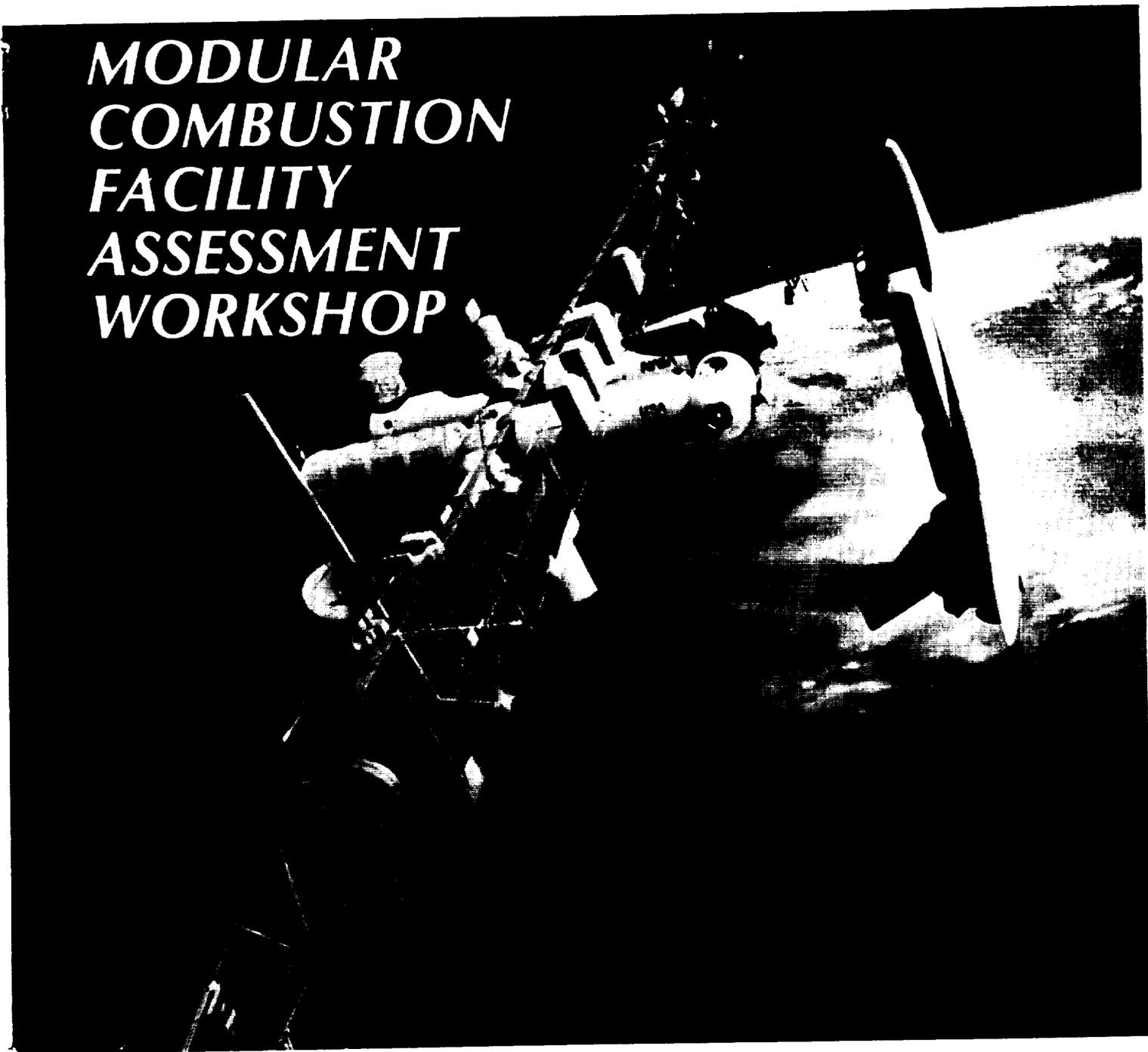


SPACE STATION FREEDOM

MODULAR COMBUSTION FACILITY ASSESSMENT WORKSHOP



NASA Technical Memorandum 102037

(NASA-TM-102037) CONCEPTUAL DESIGN FOR THE
SPACE STATION FREEDOM MODULAR COMBUSTION
FACILITY (NASA) 63 p

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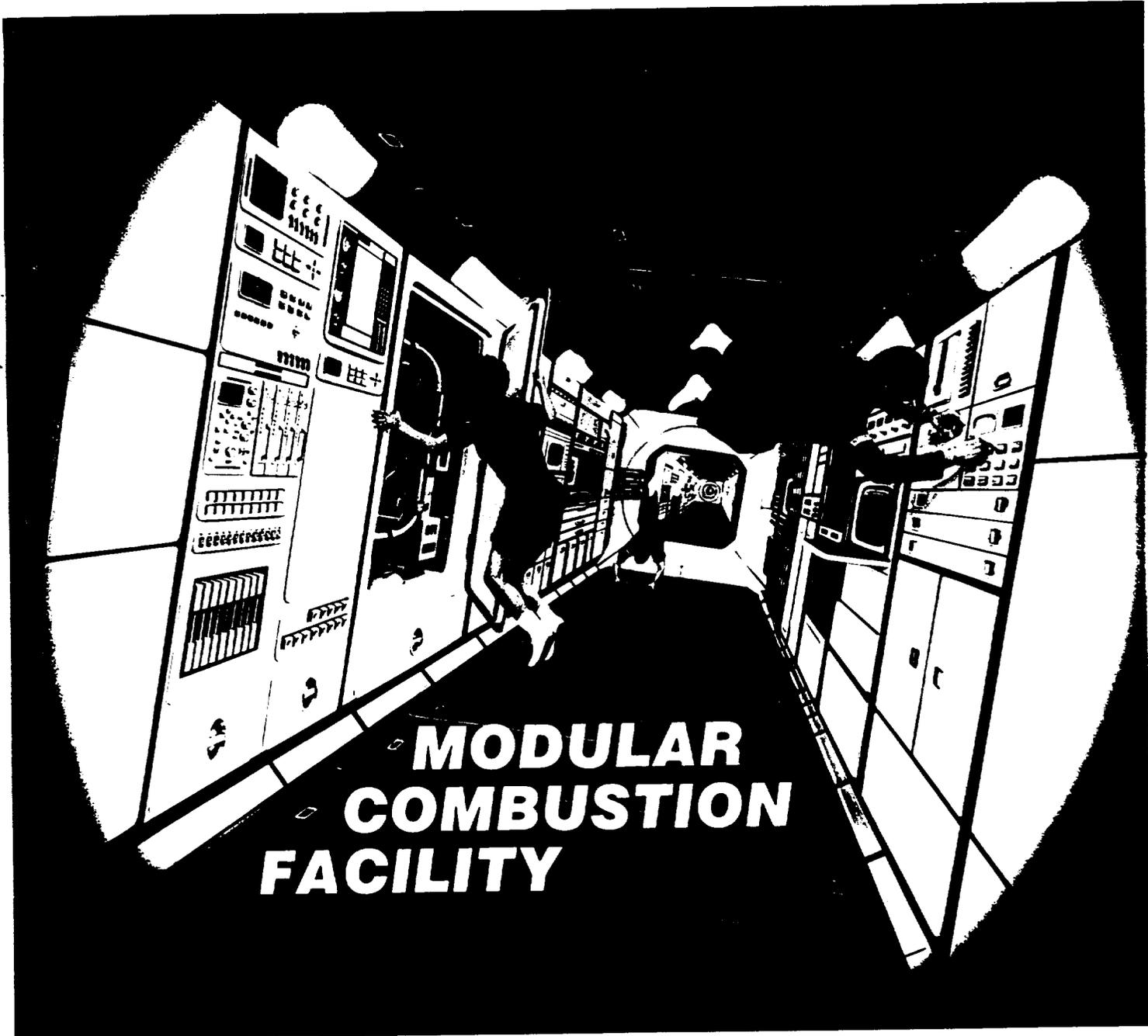
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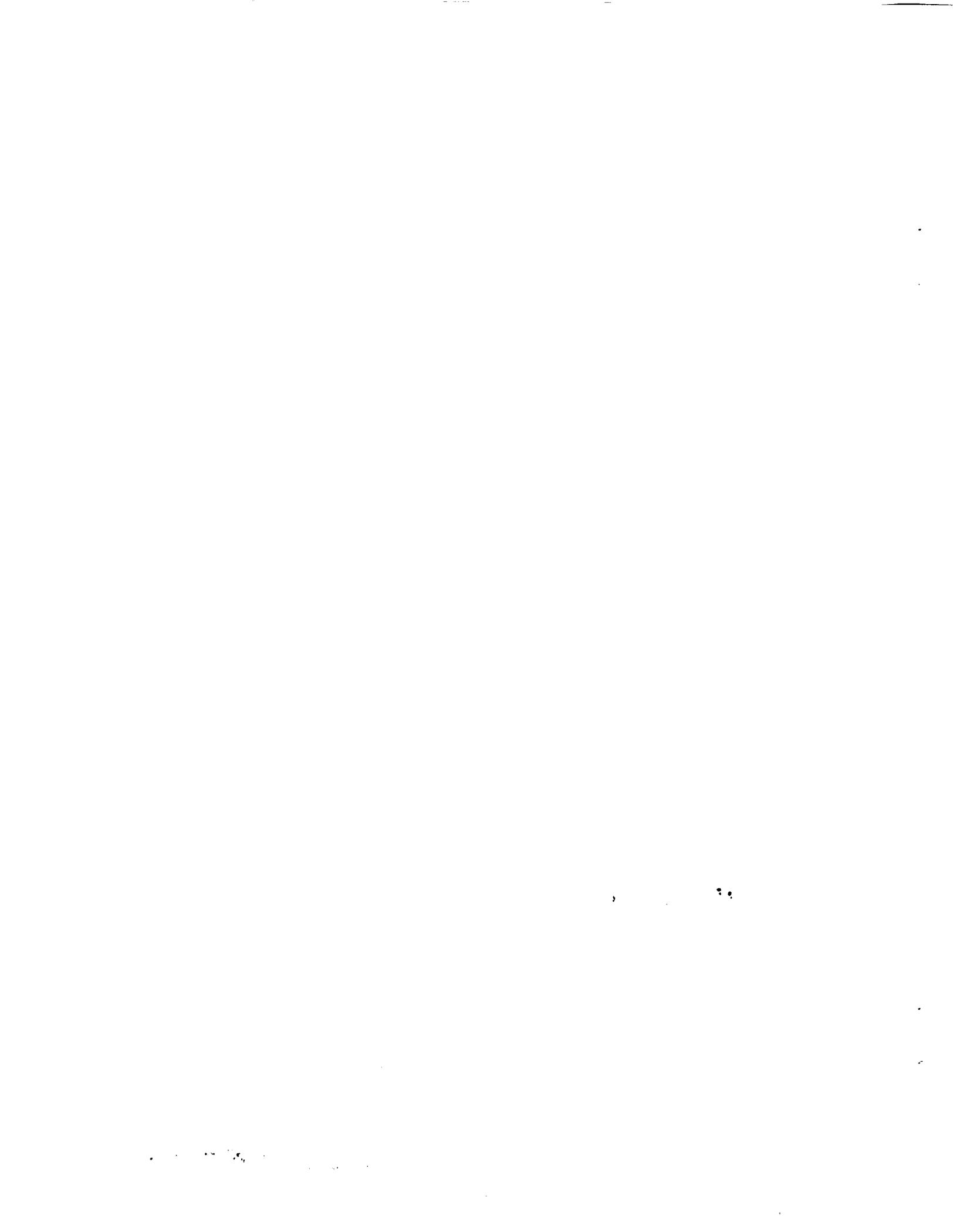
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MODULAR COMBUSTION FACILITY

An artist's concept showing the interior of the U.S. Laboratory Module on Space Station Freedom. On the left are the two racks that make up the Modular Combustion Facility, with a Mission Specialist about to make adjustments to the experiment inside the containment enclosure.

ORIGINAL PAGE
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NASA Technical Memorandum 102037

Conceptual Design for the Space Station Freedom Modular Combustion Facility



National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

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Summary

A study team at NASA's Lewis Research Center has been working on a definition study and conceptual design for a combustion science facility that will be located in the Space Station Freedom's baseline U.S. Laboratory module. This modular, user-friendly facility, called the Modular Combustion Facility, will be available for use by industry, academic, and government research communities in the mid-1990's. The Facility will support research experiments dealing with the study of combustion and its byproducts. Because of the lack of gravity-induced convection, research into the mechanisms of combustion in the absence of gravity will help to provide a better understanding of the fundamentals of the combustion process.

This document has been prepared as an advance handout for reviewers at the Modular Combustion Facility Assessment Workshop held at Lewis on May 17 and 18, 1989. It covers the background, current status, and future activities of the Lewis Project Study Team effort. It is a revised and updated version of a document entitled "Interim Report of the Concept Design for the Space Station Modular Combustion Facility," dated January 1989.

Introduction

Background

In the mid-1990's, a new, unique national laboratory will become available for use by industry, academic, and government research communities. At that time, all the many elements that make up the Space Station Freedom are scheduled to become operational, including NASA's United States Laboratory (USL) module. This laboratory will be unique because for the first time a permanently manned, multiuser facility in low-Earth orbit will provide a long-duration microgravity environment along with essential supporting laboratory services. These supporting services, taken for granted in Earth-bound laboratories, historically have been difficult to provide for long-duration flights in space because of restricted payload capacities and capabilities. The principal services to be provided are electrical power, communication and data services, consumable fluid supplies, venting, and waste disposal. Of course, the one service or condition not readily obtainable in Earth-bound laboratories is the reduced-gravity environment, which cannot be duplicated

or even approximated on Earth for any appreciable length of time. In the near-absence of gravity, research can be conducted with reduced buoyancy forces, hydrostatic pressure, and sedimentation.

NASA, its contractors, and its international partners are all working toward the common goal of achieving an operational space station in 1995. While this effort is proceeding, a parallel effort is beginning in order to be ready at that time to make immediate and effective use of the Freedom station capabilities. NASA's Office of Space Science and Application (OSSA) is currently undertaking an extensive program to provide research capability by developing experiment hardware and facilities. As part of this program, the NASA Lewis Research Center was selected to be the lead center in the definition study and conceptual design phase of developing a Modular Combustion Facility (MCF) for Space Station Freedom. This document outlines the status of that effort and describes the capabilities of the proposed combustion facility. This is one of six facilities being developed by the Material Science and Application Division (Code EN). A list of definitions is given in appendix A. Appendix B is a preliminary hazard analysis and appendix C, a fracture mechanics plan. Appendix D lists the contributors to this report.

A study team, made up of members of the Lewis Engineering Directorate and its support service contractors, has been working on the definition study and conceptual design for the proposed Facility. The objective of this study is to assess the feasibility, effectiveness, and benefits to potential users of a modular, multiuser facility for combustion science and applications experiments on S.S. Freedom. The study will determine the philosophy or mode of accommodating combustion-related experiments on S.S. Freedom and propose a plan for the development of the appropriate MCF hardware.

There are several facets to the future successful development of the MCF as described in this document. The first, and most important, of these is a positive assessment by the potential user community. Toward this end, the Lewis Project Study Team has sought comments and recommendations from all interested parties. Specific activities along these lines included reviews of the design concepts with the Microgravity Combustion Discipline Working Group and the distribution of a document entitled "Interim Report of the Conceptual Design of the Modular Combustion Facility" at the International Microgravity Combustion Workshop in January 1989. All comments and recommendations received from the workshop have been assessed and incorporated into this

document when found to be both feasible and within program constraints such as the budget and scope of the Space Station Freedom program and the USL module. The Modular Combustion Facility Assessment Workshop held at Lewis in May 1989 is another effort to seek potential user-community involvement.

Project History

Approval to begin this study was received from NASA Headquarters in June 1987. A Joint Cooperative Agreement outlined the objectives of the study and provided a baseline facility concept. This same agreement listed five tasks to be performed by the study team: (1) requirements definition, (2) trade studies, (3) concept design, (4) development plan, and (5) assessment of the concept and plan. In August 1987, a study team was assembled and the task was started. The study team is made up of the members of the three divisions of the Lewis Engineering Directorate and additional members provided by support service contractors. Two other key persons in the project organization are the Lewis Space Experiments Division (SED) Project Manager, who provides the overall project plan, budget, and schedule management, and the SED Facility Project Scientist, who assists the study team in meeting the science objectives.

Requirements Definition

To begin the requirements-definition task, the study team was provided a reference experiment list by the Facility Project Scientist. This list, which has been reviewed by the Microgravity Combustion Discipline Working Group, represents candidate experiments, the kinds that might be performed in the MCF. The list covers a wide range of experiments and provides a broad range of conditions and requirements. In some cases, these experiments are previously flown space experiments; others have not flown but have completed engineering studies; and still others are conceptual experiments representing an idea of how an experiment might be done.

