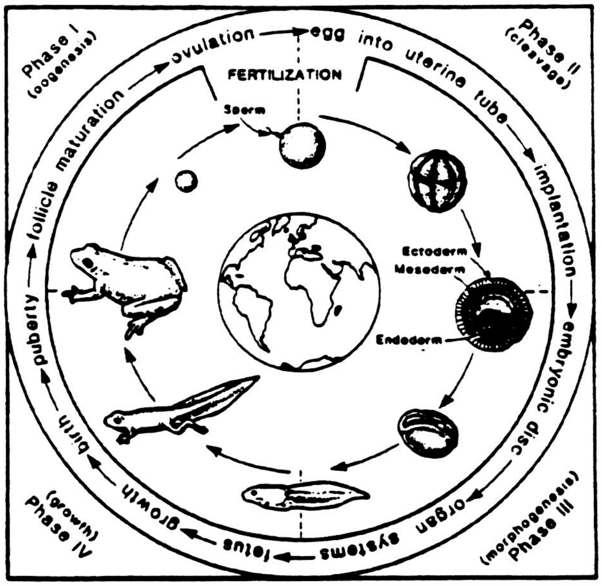

Figure 2.5. Developmental life cycles of amphibians (inner ring) and mammals (outer ring).

Several reasons exist for pursuing the study of embryonic development in microgravity environments. First, biologists are interested in gravitational influence on normal development For example, some organisms display a natural orientation in the earth's gravity. The development of eggs which rotate according to gravity is vulnerable in zero-g conditions, possibly preventing proper maturation. Scientists hope to identify common traits of development (for these organisms) in microgravity conditions.

Secondly, biologists believe that in studying microgravity experiments, there is potential for data acquisition on basic cellular processes. Therefore, the scientists hope to be able to generate information on individual cells which, again, could be applied to human embryonic development in space.

Thirdly, with the instatement of a permanently manned space station, the development of lunar and Martian bases becomes increasingly possible. Because of the complexity of such systems, it is necessary to focus now on how organisms reproduce in lunar (0.16g) and Martian (0.39g) environments. Such information will be vital to understanding how humans reproduce and develop under these conditions.

The ideal experiment is one which is self-contained, requires relatively small volume, is fully automated (with minimal power needs) and can be transported in the space shuttle's mattock locker to Space Station Freedom's experimental racks. Since several experimental microorganism systems have already flown under SSF conditions, we are confident that our canister and rack designs can ensure successful completion of the specific experiment.

2.4 Design Concept

The design concept consists of the overall rack design, the canister design, visual monitoring system design, the universal interface design, and the telerobotics system design.

2.4.1 Overall Rack Design

The main point of the design goal is to design a Universal Test Facility (UTF) capable of performing diverse microgravity experiments. In order to achieve this broad design goal several important decisions were made in regard to the overall rack design. These decisions include:

1. Optimum component layout
2. Incorporation of auxiliary equipment necessary to perform several experiments
3. Selection of a "gas can" type experiment configuration
4. Utilization of the universal interface at each canister location to activate experiments
5. Designation of intricate plumbing system to transfer the needed fluids.

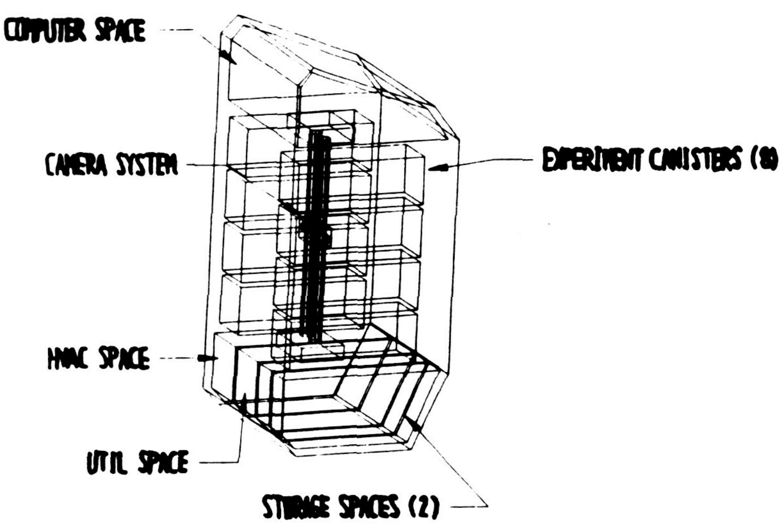

Figure 2.6. Universal Test Facility layout.