The current reference experiment list is as follows:

- (1) Stabilized gaseous combustion
- (2) Freely propagated gas flame
- (3) Flaming and smoldering combustion in low velocity flows
- (4) Pool fires
- (5) Effectiveness of candidate extinguishants for use on smoldering or flaming combustion in low gravity
- (6) Droplets combustion
- (7) Metals combustion

In a series of in-person meetings and in teleconferences with advocates of each of the experiments on the list, the study team collected user-specific experimental requirements. Concurrently the study team determined the proposed capabilities of the various USL module systems. The team has been tracking the development of such systems as the data

management system (DMS), the electric power distribution systems (EPDS), and the process materials management system (PMMS) as each of them evolves towards a preliminary design review.

The user requirements and the USL module capabilities have been summarized and tabulated by the study team in an experimental-requirements database. The information in this database, which is electronically stored in Lotus 1-2-3 files, consists of eight major sections: general information, electric power distribution, instrumentation and data acquisition, electric controls, mechanical fluid systems, mechanical structures, environmental requirements, and timelines. This is considered a living database in that information in it is expected to change constantly. At the present time this database has only limited distribution.

Conceptual Design

Following the requirements-definition phase, the study team proceeded to the conceptual design task. A modular approach was pursued, in which the MCF would consist of two or more S.S. Freedom equipment racks. One of these racks was designated the facility rack, and the other(s) the experiment rack(s). This concept is pictured in figure 1. The facility rack, shown on the left, will be the permanent part of the MCF, housing the support systems identified by the study team as being required to support potential users. These support systems will be covered in detail in the section Facility Support System. The facility rack will remain onboard the Freedom station for as long as the use of the MCF can be justified; however, this does not preclude occasional changeout of this rack for upgrade or enhancement purposes.

Adjacent to the facility rack will be an interchangeable experiment rack. This experiment rack will contain experiment modules, experiment-specific hardware, and a minimum amount of support hardware. An experiment module is defined as hardware to be used in conjunction with facility rack support systems to perform one or more unique experiments. Two strawman experiment modules have been defined and used in the conceptual design process; one is a large multipurpose combustion chamber, and the other a multipurpose very low-speed combustion tunnel. All of the experiments on the reference experiment list fit into one or both of these strawman modules. The multipurpose aspect derives from the variety of experiment-specific hardware modules that could be used within an experiment module. An example of experiment-specific hardware is a set of test sections for the low-speed combustion tunnel, each representing a different experiment. Each of these test sections would have additional associated hardware unique to the experiment, such as camera or laser optics, sample changing mechanisms, experiment-specific computer software, and transducer instrumentation. Likewise, for the combustion chamber, examples of experiment-specific hardware are sets of combustion apparatus that could be mounted inside the chamber. Again, each would require additional associated hardware.

MODULAR COMBUSTION FACILITY MODULAR CONCEPT
 SERIES OF EXPERIMENT RACKS CONTAIN DIFFERENT EXPERIMENT MODULES
 MODULES CONTAIN INTERCHANGEABLE EXPERIMENT SPECIFIC HARDWARE

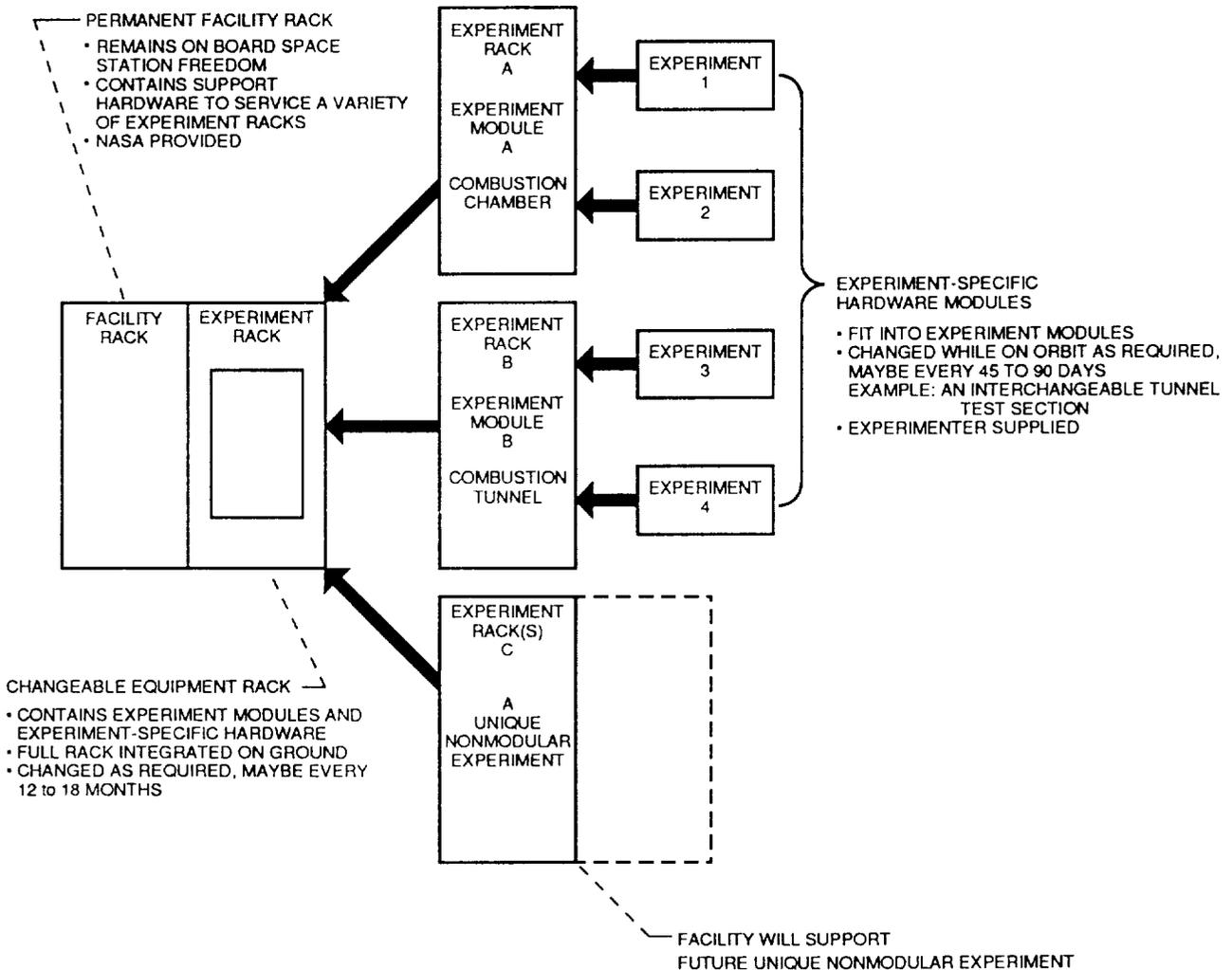


Figure 1.—Modular Combustion Facility concept.

The experiment rack, including its MCF support hardware, experiment module, and one experiment-specific hardware module, is expected to be integrated on the ground and transported via the Freedom logistics module to the Freedom station. Exchanges of entire experiment racks such as this might be expected to occur every 12 to 18 months. The concept design also allows on-orbit changeout of experiment-specific hardware modules. These changeouts might be expected to occur every 45 to 90 days.

The MCF is being designed to support future, unique nonmodular experiments or additional modular ones. The design admits the possibility of an experiment rack being larger than one Freedom rack.

As part of the conceptual design effort, the study team generated a series of conceptual schematic diagrams, one for

each of the experiments on the reference experiment list. Figures 2 and 3 are two examples of these diagrams; one shows a strawman combustion-tunnel experiment module, and the other a strawman combustion-chamber experiment module. These figures are basically mechanical fluid diagrams that show both the facility and experiment racks along with major pieces of equipment in each. On the schematic, at the bottom of each rack, USL module services are shown. The changeable part of the experiment rack, the experiment modules and experiment-specific hardware, are shown within the dashed and crossed line. Note that the study team has not attempted to conceptually design any of the experiments that might reside in these experiment racks; rather, it has tried to learn only enough about each experiment to determine what support systems would be required of the MCF.

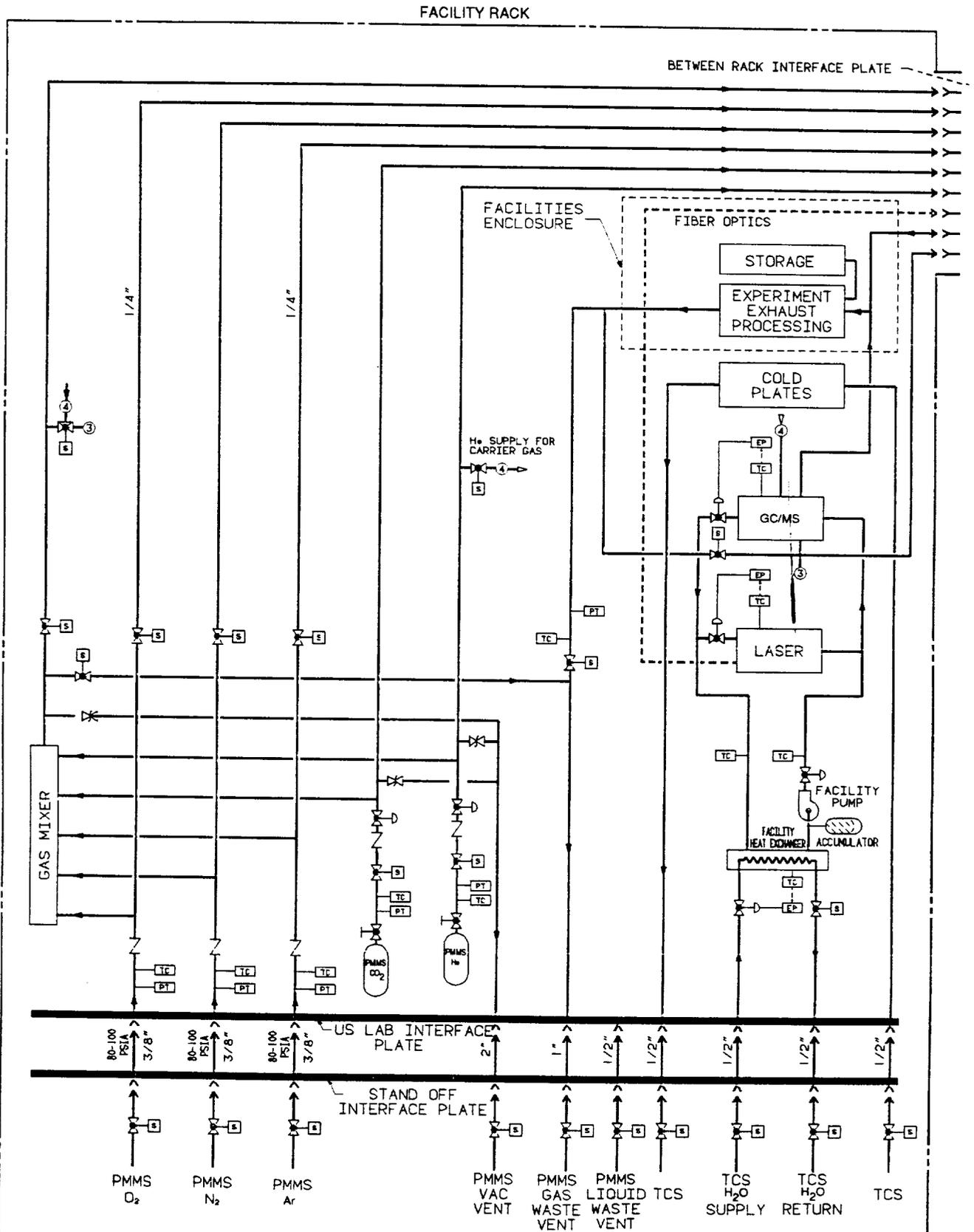


Figure 2.—Conceptual schematic of combustion tunnel experiment.

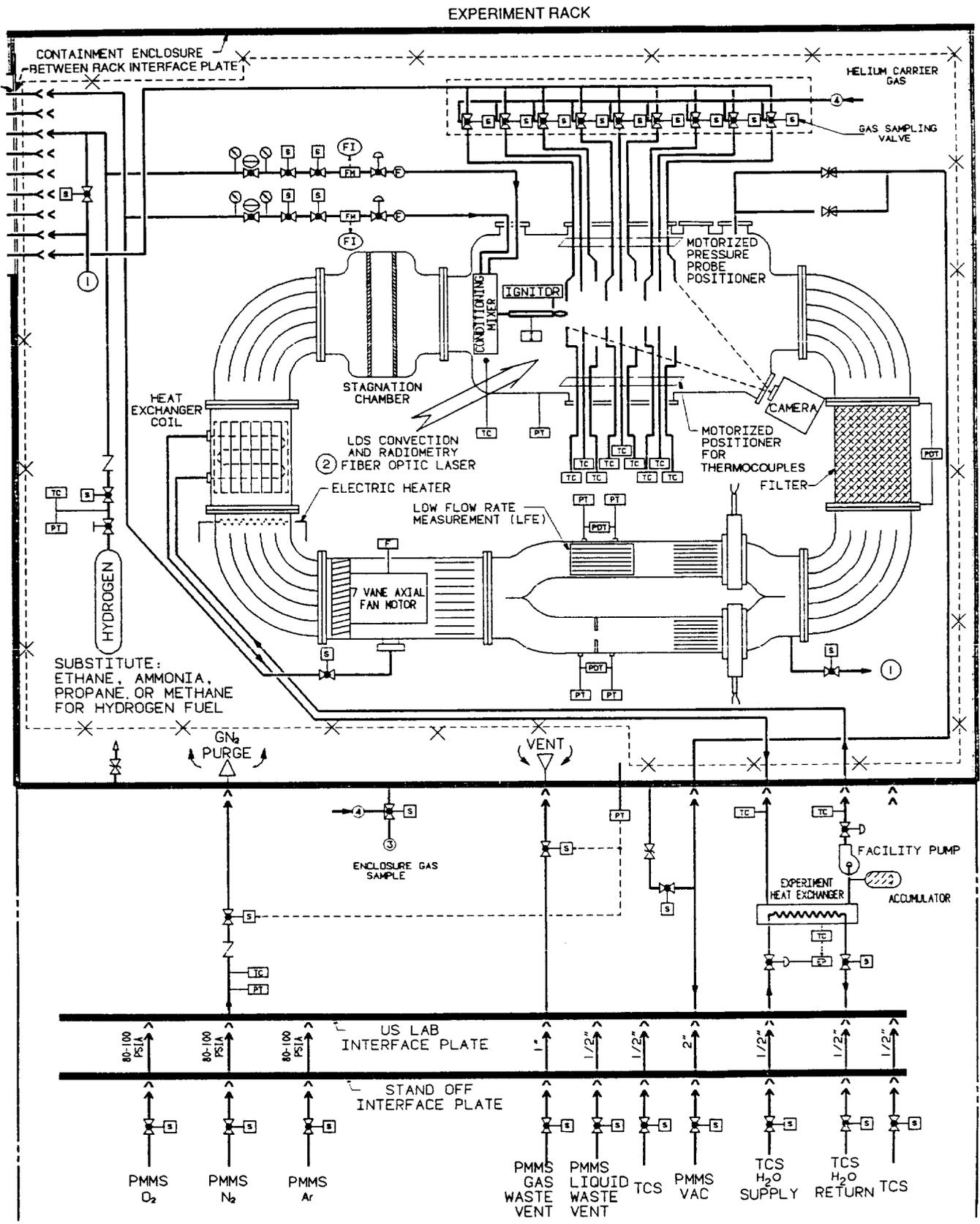


Figure 2—Concluded.

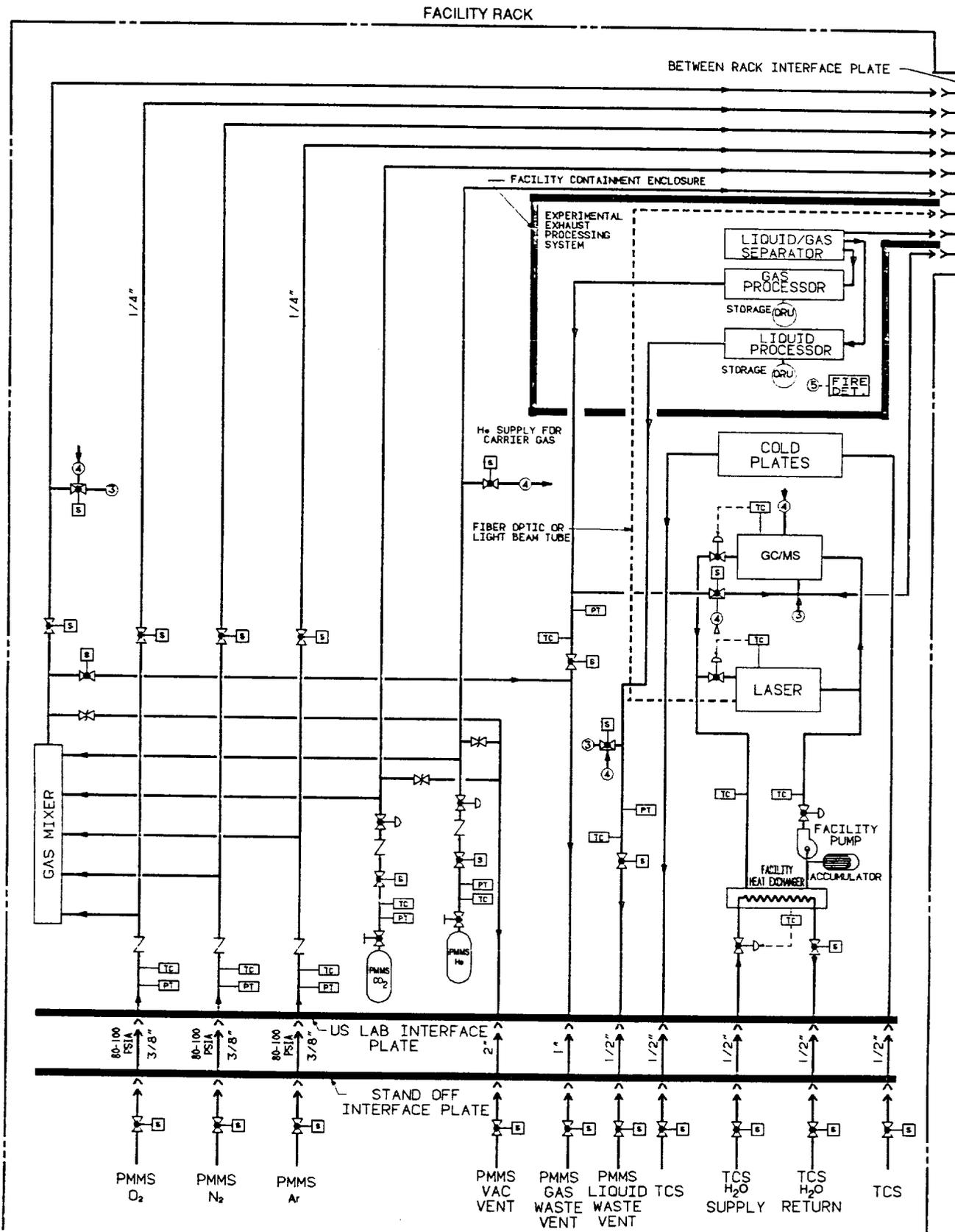


Figure 3.—Conceptual schematic of combustion chamber experiment.

EXPERIMENT RACK

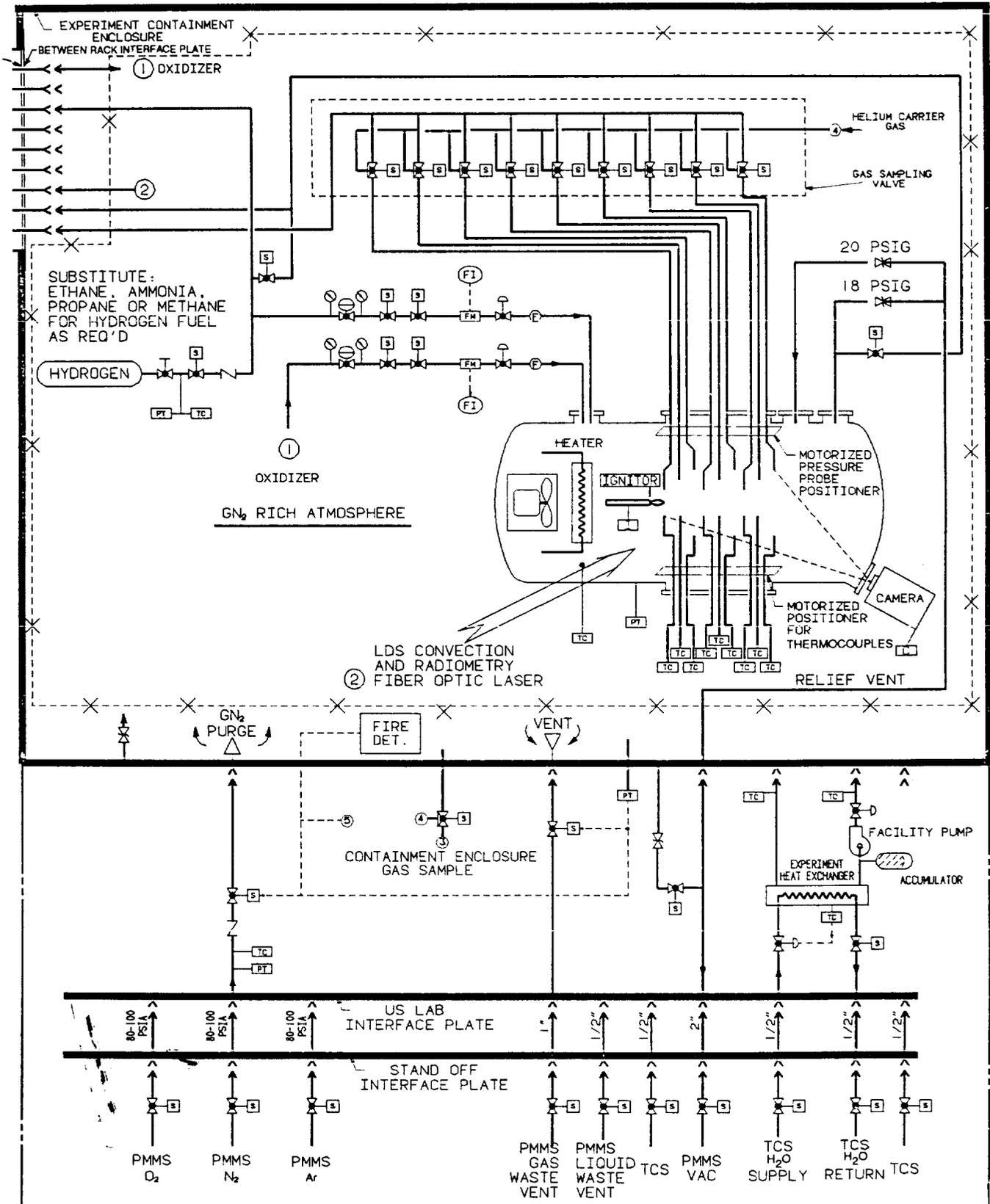


Figure 3—Concluded.

Facility Assumptions and Constraints

There are certain constraints to the design of the support systems that are included in the MCF. These constraints come from several sources: the USL module and S.S. Freedom program safety requirements; the USL module capabilities and requirements; the Freedom station operations and logistic requirements and capabilities; and program funding and schedules. Other constraints were imposed by certain assumptions made by the study team during the MCF conceptual design phase—assumptions made because of a lack of specific information on USL module systems and S.S. Freedom program operations that are in their early design phase. These assumptions are listed under Concluding Remarks.

Facility Support Systems

The study team has identified thirteen MCF support systems. These, along with subsystems, are shown in the following list:

- (1) Electrical power distribution system
 - (a) Power monitoring and control subsystem
 - (b) Power conversion subsystem
- (2) Computer system
 - (a) Multiplexer-demultiplexer (MDM) embedded data processor
 - (b) Facility local bus network
- (3) Control system
- (4) Experiment instrumentation and data acquisition system
 - (a) Pressure measurement subsystem
 - (b) Temperature measurement subsystem
 - (c) Flow measurement subsystem
 - (d) Transducer calibration subsystem
- (5) Special instrumentation systems
 - (a) Optical measurements subsystem
 - (b) Master laser light source
 - (c) Gas chromatograph and mass spectrometer (GC/MS)
- (6) Imaging systems
 - (a) Film imaging subsystem
 - (b) Video imaging subsystem
- (7) Fluid supply system
 - (a) Bottle and USL fluid interface subsystem
 - (b) Gas mixing subsystem
- (8) Waste conditioning system
 - (a) Gas and liquid separating subsystem
 - (b) Experiment exhaust processing subsystem
- (9) Thermal control system
 - (a) Avionics air
 - (b) Liquid-to-liquid heat exchangers
 - (c) Cold plates
- (10) Containment enclosure systems
 - (a) Experiment containment enclosure subsystem
 - (b) Facility rack containment enclosure subsystem
 - (c) Containment enclosures pressure control subsystem
 - (d) Portable glovebox subsystem
- (11) Operator interface system
 - (a) Element control workstation
 - (b) Facility status panel
 - (c) Facility operator interface (portable multipurpose application console)
- (12) Safety monitoring and caution and warning (C&W) system interface system
- (13) Software system

A description of each of these systems is given in the next section of this document. Following this is a description of the proposed Facility operations and integration scenario and, then, a Facility development plan.

Facility Description by System or Function

Rack Structure

One of the primary considerations in the conceptual design of the MCF has been the emphasis on user needs for the research that will be conducted in it. Because the exact experiments that will utilize the MCF in years to come are unknown, it has been structured so that the maximum possible volume and payload weight are reserved for experiment-specific hardware.

The USL module will house a total of 44 standard Freedom racks; 11 each in the floor, ceiling, portside, and starboard side of the module. The MCF will reside in two adjacent racks in the module, as shown in figure 4. One rack will house the facility support hardware, and the other rack will contain the

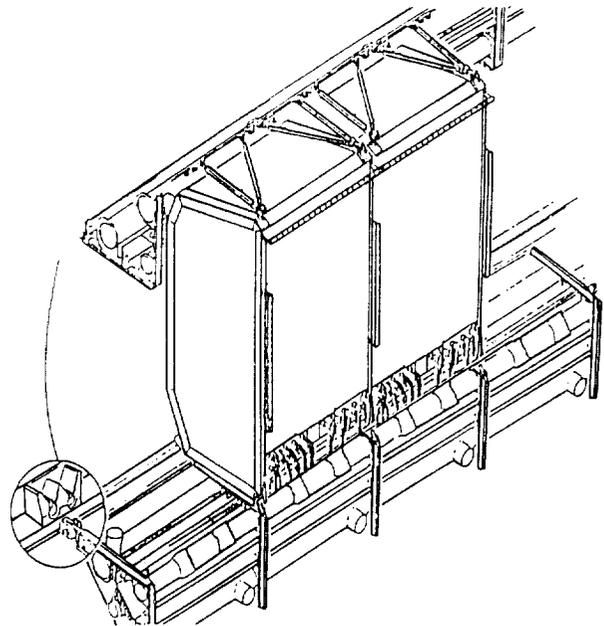


Figure 4.—Space Station Freedom standard racks.

experiment module and experiment-specific hardware. This two-rack concept, selected as a result of a trade study, evolved from the size requirements for the seven candidate combustion experiments; the volume available in an S.S. Freedom rack is sufficient to house each reference experiment, and integration and de-integration of experiment-specific hardware will require less work if the equipment is located in one rack. Another benefit is that the facility support rack can remain on the Freedom station for extended periods of time, whereas the experiment rack can be returned to Earth for experiment module changeout.

The MCF is being designed to be integrated into the USL module only; no provisions are being made for installation into an international module because of the design limitations imposed. The most critical restrictions in the Japanese Experiment and European Space Agency modules are the absence of plumbed gases and lack of a waste disposal system. The USL module will provide plumbed nitrogen, oxygen, and argon to certain racks within the module. Each of the reference experiments requires at least one of these gases, mainly for generating air mixtures. The quantities required exceed the amount that could feasibly be stored in bottles in the MCF. In addition, the combustion experiments will be producing a significant amount of exhaust products, which would be difficult to handle without a central disposal system. One advantage to restricting the MCF to the USL module only is that a larger rack can be used. The experiment racks in the USL module have 8.8 percent more usable volume per rack than the racks designed for interchangeability with the international partners' modules. The following sections discuss aspects of the facility and experiment racks comprising the MCF.

Experiment racks.—The S.S. Freedom experiment racks are being supplied for the MCF by the S.S. Freedom program. Since only one rack can be brought into the USL module at a time because of the size of the hatch leading into the module, the two racks comprising the MCF must be joined together in the USL module on orbit. The program-supplied racks may not be structurally modified by the users, and the primary rack structure may not be removed during an on-orbit installation. The S.S. Freedom program will be using some of the rack volume for program-supplied hardware. The bottom 25.4 cm (~10 in.) of the rack are reserved for the multiplexer-demultiplexer (MDM), standard data processor (SDP), power converter and protection assembly, and the Freedom station interface panel. The back 10 cm (~4 in.) are reserved for both the avionics air and the thermal control system (TCS) piping. Figure 5 shows the dimensions of the remaining available working envelope and the volume devoted to the rack user.

Payload weight restrictions.—The S.S. Freedom program has specified a maximum payload weight range between 400 and 700 kg per rack. The higher end of the payload weight range will be reached by adding additional rack-support braces,

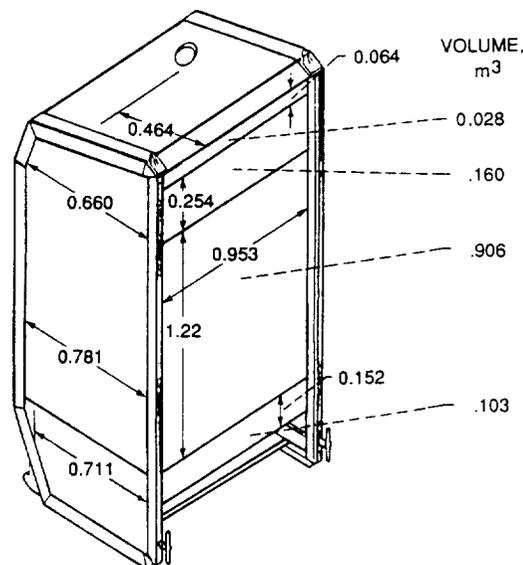


Figure 5.—Standard rack working envelope. All linear dimensions are in meters.

which are supplied by the Freedom program. If the rack payload weight were to exceed the maximum allowed, the additional equipment could be delivered into orbit independently and integrated into the rack in orbit. The maximum payload weight is specified because the racks are used as support for the MCF hardware during transport to and from the Freedom station via the space shuttle.

Rack integration sequence.—The integration of both the MCF hardware into the facility rack and the initial experiment into the experiment rack will be done on Earth. The two integrated racks will arrive on orbit by means of a pressurized logistics module. The module is a cylindrical-shaped payload that fits into the space shuttle cargo bay. On arrival at Freedom, the logistics module will be linked with the Freedom station, and the racks will be transported one at a time into the USL module. The racks will be attached to the USL module by means of a pin-latching mechanism on the upper back edge and on two of the bottom edges of the rack. Flexible hoses and cables that connect the standoff interface plate to the Freedom station interface plate will provide fluid and electrical connections to the USL module. One important feature of the racks is that they are designed to be tilted out—pivoting about the lower front attachment point to allow access to the USL module's inner wall (see fig. 6). This access is necessary in order to clean the back shell or to repair any damage that might be caused by a meteoroid or debris strike on the USL module. The flexible connections between the racks and the USL module allow the pivoting motion without breaking any connections.

Experiment changeout procedure.—Because the MCF is a multiuser facility, experiment and/or experiment-module changeout is an important aspect in its design. The assumption that a changeout of an experiment module will require de-

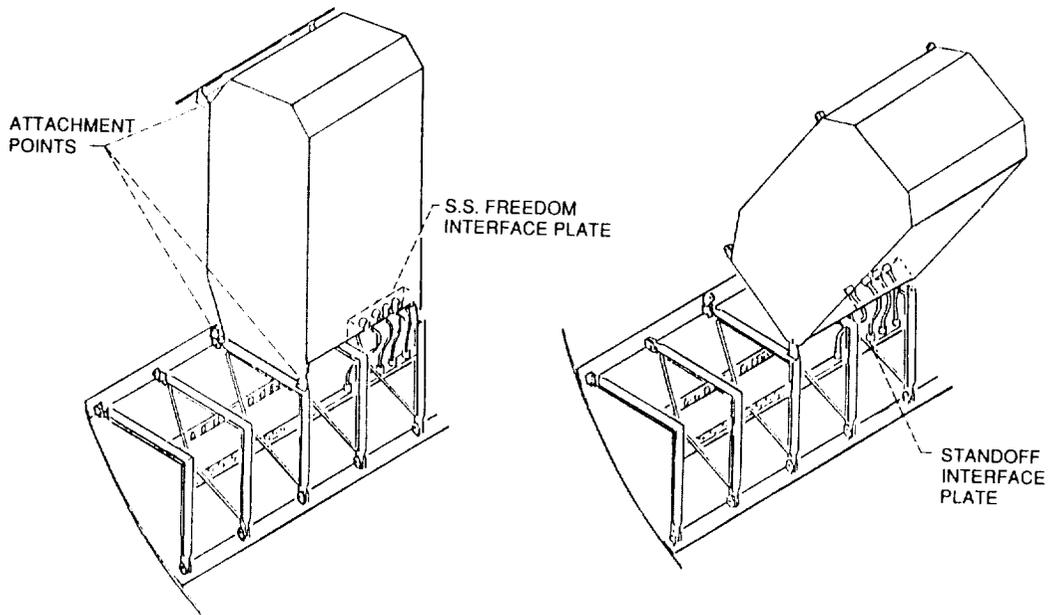


Figure 6.—Rack access and tilting feature.

integrating and then integrating a full rack was based on the difficult operations involved in changing from a combustion chamber to a combustion tunnel on orbit. This assumption, therefore, led to the decision to integrate the new experiment module into a Freedom rack while it is on the ground and then to transport the rack to the Freedom station via the space shuttle. The on-orbit integration between the facility rack and the experiment rack would then be the same as the initial integration into the USL module. Alternatively, if an experiment changeout is required within a previously installed experiment module, this operation could be performed on orbit.