The experimental facility design chosen maximizes space and has simplest configuration. The selected rack configuration is shown in the UTF layout given in Figure 2.6. The computer and the data acquisition system are located in the top of the rack. The experiment area, located in the middle of the rack, contains the canisters, the visual monitoring system, and the universal interfaces. The experimental canisters are located along the sides of the experiment area. In the center of the experiment area is the visual monitoring system. On the back wall of the experiment area are the universal interface jacks. The bottom of the rack contains the auxiliary equipment used in performing the experiments. The rear of the rack contains the plumbing and electrical systems.

The auxiliary equipment in the bottom of the rack has three main components. These components are: the HVAC, the utilities, and the storage bays. The HVAC is used to condition the air, water, and storage fluid that is supplied to the experiments. The utility section contains the pumping and filtering systems for the air and water. Finally, the two storage bays, which are purchased and internally designed by the experimenter, have the capability to store and/or recirculate the fluids used or produced by the experiments.

In order to configure the rack to be able to handle diverse experiments, it was decided that the experiments conducted in the rack must be "gas can" type experiments. "Gas can" type experiments were chosen because they require very little human interaction with the experiment itself. However, this should not limit the type of experiments that can be conducted in the rack since the size and shape of the canister is large enough that the experimenter can incorporate his or her own experiment manipulating system, if necessary.

The use of a universal interface allows each canister location to become active without being moved. The interface supplies the air, water, power, storage fluid, and data transfer devices. When the computer determines it is time to activate an experiment, the universal interface is "turned on", and supplies the experiment with the necessary elements for it to execute properly.

The plumbing system is located in the rear of the rack. The plumbing system is able to transfer fluids throughout the experimental facility. This is accomplished with the use of pumps and filters located in the utility section, in conjunction with a series of solenoid valves. These computer controlled valves will be able to transfer fluids to and from each canister, from canister to the fluid storage site (and vice versa), or from canister to canister.

2.4.2 Canister Design

The idea of using canisters in the design of the Universal Test Facility (UTF) stems from the current use of gas can type experiments on previous space shuttle missions. This format provides the versatility that the design goal mandates. The function of the canister is to enclose the actual experiments performed on Space Station Freedom (Figure 2.7). The purpose of containing the experiments inside a canister is to avoid any fluid transfer between the experiments and the Space Station atmosphere. In the interest of versatility, the design of the inner volume of the canister is the experimenter's responsibility. The canister is simply a hollow shell whose interior workings are functioning systems developed by the individual experimenter. Since the researcher is responsible for the internal makeup of the canister, the design effort of this group centered on the issues of canister volume and universal inputs and outputs.