Safety containment levels.—The S.S. Freedom safety program requires that any material that could contaminate the USL module atmosphere and cause harm to the crew must be double fault tolerant. In other words, the system must remain safe after two failures (i.e., triple contained). Because toxic and/or combustible materials could be used or produced within the MCF, most, if not all, of the experiments will require three containment levels. Through a trade study a decision was made to provide two of the three required levels by enclosing the experiment-specific hardware within a containment enclosure in the experiment rack. The pressure within the enclosure will be maintained slightly lower than the pressure within the USL module, thereby eliminating the possibility of any gas from the experiment module escaping into the USL module atmosphere through a small leak in the enclosure. The three safety containment levels are the experiment module, the negative pressure, and the containment enclosure. In the event that the experiment being conducted within the experiment module does not require containment, the enclosure can be removed. Also, there may be some situations where the

experimenter might want to furnish all required containment layers.

Facility configuration.—The overall layout of the MCF is shown in figure 7. The facility rack is shown on the left, and the experiment rack with the strawman combustion tunnel experiment module is on the right. The MCF with the strawman combustion chamber experiment module is displayed in figure 8. The layout of the MCF stresses the modular design concept. All of the electronic hardware in the facility rack resides in separate boxes that could easily be replaced if necessary. A center support was added to the facility rack to

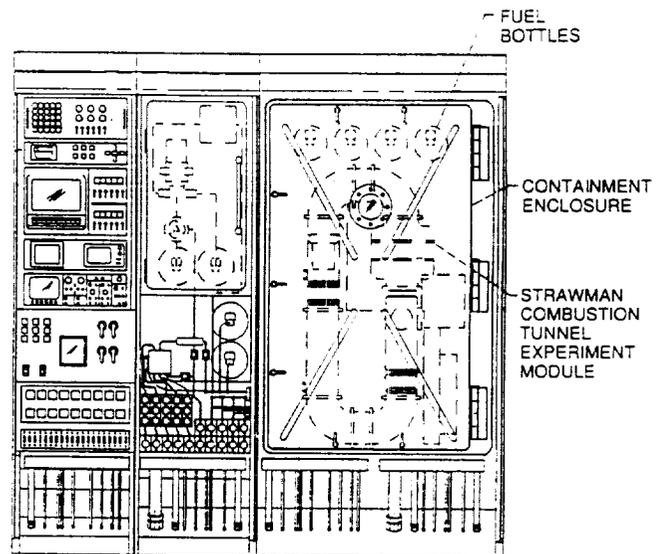


Figure 7.—Facility experiment rack and strawman combustion tunnel.

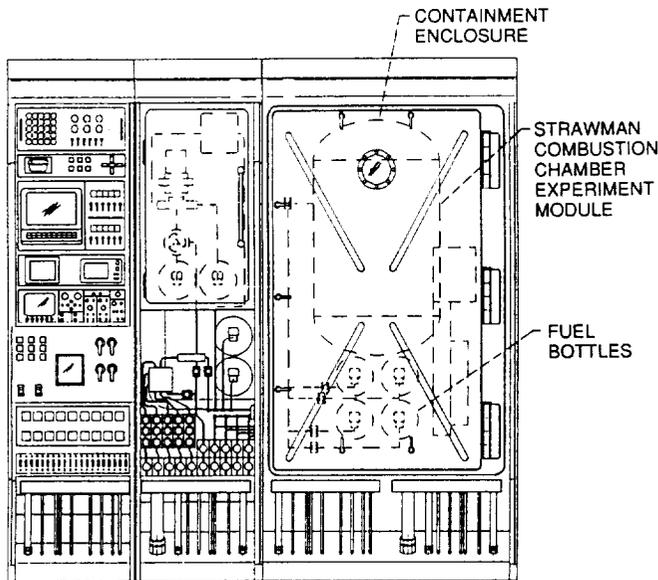


Figure 8.—Facility experiment rack and strawman combustion chamber.

aid in mounting standard 19-in. electronic boxes. The components will be mounted on rails for easy removal and replacement. The experiment module and experiment-specific hardware are located within the experiment containment enclosure. A changeout of an experiment will require exchanging hardware within the enclosure but little, if any, changing of hardware in the facility rack. A labeled drawing of the facility rack is shown in figure 9. The services to be supplied by the MCF were decided on by the study team on the basis of the reference experiments and input from researchers. Note that the actual sizes of the components are

unknown at this time, but the envelope in which the actual hardware will reside has been approximated. Figure 10 shows front and side views of the facility rack.

Facility rack containment enclosure.—A safety enclosure around the experiment exhaust-processing system has been added to the facility rack. The products of combustion from the experiment will be brought into the facility rack to be processed before either being sent to the PMMS waste system or stored. These products could cause harm to the crew if released into the USL module atmosphere. The three levels of safety containment will be the same as previously discussed for the experiment. The enclosure will occupy approximately one-quarter of a rack, have an internal volume of approximately 0.17 m³, and weigh approximately 50 kg.

Experiment containment enclosure.—As mentioned previously, the experiment containment enclosure will provide two of the three required safety containment levels for a toxic or combustible material within the combustion chamber or tunnel. The main function of the enclosure will be to keep the atmosphere within it isolated from the USL module by maintaining a slightly negative pressure with respect to the USL module. The enclosure has *not* been designed to contain an explosion or a major leak in the experiment module. Rather, the experiment modules are expected to be designed to contain an explosion, if necessary. Furthermore, the responsibility of ensuring that a major leak does not pose a credible failure mode lies with the experiment module designer. The study team concluded that designing the enclosure to contain a major leak would be impractical because of the very thick wall that would be required and the resulting increase in enclosure weight. However, the enclosure will act as a plenum for a small leak from the experiment module through a seal, fitting, or such.

- ① OPTICAL DETECTOR ELECTRONICS
- ② EXHAUST PROCESSING SYSTEM ELECTRONICS
- ③ FACILITY STATUS PANEL
- ④ BETWEEN RACK INTERFACE PLATE
- ⑤ CALIBRATION SYSTEM
- ⑥ VIDEO CONTROL UNIT
- ⑦ PORTABLE COMPUTER CONSOLE
- ⑧ GAS CHROMATOGRAPH AND MASS SPECTROMETER
- ⑨ U.S. LAB INTERFACE PLATE
- ⑩ LASER LIGHT SOURCE
- ⑪ GAS MIXING SYSTEM PROCESSOR
- ⑫ EXPERIMENT EXHAUST PROCESSING SYSTEM
- ⑬ GAS MIXING HARDWARE
- ⑭ VALVE BLOCK
- ⑮ CIRCUIT BREAKER PANEL
- ⑯ PMMS-SUPPLIED BOTTLE GASES
- ⑰ EXHAUST PRODUCTS STORAGE BOTTLE
- ⑱ GAS/LIQUID SEPARATOR
- ⑲ MULTIPLEXER/DEMULTIPLEXER
- ⑳ STANDARD DATA PROCESSOR
- ㉑ POWER CONVERTER AND POWER PROTECTION ASSEMBLY
- ㉒ FACILITY CONTAINMENT ENCLOSURE

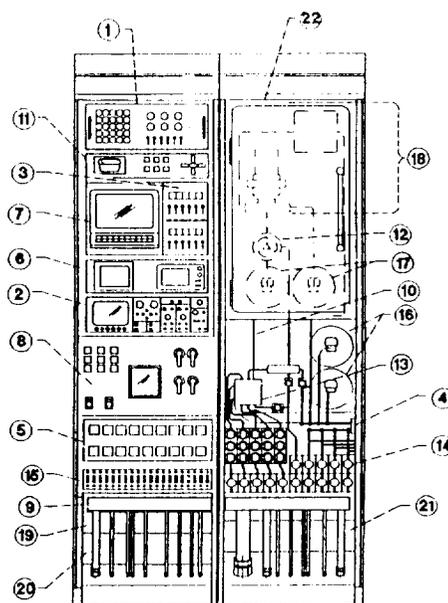


Figure 9.—Facility rack support systems.

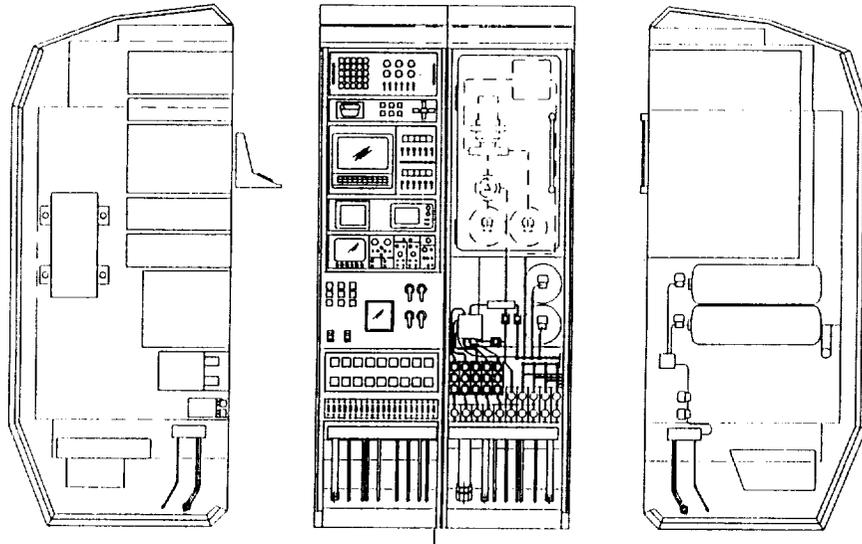


Figure 10.—Facility rack front and side views.

A small leak is defined as one that causes a pressure rise within the enclosure of less than 13.8 kPa (2 psid) with the pumping system in operation.

The size of the enclosure was based on the largest possible rectangular box that will fit within a rack that is 90.17 cm wide by 60.96 cm deep by 149.86 cm high (35.5 by 24.0 by 59.0 in.). The enclosure will have a large door on the front to allow easy access to the experiment hardware. In addition, a window will be provided to allow the crew to view the hardware. The material selected for the enclosure was 6061-T6 aluminum, because of its weldability and high resistance to stress corrosion cracking. Currently, two containment enclosure designs are being studied. The first enclosure has been designed for a full vacuum, whereas the second design has been optimized for a maximum differential pressure across

the enclosure walls of 13.8 kPa (2 psid). The key features of the two designs are summarized below.

Full-vacuum concept: The usable volume within this containment enclosure is 0.61 m³ (21.57 ft³). The inner dimensions of the enclosure are 83.6 cm wide by 54.4 cm deep by 143.3 cm high (32.9 by 21.4 by 56.4 in.). The enclosure weighs approximately 210 kg, which allows a 490 kg weight limit for the experiment module and experiment-specific hardware. Further optimization of this design is expected to decrease the weight of the enclosure. See figure 11 for additional features of this design. An advantage of this enclosure over the 2-psid enclosure is that a full vacuum could be used to eliminate harmful gases (which could be present in the enclosure if the experiment module fails). The main disadvantage of this enclosure is that it weighs more than the

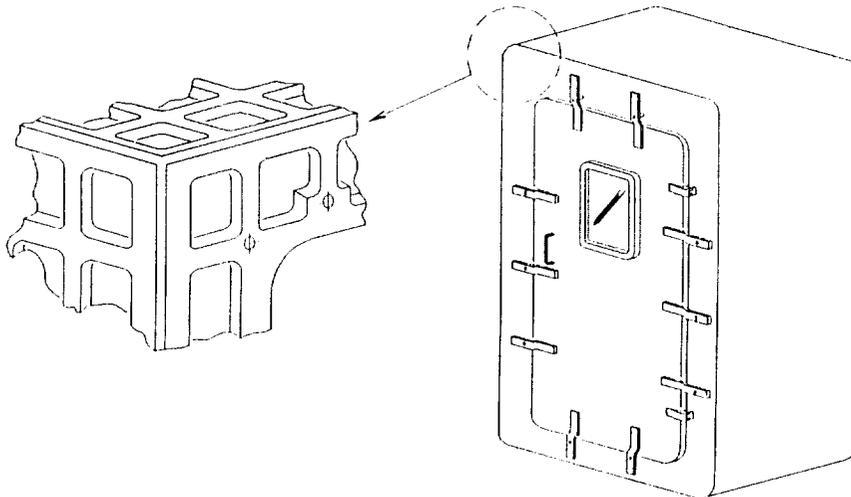


Figure 11.—Full-vacuum experiment containment enclosure design. Material, 6061-T6 aluminum; wall thickness, 0.635 cm; stiffener, 1.27 cm wide by 3.3 cm high; door, 71.1 cm wide by 127 cm long; window, 16.5 cm wide by 29.2 cm long by 1.6 cm thick; total weight 210 kg; internal volume, 0.61 m³.

2-psid enclosure, which would decrease the payload weight allotted for the research hardware. An additional concern is that all electrical and fluid interfaces, door and window seals, and so on would have to be rated to seal a full vacuum.

Two-psid enclosure concept: This enclosure weighs approximately 120 kg, compared to the 210 kg for the full-vacuum enclosure. Since this design has not yet been optimized, further investigation will probably decrease this estimate. The usable volume within the enclosure is approximately 0.79 m³ (27.8 ft³). A vacuum cannot be used to purge the 2-psid enclosure; the design assumes that a vent and purge sequence will be used to eliminate any dangerous gases that could be contained within the enclosure.

Optical bench: An added advantage of encapsulating the experiment within a containment enclosure is that the enclosure provides a mounting surface for experiment hardware. Rigid mounting of the experiment module and its related diagnostic equipment will be extremely important to the success of the experiment. If precise alignment of the optical equipment is critical, it will be done on the ground. The mounting surfaces, then, would have to be rigid in order to hold this alignment during launch. For other experiments where the alignment is less critical, on-orbit alignment could be performed. Either scenario would require a rigid mounting surface. Perhaps the back panel of the containment enclosure could be used as an optical bench. Since panel deflections due to the differential pressure across the enclosure must be prevented from causing misalignment of the optical hardware, if mounting on the containment enclosure is impractical, a rigid mounting plate, to be used as an optical bench, will have to be added within the enclosure.

Between-rack interfaces.—Between-rack fluid and electrical interfaces will be required because the experiment will be housed in one rack and the control hardware will reside in an adjacent rack. The number of interconnections between the racks has been minimized in order to decrease the time required to integrate the two racks. The initial concept proposes using quick-disconnect fluid fittings and flexible lines to connect the PMMS-supplied consumables and the waste system to the outside of the experiment containment enclosure side panel. The experiment will interface with these systems on the inside of this panel. Electrical connections will be made by using a similar concept with electrical pin connectors. This design provides a generic interface at the containment enclosure wall. Some extra ports will be provided for experiment-specific connections that may be required. Another design option proposes two interface plates, one for fluid connectors and one for electrical connectors. The latter design also uses quick-disconnect connectors and flexible hoses and cables, but all connectors are mated simultaneously through the use of a linear drive mechanism. One advantage of this design is that wrong connectors would be prevented from mating.

Portable glovebox.—One of the most difficult activities the crew will be performing in the MCF is experiment-module

cleaning. Some of the combustion experiments performed in the MCF will produce soot. This soot and any residual combustion products in the experiment modules would have to be cleaned out prior to experiment changeout. The present concept intends using filters to take out the particulate and a vent and purge sequence to do the initial cleaning of the module. Final cleaning would be performed by a crew member using a portable glovebox as shown in figure 12. The glovebox will be an S.S. Freedom program-supplied device, which is expected to be designed as a standard piece of equipment that could interface with any rack in the USL module. This one-size-fits-all design is expected to cause some complications in the interface design.

The S.S. Freedom program will supply these gloveboxes with a flat plate for attachment directly to the chamber or tunnel; this will require an experiment-specific adapter plate because of the varied module geometries. A gas analyzer will monitor the atmosphere and serve as a permissive to open the enclosure door. The initial atmosphere within the experiment containment enclosure will have to be safe since the enclosure door will be opened before attaching the glovebox to the experiment module. In the event that the atmosphere within the enclosure is known to be contaminated, a series of vent and purge sequences will rid the enclosure of the contamination. This concept allows containment to be maintained at the lowest isolation level (i.e., at the experiment module level). In addition, a glovebox interface on the experiment containment enclosure door will provide some cleaning access to the enclosure if the door cannot be opened. Because of the large size of the enclosure and the relatively small size of the glovebox, however, only a small area in the enclosure will be accessible. If the chamber walls are not reachable through the glovebox or if the back sections of the experiment module should need cleaning, an automated cleaning system might become necessary. If the enclosure is severely contaminated, the experiment rack might have to be brought back to Earth for cleaning. If a failure is not detected and the enclosure environment is clean, the enclosure doors will be opened and the glovebox attached to the chamber/tunnel for cleaning. Alternatively, perhaps a free-form, disposable

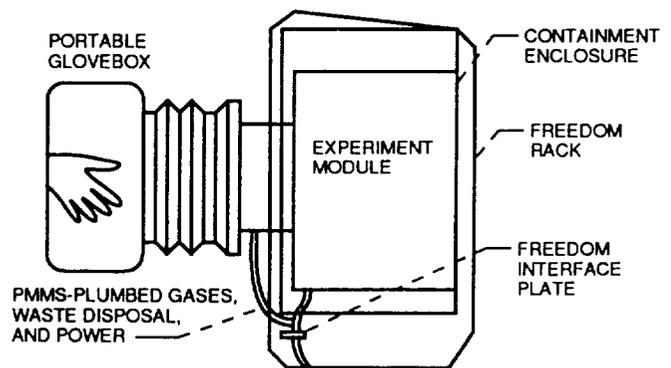


Figure 12.—Portable glovebox concept.

glovebox should be studied as a means of eliminating the access problems involved in a solid box design.

Electrical Systems

Computer system.—The MCF computer system (see fig. 13) will be based on S.S. Freedom data management system (DMS) hardware and software. The MCF computer system will be a node on the Freedom payload network through which data and commands will flow. The Freedom program is expected to provide most of the basic hardware and software, including networking boards, processor boards, some selected input/output (I/O) boards, and appropriate software to run these boards. Most of the operations of the MCF will be managed through the element control workstation (ECWS), which is a centralized workstation in the USL module that contains displays, a keyboard, and other I/O devices. Experiment runs will usually be automated, with the ECWS used to initiate and monitor the experiment. The DMS will handle all of the data storage and data downlink for the MCF.

Automation will be an important factor in experiment operations. Although a mission specialist will be invaluable for sample preparation, sample retrieval, and data analysis, a computer-controlled timeline usually is the most effective

way to run a test. Telescience will allow a principal investigator (PI) on the ground to monitor experiment conditions in real-time and, possibly, to change process parameters as necessary.

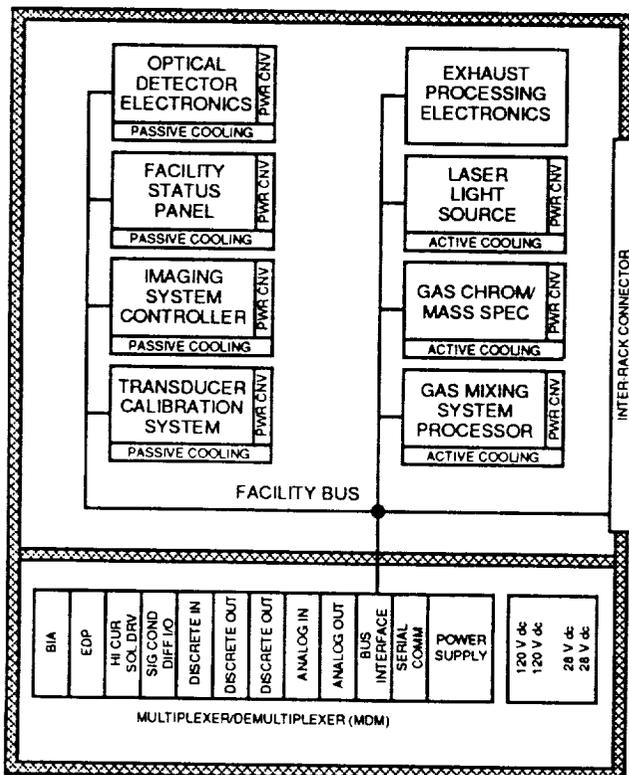
System design: The MCF computer system will consist of two MDM's, each composed of an embedded data processor (EDP), an I/O control unit, assorted I/O cards, and an MCF local bus card. An MDM will be located in the bottom of both the experiment and facility racks. About half of the I/O resources of the MDM will be dedicated to Freedom-unique requirements such as fire detection and suppression and power control. The remainder will be used for Facility or experiment control and instrumentation.

The processor board, known as an EDP, has a 32-b Intel 80386 microprocessor with 4 MB of memory and is capable of 4 MIPS (million instructions per second). It has an internal IBM microchannel architecture and an external Intel Multibus II interface. The rationale for these choices was a desire to use state-of-the-art, off-the-shelf technology in order to provide a lower overall cost and to permit users to develop experiment-specific hardware with available technology.

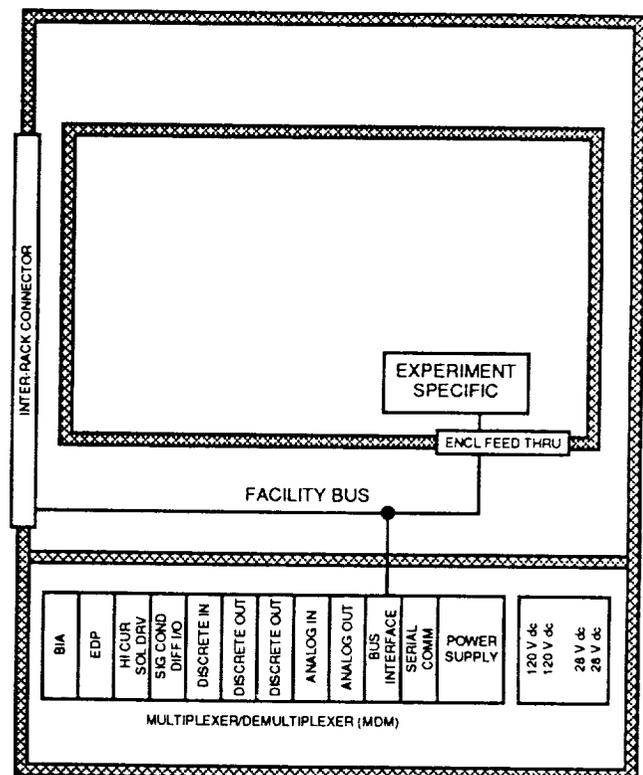
The data acquisition section of the system will consist of an I/O control unit and an assortment of I/O boards that include the following: temperature inputs, pressure inputs, analog voltage inputs, analog voltage outputs, discrete inputs and

BIA = BUS INTERFACE ADAPTER
 EDP = EMBEDDED DATA PROCESSOR
 PWR CONV = POWER CONVERTER
 SERIAL COMM = SERIAL COMMUTATOR

ENCL FEED THRU = ENCLOSURE FEED THROUGH
 GAS CHROM/MASS SPEC = GAS CHROMATOGRAPH/MASS SPECTROMETER
 HI CUR SOL DRV = HIGH CURRENT SOLENOID DRIVE
 SIG COND DIF I/O = SIGNAL CONDITIONER DIFFERENTIAL INPUT/OUTPUT



FACILITY RACK - MODULAR COMBUSTION FACILITY



EXPERIMENT RACK - MODULAR COMBUSTION FACILITY

Figure 13.—Modular Combustion Facility computer system.

outputs, valve and solenoid drivers, and a serial digital bus. User-unique boards could also be accommodated. Some experiments may need higher accuracy and/or a higher sampling rate and for these, boards would have to be developed.

The I/O control unit acts as an I/O processor for the EDP. It can take a list of channels, acquire the data from the specific boards, and send the data back to the EDP; this removes the burden of low level I/O processing from the EDP. The I/O control unit also has built-in monitoring and self-testing features to ensure proper operation.

The MCF local bus will be used to communicate with most subsystems (see fig. 13). Most of the subsystems will contain enough intelligence to receive and interpret commands from the MCF local bus. Intelligent subsystems will relieve the MCF computer of the low level processing necessary to accomplish some of the functions required by the subsystems. For example, the flow control unit in the gas mixing system will be able to monitor instrumentation and to set flow rates based on simple commands from the MCF computer. The MCF local bus will be connected to all appropriate devices in the experiment and facility racks. A connection will also be available for experiment-specific devices. The MCF local bus will be either an IEEE-488 or Military Standards 1553 bus. Both of these being command and response protocols implies that there is one bus master (controller) that allocates bus resources to all of the devices. The MDM in the facility rack would be the bus master in this case.

The mission specialist will do most of the interacting with the computer system at the ECWS where there will be keyboards, "mouse"-like devices, video displays, voice communications, and other devices that operate the MCF. The specialist will be able to send commands to the MCF, to monitor experiment parameters by displaying data from the MCF, and to display video from a camera monitoring the experiment. A portable computer unit, which can be located at the MCF if a particular operation requires it, will also be available. And a status display panel will show the MCF health status in case there should be a problem with the communications.

There will be three paths for data to flow from the MCF: a 1-Mb/sec local bus, a 10-Mb/sec local area network, and a 100-Mb/sec high-rate link. The local bus is an IEEE 802.4 standard, which is a 1-Mb/sec (10-Mb bandwidth) balanced protocol. The local bus will deliver commands to the MCF and will transmit status and housekeeping data to a user at the ECWS or to mass storage. The 10-Mb/sec network is a fiber-distributed data interface (FDDI) protocol. It has a 10-Mb/sec throughput with 100-Mb bandwidth. This network could be used for some video data transmission or for a mass spectrometer. The 100-Mb/sec high-rate link is a fiber-optic link that connects through a patch panel directly into the communication system. This will be used mainly by the high-resolution, high-frame-rate video system to downlink experiment image data.

Facility capabilities: The MCF computer will contain the major portion of the MCF software and will exercise overall control of the facility and experiment racks by receiving and acting on commands from the mission specialist via the ECWS. The computer could receive a new set of operating parameters for an experiment. It would then set up the Facility hardware for these new conditions and send the remaining parameters to the experiment rack computer. The facility- and experiment-rack MDM's will be able to communicate via the MCF local bus, which will be connected inside the rack. The configuration of the facility computer will not change from experiment to experiment, since the facility rack should not change much from experiment to experiment.

The experiment-rack computer will be responsible for interfacing with the experiment-specific hardware and will be able to adapt to the changing needs of each experiment by utilizing modular signal conditioners. The computer will receive commands from the facility-rack MDM, but it will send out data by using the network. The processing capability of the experiment computer can be augmented if an experiment has a unique requirement. This would be accomplished through the use of another EDP, which could reside in the same box.

The MCF computer software will consist of (1) software written for the Facility and (2) software written for the experiment. New software will be uplinked to the Freedom station and routed through the network to the facility rack MDM. A backup copy of the software will be kept in a mass storage unit, which will be available through the network.

When a new experiment is installed, the software will be the most important thing changed. Other changeable things might be the signal conditioners, a board in the MDM, additional hardware in the MDM, and new diagnostic instruments to be connected to the MCF local bus; most of this changeout will be done at the Science and Technology Center (S&TC). After the hardware is installed, the new software will be loaded, and some tests will be run to ensure proper operation of the hardware and the software.

Control system.—The functions of the control system are to control and monitor the MCF experiment and to detect and take corrective action for any unsafe condition that could result in a safety hazard.

The design of the control system will depend both on the operational and safety requirements imposed on the MCF by the S.S. Freedom program and on the control and safety functions inherent in the data management (DMS) and electric power systems (EPS). In addition, hardware being developed under the S.S. Freedom program that will be available to users will have some effect on the design of the control system.

These requirements, functions, and hardware are presently being defined and/or developed, so details of the control system design are still evolving. Some basic control concepts and principles that are being considered are given in the following paragraphs.

The facility-rack MDM will be the primary controller. Individual devices or systems such as the gas chromatograph

and mass spectrometer and the experiments products conditioning system may have embedded processors. A processor will be programmed to provide the functions necessary for control, data acquisition, and to some extent, safety unique to its system. These smart devices will be connected to the facility-rack MDM via the MCF local bus.

The software for overall experiment control and for safety maintenance will reside in the facility-rack MDM, which will monitor all such parameters. It will also send commands for specific actions to smart devices and will monitor these devices for proper operation.

Inhibits will activate or apply power to any device or system in the MCF. Relays located in the power distribution and control unit (PDCU) will provide these inhibits. The facility-rack MDM will be configured to allow direct computer control of these relays by means of a discrete output card rather than through the MCF local bus. The PDCU will also contain circuit protection and isolation hardware, as discussed in the section on electric power distribution.

In the event of an unsafe condition and/or hardware failure, facility-rack MDM software would direct the computer to shut down and "safe" the MCF in an orderly fashion. Two emergency situations that need to be addressed are (1) requirements to shut down and "safe" the MCF in the event of loss of power and (2) failure of the facility-rack MDM. For the latter case the DMS should detect the failure and remove power from the MCF.

Ideally, equipment in the MCF can be designed to fail-safe in the event of removal or loss of power; if it did fail-safe, no action would be required. If it did not, or if specific actions were necessary (i.e., dump waste products), circuitry and backup power that would be capable of sequencing through a series of operations would be needed.

Instrumentation data acquisition system.—The MCF will provide an in-place, user-friendly, easily accessible method of interfacing with many of the standard analog transducers that a user may require for an experiment. The size and configuration of this proposed system has been based on the experiment requirements determined in the MCF requirements-definition phase.

Assumptions and constraints: The instrumentation data acquisition system will utilize the MCF computer system together with a series of analog and digital I/O cards (previously described) as the basis of the data acquisition system. If an experiment requires any transducer beyond the MCF's support capability, the experiment will have to include experiment-specific signal conditioners. These must be compatible with the instrumentation data acquisition system.

System capabilities: All analog signals, including those derived from the experiment, the MCF, and the MCF support system, will be routed through the instrumentation data acquisition system to the MCF computer system and then to the Freedom DMS. Once in the DMS, user-selected data signals will be available for engineering unit display onboard at the ECWS, locally at the Facility, or on the ground after

being downlinked. The experiment-instrumentation interface will be located inside the containment enclosure. Connectors or other interfacing devices will be provided so that the user can terminate experiment transducers. The types of measurements that will be accommodated, at a minimum, will include the following:

- Thermocouples, including any National Institute of Standards and Technology calibrated type
- Resistance temperature devices (RTD's), including platinum ones
- Strain gage devices, including pressure transducers and flowmeters
- Frequency generating devices, including flowmeters and tachometers

In general, any transducer producing a voltage output compatible with the system voltage level will be usable with this system, as will transducers producing a digital, binary-coded-decimal, or binary output.

A software development system will be provided as part of this system. This ground-based service will allow a user to program input channel scan patterns, gains, and characteristics. Output displays, including channel selection and engineering unit determination, will also be supported.

Signal conditioning and data processing: Signal conditioning is considered to include all functions from the power source to the sensor and from the sensor output to the analog-to-digital (A/D) converter. Among these functions are isolation, excitation, amplification, reference junctions for thermocouples, bridge completion circuitry, frequency-to-analog conversion, grounding, and shielding. In addition, such data processing as linearization of thermocouple outputs or generating special algorithms that are accomplished through software can be considered signal conditioning.

Versatility will be required in order to accommodate many different kinds of sensors. Even so, there will probably be some cases where experiment-specific conditions require that the experimenter provide the necessary signal conditioning as a black box, input card, or software module. Some instruments require only a source of power and a compatible data bus for input/output. The only concerns of the MCF will be isolation and proper configurations of wire runs (grounding, shielding, impedance, cross-talk suppression, and mechanical considerations such as protection from stress and providing dependable connectors).

Thermocouples, if they are to meet tolerance requirements better than 5 K, require attention with respect to a reference junction and linearization of the output. The reference junction favored for this application is the isothermal reference unit (IRU), which is a passive device designed to maintain all junctions from alloy to copper at the same temperature while measuring this temperature with a highly accurate, stable sensor such as an RTD. The compensation can be accomplished digitally. An important advantage of the IRU is that it can be located close to the thermocouples; preferably it will constitute the first connector. Thereafter all wiring will

be copper, which eliminates long runs of alloy and alloy-connector parts. Also, only the designation of thermocouple type need be loaded into the computer.