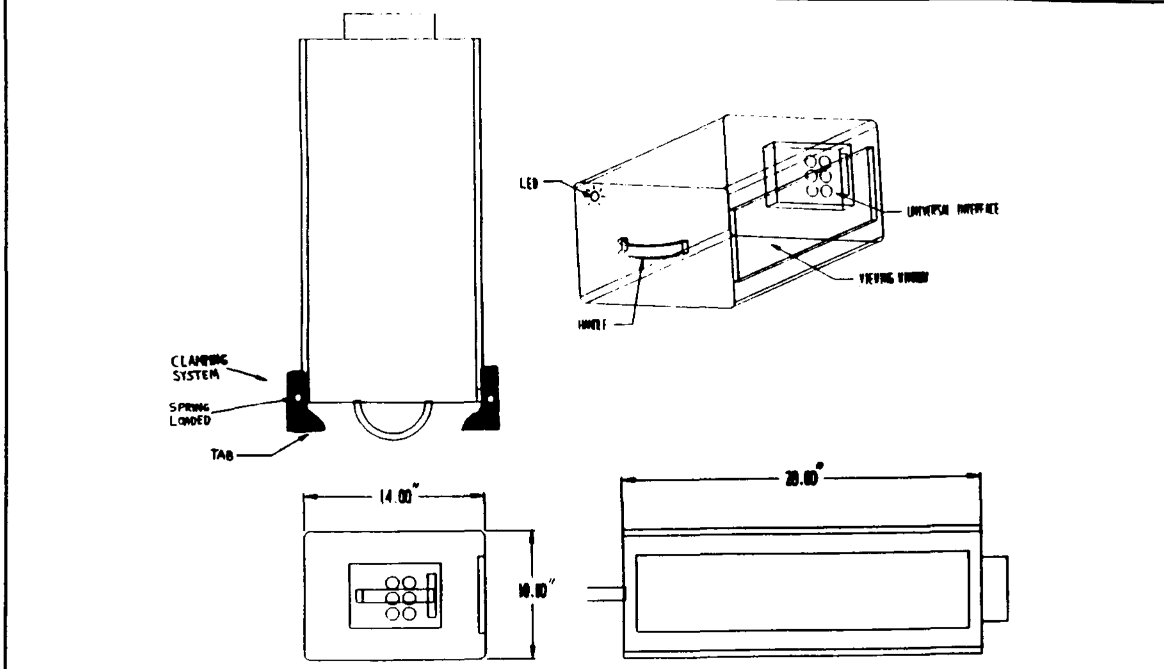

Figure 2.7. Experiment Canister.

The canister design is in the form of a rectangular box with a cross section 10 inches tall by 14 inches wide and a depth of 28 inches. These dimensions give the individual experimenter approximately 4000 cubic inches or 2.25 cubic feet of space within which to contain their experiment. The dimensions are determined from the overall rack dimensions and the total number of sites (8) desired. The large volume that the canister encloses is necessary in order to enhance the versatility of the rack. The large canister volume allows for larger experiments or in the case of a small experiment, a large canister allows more experiments per canister.

The determination of the universal inputs and outputs to the canister results from the cross section of experiments the group chose to research. There are only four essential requirements common to all six experiments that Space Station Freedom needs to provide. These four fundamental inputs consist of air, water, power and data transfer. The inputs and output connections are part of a versatile jack that is now the universal interface (UI). (See section 2.4.4). In addition to the four inputs already mentioned, the UI allocates an extra input and output for an optional fluid transfer. This extra interface offers experiments such as hydroponics an additional input, i.e. a nutrient solution.

There are several other issues addressed by the group concerning the design specifications of the canister. The first issue deals with the visual monitoring system (See section 2.4.3). In order for the researcher to visually monitor a experiment inside the canister, there has to be some kind of transparent window along the length of the canister. Figure 2.7 shows the location of this window. The second issue centers on how to anchor the canister to the rack after insertion of the experiments. To solve this problem, the group proposes a system of spring loaded clips (Figure 2.7) that snap into place when the canister is completely inserted into the rack, thus locking the canister in place. To remove the canister, an astronaut simply has to press the clips outward until they clear the sides of the canister. Small springs located on the UI aid the removal by pushing the canister out past the clips. The canister comes with a handle to aid the astronaut in carrying it. Finally, to ensure proper connection to the power source, a light on the front of the canister signals proper insertion of the canister into the interface.

2.4.3 Visual Monitoring System Design

Many of the experiments in the Universal Test Facility require frequent visual inspections. Thus, a method must be available to record and store the video monitoring of the experiments. Also, the monitoring system must allow the researcher on Earth to visualize his or her experiments. For these reasons, the facility has a camera system that records and stores the experiments progress but is also capable of interfacing with the telerobotics system (Figure 2.6).

The monitoring system utilizes two cameras located in the center of the rack. The use of two cameras allows the viewing of each of the two columns separately. The camera moves longitudinally (from canister to canister) by screw-type drives. In addition, the cameras can to translate along the length of the canister by means of a track system incorporated into the top and bottom of the compartment. Thus, the cameras supply video for the entire length of each of the canister's window. Positioning control of the camera system, generally, comes from the on board computer. The on board computer receives its instructions from the software that accompanies each experiment. The researcher may control the cameras as well via the telerobotics system discussed in section 2.4.5

2.4.4 Universal Interface Design

To make the Universal Test Facility (UTF) more versatile, the inputs and outputs to the experiments must have a generalized format. These generalized inputs and outputs make up the universal interface. The universal interface (UI) makes the UTF more versatile. The UI provides the input and output of the resources that Space Station Freedom supplies, the resources from the storage tanks, and the data link to the on board computer. A UI lies behind each of the canisters, making all the experiments active. The decision to use a UI, making all the sites active, avoids the need for a robot to move canisters, test tubes, etc. from active to latent sites within the facility. The use of the UI allows some of the experiments which require constant access to resources to sustain the experiment.