For RTD's, including thermistors, the signal-conditioning requirement varies according to the way in which resistance is converted to an analog voltage. Bridge circuits are common items with respect to the bridge completion elements. Only the wiring is different from two-wire and three-wire circuits; this difference is easily accommodated on input cards. Four-wire circuits require a constant current source, which is available on I/O cards.

Instruments such as the gas chromatograph/mass spectrometer (GC/MS) provide the integrated hardware and software necessary to automatically identify a sample according to source and time, process the sample and the data, output a specified format, and calibrate the instrument. The computer function in such a case is assumed to belong with the unit, not with the MCF computer. On the other hand, the calculation of mass flow rate from orifice data is a routine computer function. In such cases, analog input cards will be available to accept the output from standard transducers and provide the necessary conditioning and analog-to-digital conversion to format the data for the system.

Calibration subsystem.—Calibration could be handled much as in a ground-based operation; that is, by returning instruments for recalibration and by maintaining a stock room for replacement of equipment that is suspect. If this practice were to be applied on the Freedom station, the impact on logistics would have to be considered, as would the need to work around the limitations imposed by the 90-day resupply cycle.

An alternative is to provide calibration service as part of the MCF. The logistics and storage burden would be reduced substantially—to maintaining a calibration standard only. Furthermore, the availability of calibration equipment would make feasible the use of instruments that have special advantages but limited stability.

Besides the considerations normally applied in the selection of instruments, the S.S. Freedom-USL module situation imposes some special constraints associated with the 90-day period of isolation. In addition, there are the well-recognized limitations on weight, size, power, and operator involvement inherent in the design and operation of manned spacecraft. And finally, all other considerations must yield to the paramount position of safety in the list of manned spacecraft design factors.

Assumptions and constraints: Calibration standards will meet stability requirements for a period of time long enough to fit into the 90-day resupply cycle. The onboard computer can handle the automation requirements.

Individual experiment modules can be designed to facilitate calibration of instrumentation without compromising the function of the module. Where the only means of calibration requires removal of the sensor, practical hardware designs and operating procedures can be worked out. Of course, if this is not possible, calibration on orbit cannot be accomplished.

However, if a suspect sensor can be replaced, then it can probably be calibrated.

Direct sensor calibration: Calibration of pressure, temperature, and flow sensors should be possible on orbit. State-of-the-art methods that perform continuous on-line multipoint calibration of pressure transducers are available, in particular those of the diffused junction strain-gage type. This system not only detects leaks but also includes all functions in the operate and calibrate package. This method requires the addition of tubing to bring the calibration pressure to the sensor and the electrical control wiring, neither of which occupies much space nor entails an installation problem—at least not in wind tunnels where it is commonly used.

The major problem in calibrating temperature sensors involves submitting the elements to an accurately known temperature. If the sensor can be removed and placed in a calibration device, the problem is largely a matter of how readily the sensor unit can be removed and replaced. When removal is not practical, as with attached thermocouples or rakes that are installed during assembly of the experiment module, the creation of a calibration environment becomes a challenge.

As with the calibration of temperature sensors, the calibration of flow sensors should be considered when designing the equipment. Facile removal and replacement of sensors should be ensured if there is no practical way to calibrate in situ or if a reference sensor must be installed. A means to introduce a reference flow should be incorporated, and computer-recognizable criteria for the attainment of steady state should be established.

Reference sample calibration: Calibration of the GC/MS or other substance detectors such as flue-gas analyzers, oxygen sensors, and toxic-species detectors will be accomplished by introducing reference samples into the analysis system. The GC/MS sampling system can routinely include the sampling of a small amount of reference mixture; concurrently, the transit time in the sampling system can be checked, and the sampling sequence can be indexed. For other detection devices, the reference sample can be introduced in the same way that the calibrating pressure is handled in the calibration of pressure sensors.

Electric power distribution.—The USL module will provide users with 120-V dc power at the bottom of each rack within the module. The function of the electrical power distribution system (EPDS) will be to distribute this power to the various loads in both the facility and experiment racks. This system must also provide circuit protection, monitoring, and voltage and frequency conversion for loads requiring other than 120 V dc.

Background: The known subassemblies that make up the MCF fall into two categories: (1) clearly defined functional boxes such as cameras, the gas mixing system, and laser assemblies; and (2) the more diffused functions such as solenoid valve assemblies and instrument transducers. For equipment that is designed specifically for S.S. Freedom use,

120 V dc will be specified as the operational input voltage requirement. For the diffused subsystems, the voltage of preference will be 28 V dc, because of the large selection of such flight-verified hardware available and design familiarity with this hardware. One or more 120-to-28-V dc-to-dc converters will be part of the EPDS.

All equipment located within the USL module must be able to withstand depressurization (nonoperating) and repressurization without presenting a reliability or safety hazard. Although this requirement does not preclude the use of commercial equipment, it does require that the design, testing, and verification of commercial equipment be rigorous enough to ensure meeting the requirement for vacuum condition survivability without rupture, leakage, or other degradation that could cause a hazardous condition to occur. Commercial designs and parts rarely are of the quality needed for off-the-shelf application to space environments. For these reasons, this conceptual design has assumed that commercial-grade parts and equipment will not be used; only Military Specification parts rated for operation in a space environment will be used. Since most electrical power consumed is ultimately converted into heat, close attention will have to be paid to the thermal control schemes employed to keep the facility and experiment racks within the cooling capacity limits available. Additional studies will be required to generate an integrated philosophy of power control, distribution, and thermal impacts. Such an approach will be necessary to achieve efficient packaging and operation of the facility and experiment racks. Some of the considerations of this evolving strategy are as follows:

(1) The use of any voltage other than the USL module-supplied 120 V dc will require the use of power converters within the MCF. Since power converters are typically only about 90-percent efficient, they are inherently wasteful of the limited power resource. Although power conversion is essential, multiple conversions are to be avoided.

(2) The collocation of power converters with high power users is required so that the converter-efficiency heat loss can be controlled by the same means that cools the device being powered.

(3) Power conversion for required dc logic levels should be done by small dc-to-dc converters located on or close to using boards. This will give better regulation, electromagnetic compatibility control, and isolation than will a larger unit serving many boards. Although some loss of volumetric or weight efficiency may be incurred in this approach, power levels should be small and electrical efficiencies high.

(4) Power conversion for such heavy motors as might drive a compressor will require soft-start and current-limiting circuitry to limit the stalled rotor current at startup. Tentatively, such motors are assumed to be 400-Hz, three-phase ac input, but tradeoff studies will be required for each application.

(5) Within the facility and experiment racks, power distribution and protection should take place at the 120-V dc level. Emergency backup power (for rendering an experiment fail-safe under power-loss conditions) and caution and warning power must be separate from the normal utility power source in order to meet program requirements.

Concern for the health and well being of the Freedom station crew affects the conceptual design in many ways. Numerous safety reviews will be required to prove the inherent safety of the MCF systems. Although safety guidelines are not yet available for the USL module, rules for the space transportation system (shuttle) can be assumed to be the level that is minimally acceptable. Two rules in particular must be considered even at this preliminary stage of electrical system design: (1) A loss of input power at any time shall not cause any hazardous condition to exist that would violate the basic safety requirements placed on the MCF or the experiment, and (2) a loss of cooling or heating at any time shall not cause any hazardous condition to exist that would violate the basic safety requirements placed on the MCF or the experiment.

These requirements are referred to as the fail-safe conditions, and for the operation of the MCF they must be considered fundamental to the design of hardware and software. Verification of these capabilities will be required by safety board review. From the electrical system viewpoint, the conceptual design assumes that the MCF can attain a fail-safe condition without the use of electrical power.

System design: Figures 14 and 15 show the block diagram of the Facility EPDS. The EPDS consists of wiring, cables, coaxial lines, connectors, disconnectors, dc-to-dc converters, circuit protective devices, switches, insulation protection, and power supplies. All electrical power distribution, signal routing, and electrical interface interconnections are provided by the EPDS. Since grounding-path and equipment-bonding resistance are also electrical parameters, these are also part of the electrical system, along with the shielding or filtering necessary to meet electromagnetic compatibility requirements. Experiment-specific hardware, such as igniters, sample positioners, fans, and lights, will use electrical power under the direction of the control system; therefore, these are not shown other than as power directed from the PDCU.

The PDCU provides the MCF with the capability to isolate itself from the Freedom station and to distribute electrical power within the racks. Each rack will contain a PDCU consisting of four components: power relays, manual circuit breakers, power instrumentation, and a bus interface. As shown in figure 16, 120-V dc power is brought into the PDCU through the Freedom station interface. The Freedom-supplied power is then branched into individual circuits, each consisting of a power relay, a manual circuit breaker, and required instrumentation. Power distribution is controlled via discrete outputs from the appropriate rack MDM to the associated power relay. The output of the power relay is fed through a

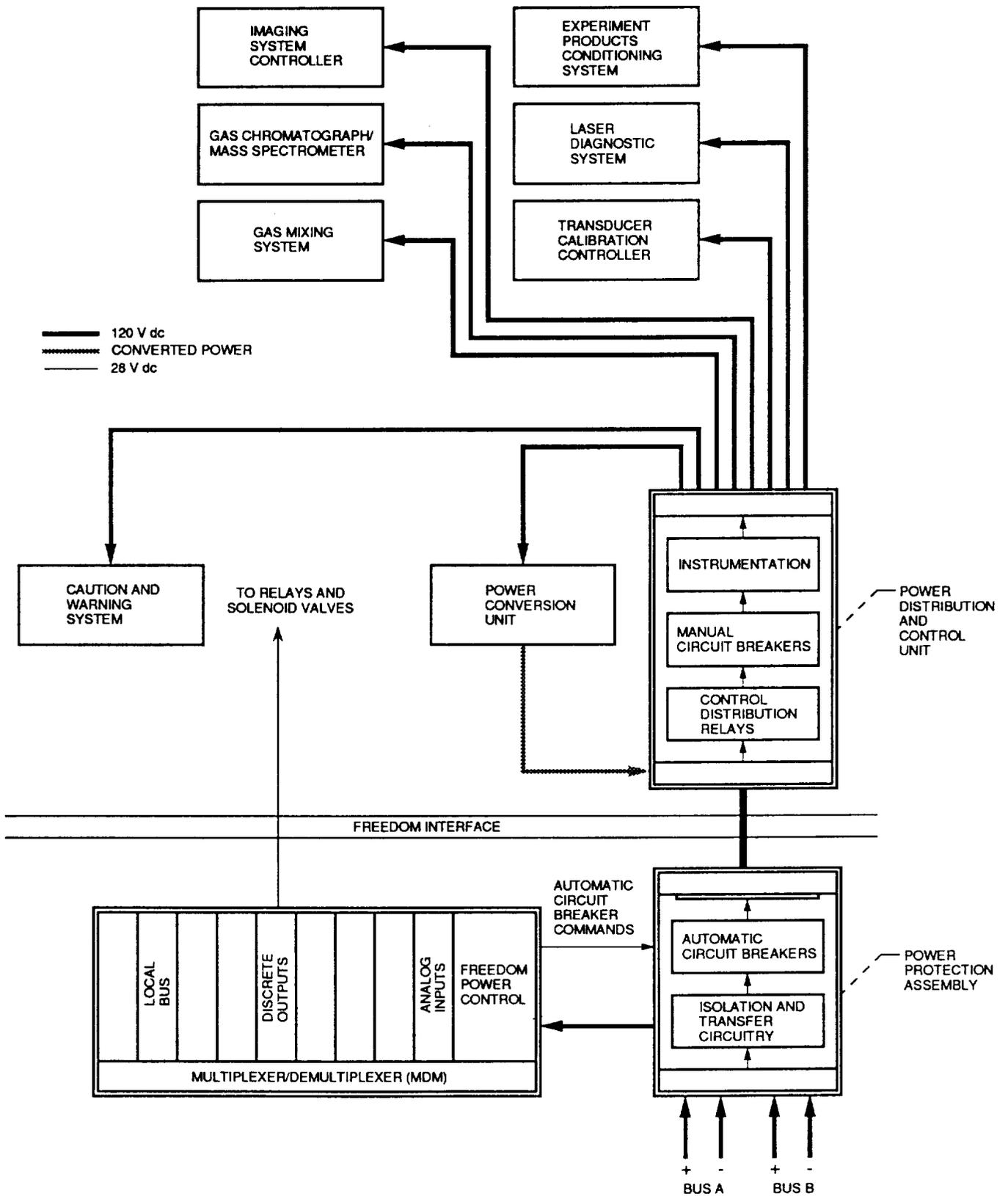


Figure 14.—Facility rack electrical power distribution system.

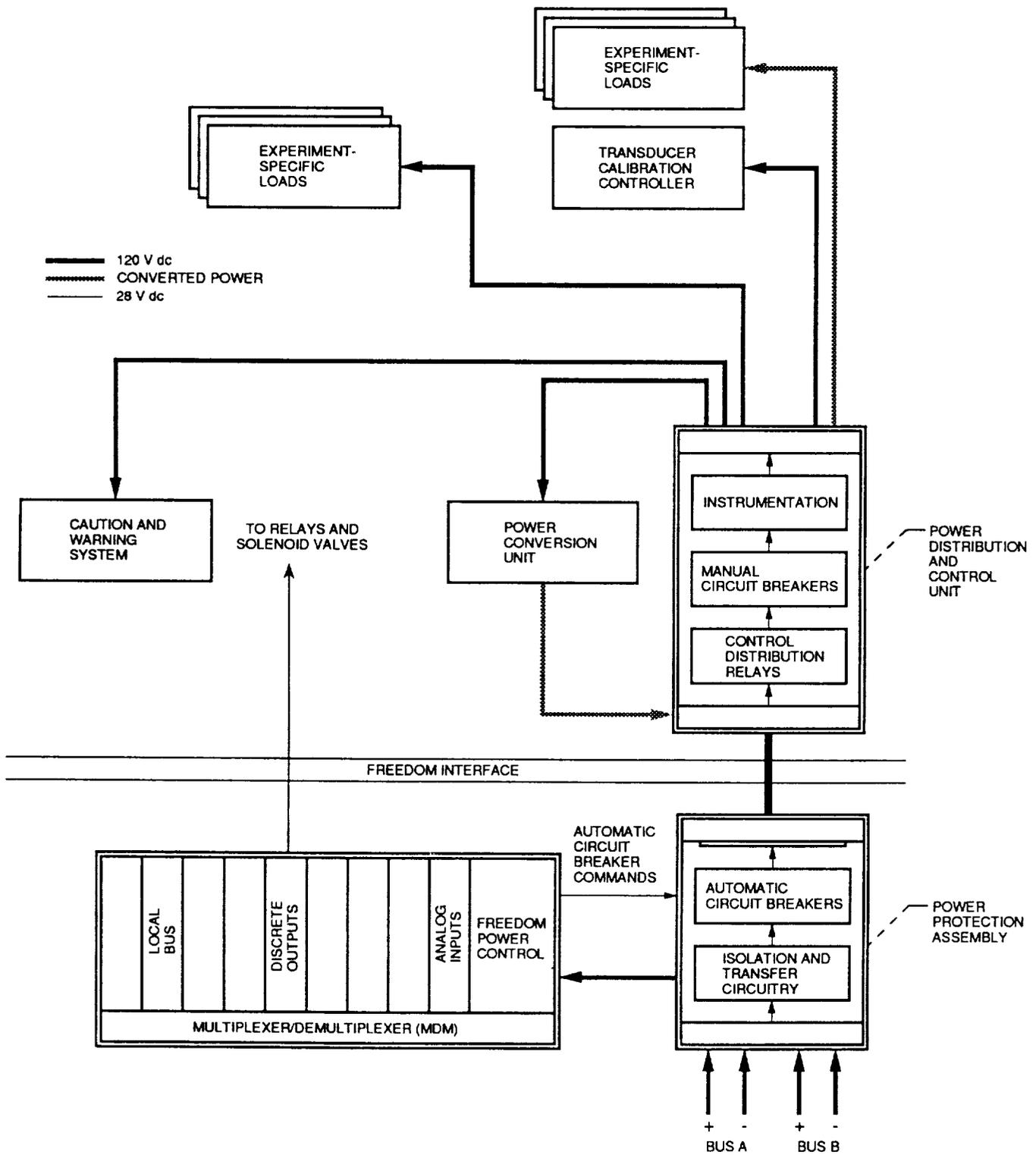


Figure 15.—Experiment rack electrical power distribution system.

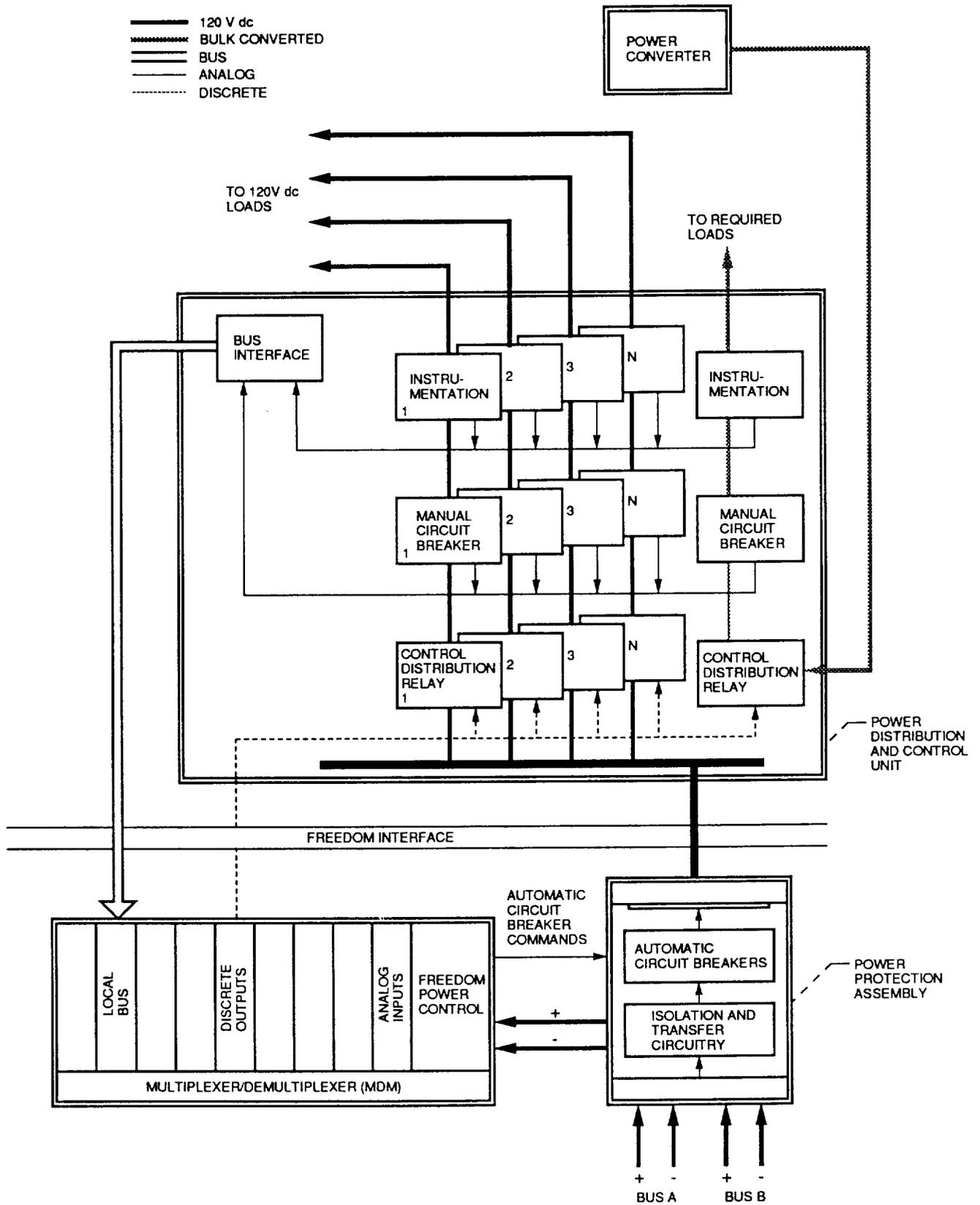


Figure 16.—Modular Combustion Facility electrical power distribution system.

manual circuit breaker, which is switched at the front panel of the rack. Tripping the circuit breaker provides a manual override of MDM commands, preventing inadvertent energizing of the circuit. During controlled sequences, the circuit breakers will be closed to provide overcurrent protection to the circuit. Each branch will also contain power instrumentation that is still to be determined. Instrumentation and breaker position information will be fed to the MDM through a local bus interface.

Facility capabilities: The EPDS will be designed to provide the power needed by the identified MCF support system equipment and by anticipated experiment-specific hardware equipment that was identified in the experimental-requirements database. Currently the facility rack is expected to require 6 kW of 120-V dc power, whereas the experiment rack will have 3 kW of 120-V dc power. Bulk dc-to-dc conversion of 120-V to 28-V will be provided through the Freedom station interface or by a power conversion unit within the racks. In either case, the 28-V dc power will be routed through the PDCU to the required loads. Other conversions, such as to 400 Hz, will be supplied as required. Elements that are peculiar to a facility or experiment designed for multiuser combustion experiments include the following items, which were found to be common to many of the experiments reviewed during the definition study phase:

(1) *Heaters.* Electrical heaters used will be of two general types: open-loop controlled heaters, wherein power is applied and heat is produced until the power is removed; and closed-loop controlled heaters, wherein the heater is controlled by some means of feedback such as a thermostat, thermal switch, proportional controller, or computer software. The direct use of the USL module-supplied 120 V dc will be the preferred voltage for heater loads. A special case of heater control might be one in which the thermal output of a heater is a parameter of an experiment. In such a case, the power would require a closely regulated voltage source; this would preclude running these heaters directly on the program-supplied power source. The experiment-specific heater power control would reside in the experiment rack.

(2) *Illumination.* Illumination within the experiment test chamber will be required during the setup and removal phases in most combustion experiments. Aircraft-type 28-V, 20-W minifloodlamps have been used successfully for this purpose and are proposed for this application. Illumination is generally not needed during the test phase since the combustion process itself provides adequate illumination in most cases.

(3) *Solenoid valves.* Solenoid-operated valves will be the nonlatching type and will require coil-excitation power continuously during operation. The preferred operating voltage for solenoid valves will be 28 V dc.

(4) *Lasers.* The use of lasers in this Facility, especially a master laser light source for use by a laser diagnostic system, is discussed in the section Special Instrumentation—Optical Diagnostic Systems. Future advancements in laser technology will determine the power required by such a laser light source.

At this point in the MCF conceptual design, the study team is taking a worst-case approach and allocating 1 kW of 120-V dc power for this purpose. Future developments in pumped solid-state lasers are expected to reduce this power requirement by 50 percent or more.

(5) *Motors.* Motors rated at 1/16 hp or less will be powered by 28 V dc. Because of the capacitive energy storage in the dc supply, no special startup circuitry will be required. Such motors will be sealed and will be operated with an intermittent duty factor of less than 10 percent. Heat produced by these small motors will be conducted away by their mechanical mounting and, ultimately, by the avionics air cooling. Motors with ratings greater than 1/16 hp must be evaluated to determine the proper supply voltage and frequency for the intended purpose. Compressors and other heavy motor-starting loads will probably be run on 400 Hz and, thus, will require a power converter to convert from 120 V dc. Such a converter will also include a special motor-starting circuit in order to stay within the Freedom station load-limit requirements. The larger motors and small, continuous-duty motors will probably have to be dc-brushless or 400-Hz polyphase types. These may require active cooling to keep within the avionics air cooling capacity for the Facility.

(6) *Igniters.* Igniters are classified as two general types: contact igniters and spark igniters. A contact igniter is an electrically heated wire that ignites a flammable test specimen by contact. A spark igniter is a device that creates an electrical arc of sufficient energy and duration to cause ignition of a flammable gas or vapor. For conceptual design purposes, contact igniters are assumed to be essentially the same as open-loop controlled heaters, but they are switched off after some set operating time or when some other means has detected ignition. Spark igniters are experiment-peculiar and require knowledge of the energy needed and the duration of the ignition cycle. A capacitive discharge spark system has been assumed, with a 28-V dc power supply requirement. Both types of igniters draw considerable power, but only for a short part of the test run. Because spark discharge systems generate a broad spectrum of electromagnetic interference, special care must be taken in their design and shielding.

(7) *Computer.* The computer that the MCF will use for data acquisition and control will have the same hardware as that being designed and built for the Freedom data management system. This hardware is expected to be specified to operate on 120 V dc and provide the necessary power conversion to operate its analog and discrete I/O cards.

Mechanical Fluid Systems

The MCF mechanical fluid system consists of five subsystems: gas mixing, fluid supply, experiment exhaust processing, enclosure pressure control, and facility thermal control. The need for these five basic mechanical subsystems was determined in the MCF definition study on the basis of experiment requirements in the reference experiment set. The block diagram in figure 17 indicates how these MCF

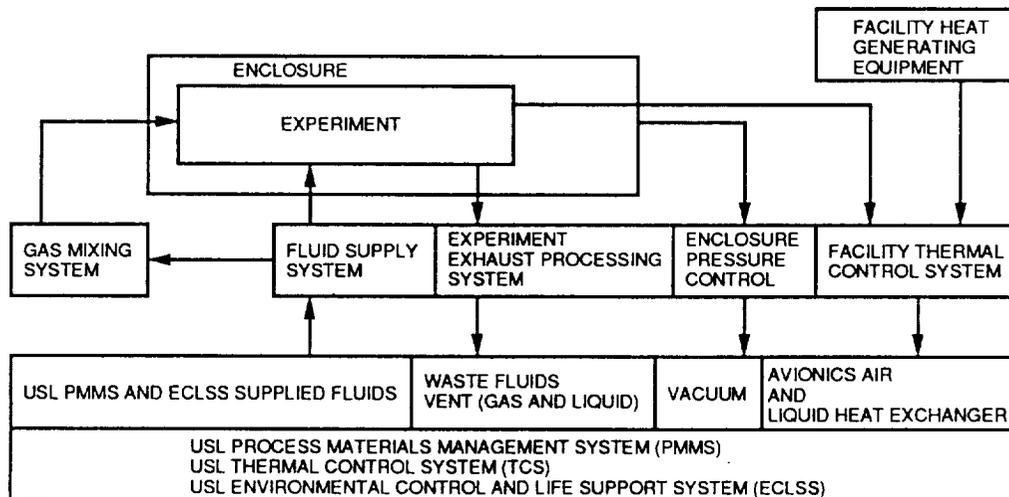


Figure 17.—Facility mechanical fluid system.

subsystems interconnect with the experiment on one end and with three USL module systems on the other end. These three USL module systems are the process materials management system (PMMS), the thermal control system (TCS), and the environmental control and life-support system (ECLSS).

The PMMS, which is a system of critical importance to combustion research on S.S. Freedom, is a very complex system that is currently going through some redefinition by the Freedom station designers. The system, as currently configured, consists of eight subsystems, which will not be listed here so as to avoid confusion. Of these eight, the most important to the MCF is the waste fluid management system. This system will provide disposition and storage of solid, liquid, and gaseous wastes produced by the USL module users.

The PMMS will also plumb or bottle-supply the fluid supply system. The fluid supply system consists of valve modules, bottle storage, and a distribution system that will provide gases to the gas mixing system or directly to an experiment. The gas mixing system will offer various mixtures of the five gases to be supplied by the MCF fluid supply system. Alternatively, an experimenter can substitute bottled gases different from those provided. Fuels will be stored and supplied by containers located within the facility containment enclosure. Gaseous hydrogen is the only fuel that is supplied by the present PMMS configuration. Combustion products, raw fuel mixtures, waste products, and gases will be conditioned by the facility experiment exhaust processing system before they are passed on to the PMMS waste fluid management system.

The containment enclosure pressure control system will maintain the pressure inside the enclosure at a level slightly below the USL module cabin pressure. This will be done to prevent leakage of gases from the experiment and the containment enclosure into the USL module. In an abnormal condition, any gases that might escape from an experiment into the containment enclosure will be vented from the experiment module into the PMMS waste gas vent. This system will provide one of the three required levels of

containment mandated by the S.S. Freedom program safety requirements.

Heat energy generated by the MCF and the experiment will be removed from the two MCF racks by liquid-to-liquid heat exchangers, cold plates, or avionics air cooling. Heat exchanger cooling is the preferred method since cooling air is a limited resource. The MCF thermal control system will control fluids on the Facility side of heat exchangers, whereas the USL module TCS will control the other side. Air cooling loads will be directly supplied to the USL module ECLSS.

Gas mixing system.—The definition-requirements-phase results indicated that each experiment will require various mixtures of oxygen with other gases for an atmosphere in the combustion chamber or flow tunnel. An MCF gas mixing system would provide space- and weight-reduction advantages over experimenter-provided individual bottles for each mixture required. One of the main advantages of a gas mixing system would be the capability to perform more tests during a 90-day period. In a trade study to select a method of mixing gases to produce atmospheres in a combustion chamber or flow tunnel, five methods were evaluated, and one conceptual design was selected. Currently a breadboard design is being developed to verify the conceptual design's functionality.

Assumptions and constraints: As mentioned previously, gas mixtures will be created from plumbed gases (O_2 , N_2 , and Ar) and bottled gases (CO_2 and He) available from the PMMS. Bottles of CO_2 and He will be installed in the facility rack as required by the experimenter. Other gases can be substituted for the bottled gases; however, those substitute gases must be provided by the experimenter. Gaseous fuel will not be mixed with the other gases in the gas mixing system. Gas mixtures at chamber pressures greater than 3 atm must be supplied by the experimenter. Temperature conditioning of the gas mixtures will be provided by the combustion chamber or tunnel.

Design: In the selected conceptual design the gas mixing system resides in the facility rack, as shown in figure 18, where

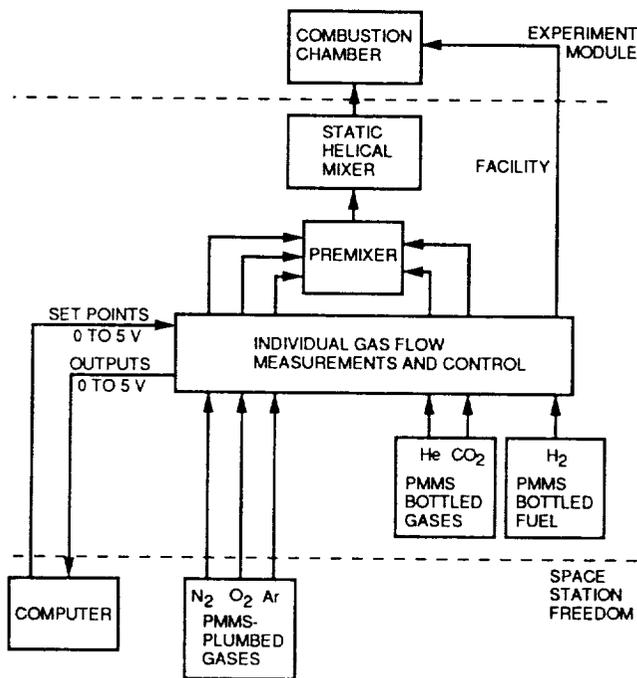


Figure 18.—Gas mixing system block diagram.

PMMS-supplied gases are mixed and introduced into the combustion chamber or tunnel. The bottled gases are regulated to the same pressure as the plumbed gases. Each individual gas is metered and controlled by a mass flow controller (see block diagram in fig. 19). Gases are combined first in the mixing chamber and then more thoroughly by a static helical mixer enroute to the combustion chamber. See figure 20 for the proposed flow schematic. Design parameters for the gas mixing system are given in table I.

The thermal mass flow controllers are the heart of the gas mixing system. The mass flow controllers were developed for the computer chip industry. This industry's demanding market ensures continual development of mass flow controller technology as well as compatible replacements controllers, should any technological breakthroughs occur. The mass flow

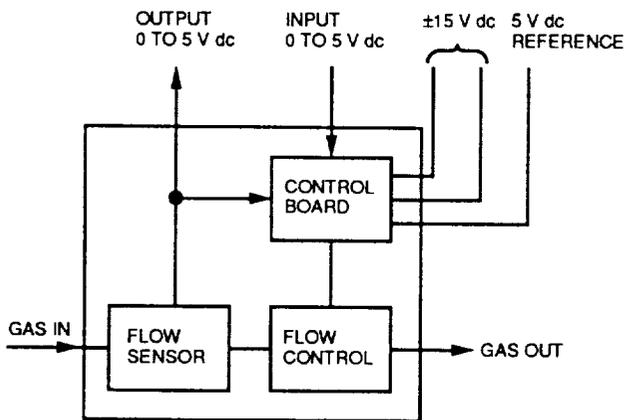


Figure 19.—Gas flow measurement and control for gas mixing system.

TABLE I.—MIXING SYSTEM DESIGN PARAMETERS

Inlet gas	
Pressure, psia (kPa)	80 (551)
Temperature, °C	23 (amb.)
Outlet gas	
Pressure, psia (kPa)	45 (310)
Temperature, °C	23 (amb.)
Maximum O ₂ flow, SCFM (SLPM)	0.71 (20)
Mass flow control range	50:1
Maximum chamber volume, ft ³ (m ³)	4.36 (0.124)
Maximum tunnel volume, ft ³ (m ³)	8.3 (0.23)
Accuracy, percent full scale	0.5
Repeatability, percent	0.05
Maximum number of gases	5
Power required, W	19
Estimated weight, lbs (kg)	50 (9.07)

controller receives a setpoint signal, compares the signal with an output signal from the mass flowmeter, and directs the control valve to adjust the flow. Generally, a single gas is selected as master, and other gases are slaves. This allows the operator to select a flow rate for the master and give the flow rate of other gases as a percentage of the master's flow rate. Procedures for purging, startup, and shutdown of flows will be developed with the breadboard model. Purging will be accomplished with the PMMS waste gas vent.