The UI has two standard input and output jacks. These jacks are for the air and water that the Space Station supplies. In addition, the UI contains an extra input and output jack that connect s the experiment to the storage canister. This connection allows the experiment to supply its own additional that the UTF does not provide in the storage canister. The connection also removes exhaust products that Space Station can not recycle to the storage canister for later disposal. The UI provides the link for power and data transfer. The data port transfers instructions from the on board computer to the experiment. Also, this port allows the use of the telerobotics system discussed in section 2.4.5. (See Figure 2.8)

2.4.5 Telerobotics System Design

The ability to communicate with the automated Universal Test Facility, while in space, is necessary for the monitoring of the experiment. For example, if an experiment is not performing as it should, the researcher will have the option to try to correct the problem in order to salvage the experiment. On the other hand, if the experiment performed successfully to completion, the researcher will be able to download the data in order to analyze the results. These examples demonstrate the need to have the ability to interact with the experiments being conducted in the Universal Test Facility from Earth. Thus, the Universal Test Facility has included a telerobotics system in order to allow the experimenter the option to interact with the experiment while it is in space.

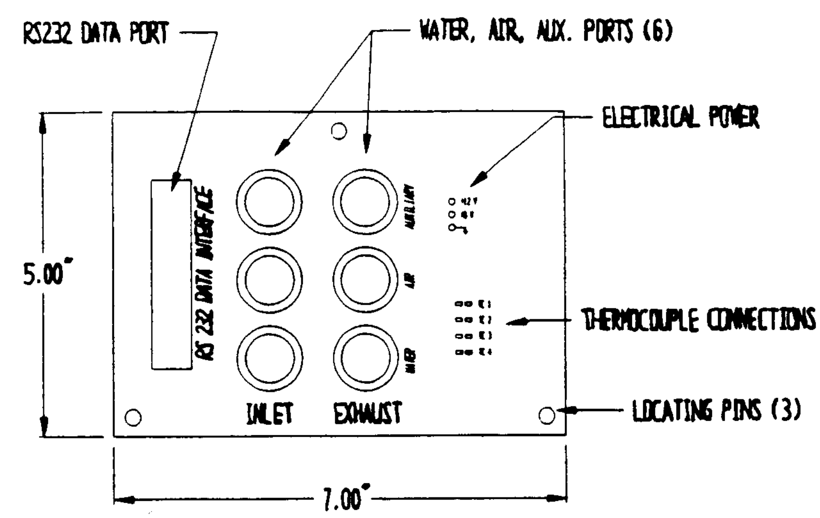

Figure 2.8. Universal Interface schematic.

In general, a telerobotics system connects the user to his experiment from ground control via a simple PC terminal. The connection permits the transmission of electronic data signals to and from the test facility in space. The type of data that can be transmitted ranges from new instructions from the researcher to alter variables in the experiment to the experimental data that can be downloaded to the ground by the data acquisition computer in the test facility. The link between the space station and the ground is via a direct path to the space station if in synchronous orbit or via an optional satellite link up. The telerobotics system is also used to control movement of the two monitoring cameras.

A personal computer acts as the processor for the incoming and outgoing signals. The researcher, utilizing the PC terminal, can view the experimental data, and if needed, view a picture of the actual experiment which is currently in progress. Upon viewing the progress of the experiment, the researcher can enter an interactive software program, e.g. LABview , in order to input new variables to be relayed to the experiment. This ability gives the experimenter a way to alter the experiment from the ground. Thus the researcher is given a greater sense of control of his experiment and ultimately a higher rate of success.

2.5 Conclusion

With the conceptual designs of the universal test facility complete, the design objective is satisfied. Specifically, the identification of six microgravity experiments, which our rack design is able to accommodate, makes the design "highly marketable" to researchers and industry, alike. The ability of the design to sustain multiple and diverse experiments within the same rack fulfills another key goal. Finally, with the development of the UI, optical, and telerobotics systems, a high level of automation is reached, essential to the successful completion of each experiment.

2.6 Recommendations

Hardware identification dominates the next design phase for the Universal Test Facility. The first step should be the design of the plumbing system in the rear of the rack. The type of hose and connectors, as well as the computer controlled solenoid valves, need to be selected. Next, the HVAC system to be used in the rack should be designed. The utilities section of the rack, which includes the pumps and filters for the various fluids, should be designed in order to supply the needed pressure and volume of fluid to the experiments. Also, the data acquisition system and computer control system need to be identified. Finally, after the bill of materials has been completed, a detailed cost analysis of the rack design should be undertaken.