Facility fluid supply system.—The inlet gases to the MCF fluid supply system are provided by either the PMMS plumbed or bottle supply (see figs. 17 and 20). The MCF fluid supply system distributes these gases either to the gas mixing system or directly to the chamber or tunnel.

Assumptions and Constraints: The gases made available to the MCF fluid supply system are plumbed O₂, N₂, and Ar and bottled He and CO₂. Nitrogen and water will be supplied from the experiment rack as fluids that have been stored in bottles within the containment enclosure. Other gases may be substituted for one of the bottled gases, as required by the experiment. Conditioning of the gases will be performed by the experiment, not by the MCF.

Design: A valve module and check valves isolate the PMMS-supplied gases from the interface and experiment. Design parameters for the MCF fluid supply systems are given in table II.

Experiment exhaust processing system.—Exhaust products from the experiment will require conditioning before they enter the PMMS waste management system. Although trade study results were inconclusive in selecting a specific design concept, additional information on the capabilities of the PMMS waste system has been obtained from a USL Module Workshop held at Marshall Space Flight Center in August 1988. One approach, among many, to conditioning the effluents to meet the requirements listed in table III would be to utilize a technology known as the reactive bed plasma (RBP) system. The RBP system would condition exhaust gases from

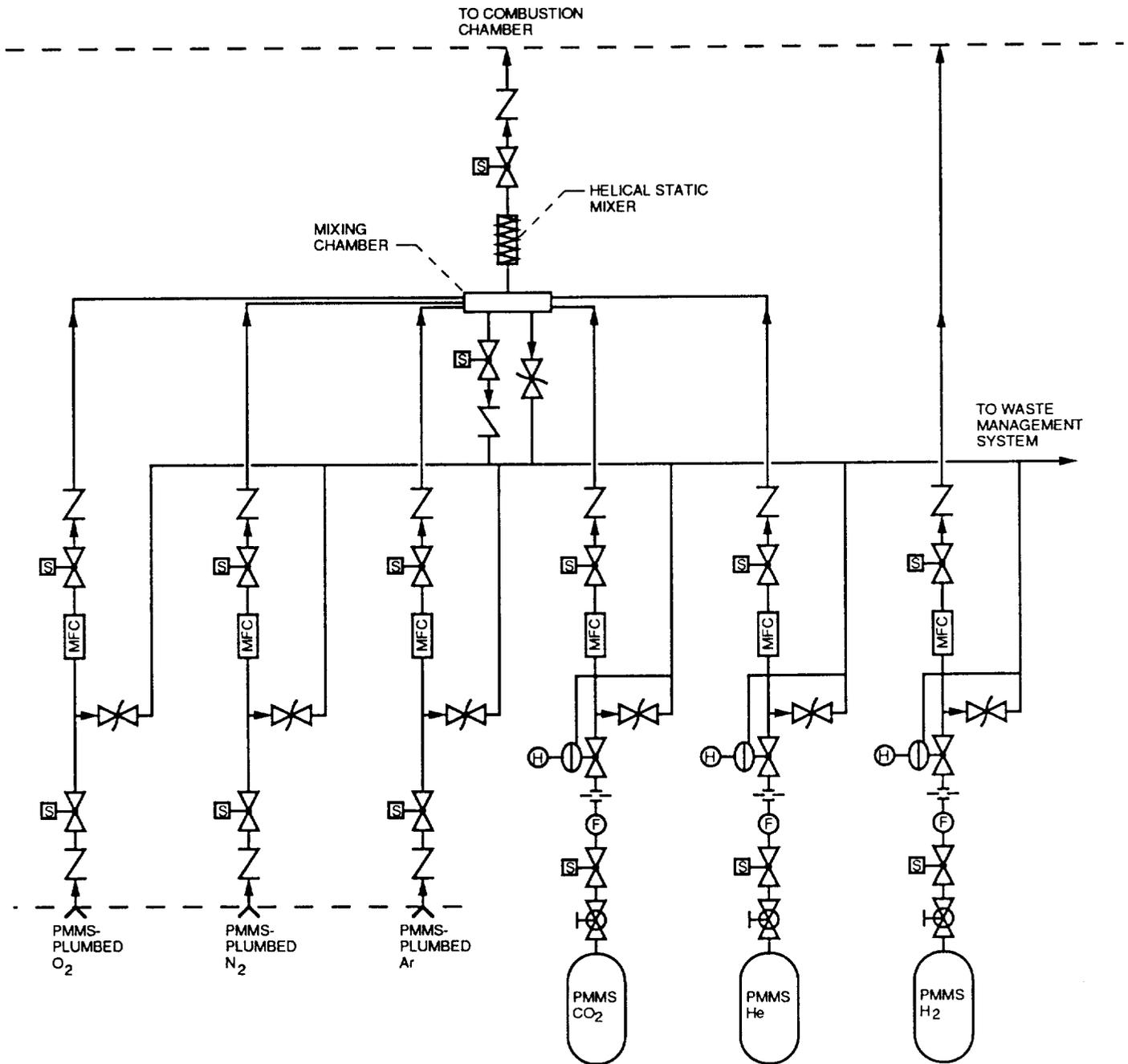


Figure 20.—Proposed flow for gas mixing system.

successful combustion experiments and would provide some safety protection if the gases in the chamber should fail to ignite.

Description of the reaction bed plasma system functions: The RBP is a synergistic combination of a plasma (or ionized gas) and catalytic technologies to produce clean air. The RBP does not suffer from the characteristic poisoning problems found with thermal catalytic oxidation systems. Moreover, it efficiently decomposes toxic chemicals and processes hazardous aerosols at temperatures around 100 °C. Hence, with a minimum amount of cooling, the relatively low-

temperature processing by the RBP is compatible with the temperature limitations for exhausting into the PMMS waste system. The decomposition products of some materials may require additional treatment in a posttreatment module that contains an in situ regenerable modular bed; however the RBP system can process exhaust gases to meet the PMMS waste system requirements for the MCF.

Assumptions and constraints: The following assumptions apply to the design of the experiment exhaust processing system:

- (1) The combustion chamber or tunnel will hold the fluids

TABLE II.—FLUID SUPPLY SYSTEM DESIGN PARAMETERS

Inlet gas	
Temperature, °C	23 (amb.)
Pressure, psia (kPa)	80 (551)
Outlet gas temperature, °C	23 (amb.)
Maximum airflow, SCFM (SLPM)	2.3 (65)
Maximum chamber volume, ft ³ (m ³)	4.36 (0.124)
Maximum tunnel volume, ft ³ (m ³)	8.3 (0.23)
Maximum number of gases (Facility)	5
Experiment-rack-supplied fluids	H ₂ O, H ₂
Tubing size	
Inlet, in. (cm)	0.375 (0.95)
Outlet, in. (cm)	0.25 (0.64)
Valve	
Power, W/valve	28
Direct current (supply), V	24
Weight, lbs estimated (kg)	1.5 (0.68)
Size (supply), in. (cm)	0.25 (0.64)

TABLE III.—CONSTRAINTS ON FLUIDS ENTERING THE PMMS WASTE SYSTEM

Temperature range, °F (°C)	-200 to 212 (-129 to 100)
Maximum pressure, psia (kPa)	80 (551)
pH	1.5 to 6.5
Liquid volume (condensed at STP), liters	< 0.3
Particulates	
size, μm	< 300
density, gr/ft ³	< 10
Maximum flow rate	
at 4000 to 10 torr, liters/min	225
at 10 to 10 ⁻³ torr, liters/min	200
Combustibles mixtures	outside flammable range

to be vented until the PMMS waste system is available for accepting experiment byproducts.

(2) The exhaust products vented through a combination of the five elements can meet the requirements of the PMMS.

(3) Large amounts of liquids will be separated from the gases to be vented to the PMMS waste system.

(4) The exhaust processing system will be used for vacuum purging the combustion chamber or tunnel.

Design: The RBP waste conditioning system will consist of a combination of five basic elements shown in the block diagram in figure 21. Each element, which will be modular, will be tailored to meet the requirements of many experiments. Materials that are expected to be exhausted from the experiments include aliphatic, aromatic, and halogenated hydrocarbons, carbon (soot), and other gases. Conceivably, liquids could condense and require separation before exiting to the PMMS waste system.

Constraints on fluids entering the PMMS waste systems appear in table III. The following chemicals are restricted from entering it:

Aqua regia	Hydrogen peroxide, 30 percent
Mercury chloride	Mercury
Nitric acid 50 percent	Potassium chlorate
Nitric acid, anhydrous	Potassium hydroxide
Oleum	Sodium chlorate
Chlorine trifluoride	Sodium nitrate
Oxygen difluoride	Sulfuric acid, 75 to 100 percent

Containment enclosure pressure control system.—The pressure control system provides one of the three levels of containment (required per NASA Handbook 1700.7b) for toxic combustion fluids by maintaining the containment enclosure pressure below that of the USL module. This imbalance causes any inadvertent leakage from the experiment to be vented to the PMMS waste gas vent system instead of to the USL module

atmosphere. The atmosphere within the enclosure will be nitrogen-rich to prevent possible combustion.

Assumptions and constraints: Test operations will not be permitted unless the containment enclosure pressure is below the pressure of the USL module. Test operations will be restricted when the PMMS waste gas vent system is not available for accepting fluids (gases).

Design: The proposed design of the pressure control system, as shown in figure 22, consists of a nitrogen shutoff valve, a vent valve, and the MCF computer system. Gases from the containment enclosure are vented to the PMMS waste gas vent system via the MCF vent valve. Out-of-tolerance conditions will be monitored by the MCF computer system. Two relief valves and a normally open solenoid valve protect the enclosure from positive or negative overpressures. These devices also provide redundancy to the control system. The aforementioned valves are not shown in figure 22, but they are depicted schematically in figure 2.

Facility thermal cooling system.—The MCF thermal control system (TCS) consists of three methods of rejecting heat from the racks. One method uses the avionics air system to reject heat from the electronic packages, as shown in figure 23. A

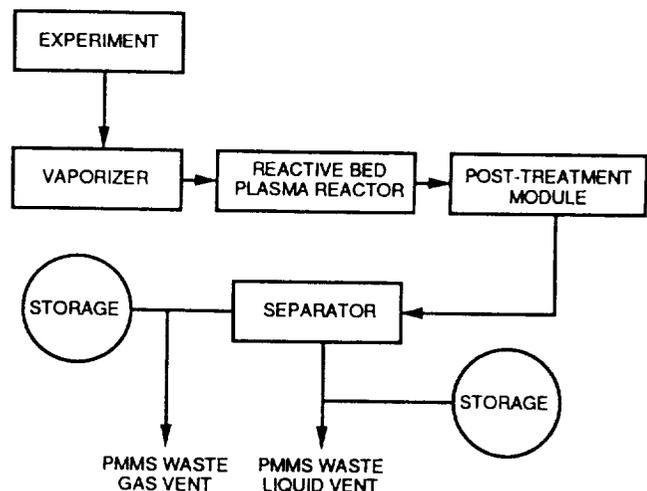


Figure 21—Facility experiment exhaust processing system.

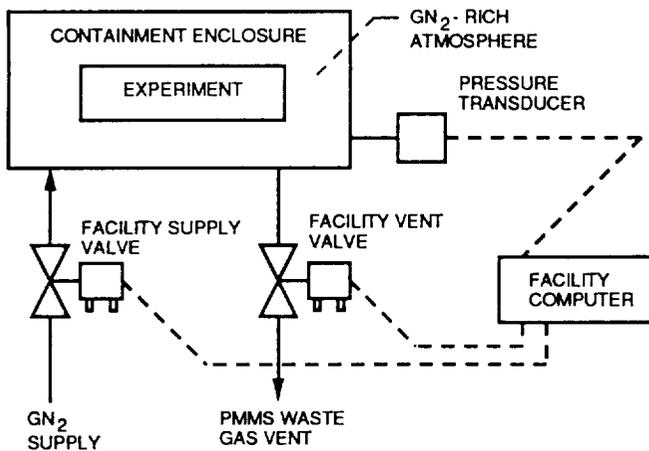


Figure 22.—Containment enclosure pressure control system.

second method uses liquid-to-liquid heat exchangers (see fig. 24), and the third method uses cold plates to conduct heat from the source directly to the USL module's TCS. The MCF has no direct control over the avionics air or the flow through the cold plates. Control of the avionics system is maintained by the ECLSS of S.S. Freedom; control of the cold plate coolant is maintained by Freedom's TCS.

Assumptions and constraints: The following assumptions and constraints apply to the design of the Facility TCS:

(1) The MCF will be allowed to reject 30 kW (15 kW/rack) of heat to the Freedom station. The heat exchangers and cold plates used by the MCF for rejecting heat to the TCS will be designed and furnished by the TCS of the USL module. The largest heat load to the TCS will come from the facility rack.

(2) The individual heat load from each MCF experiment will not exceed the 15-kW requirement.

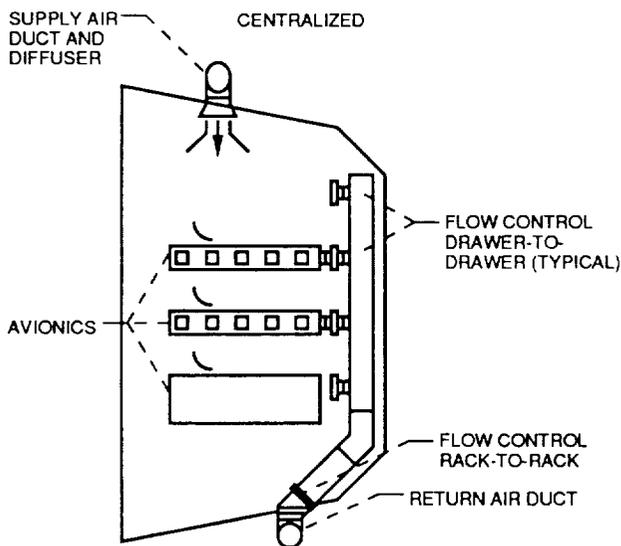


Figure 23.—Avionics cooling concept.

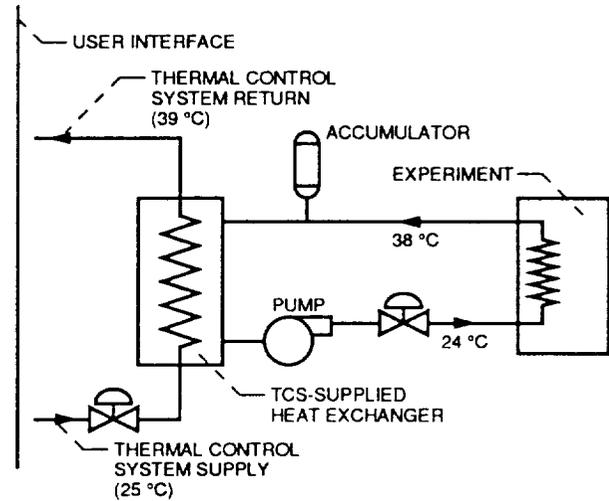


Figure 24.—Liquid-to-liquid heat exchanger.

(3) Two low-temperature coolants that will be available from the TCS are at 4 and 21 °C. Maximum return temperature to the heat exchangers will be 49 °C.

Design: Two liquid-to-liquid heat exchangers are used in the MCF, one to reject heat from the equipment housed in the facility rack, and one for the heat loads in the experiment rack (see fig. 24 and the schematic shown in fig. 2). Control of the flow on the Facility side of the heat exchanger allows temperature control on the user side of the interface. Cold plates are used in the facility rack but not in the experiment rack because a need was not identified for them. Design parameters for the TCS are given in table IV.

Vacuum system.—One of the eight subsystems of the PMMS is the vacuum system. This system, designed to provide a vacuum source to the user, will not support flow rates larger than 0.01 scc/sec. The mechanical fluids system was designed to use this system as a vent for emergency use only. With this system the Facility relief valves and the normally open solenoid valve will vent out-of-tolerance gases. Figure 2 shows these devices schematically. The vacuum system will probably not be used routinely during MCF testing; however, for safety reasons a vent must be made available during all phases of operations of the MCF. For this reason the vacuum system will be used by the MCF only for abnormal conditions such as overpressures.

Imaging Systems

Background.—The objective of using an imaging system in the MCF is to allow experimenters to learn as much as possible about the science being performed. Toward this end, knowledge of the user's scientific requirements and MCF engineering requirements is necessary. Ideally, careful selection from available and proposed imaging systems and the use of telescience will provide the experimenter a means to extract useful visual information and to better understand the science.

TABLE IV.—MODULAR COMBUSTION FACILITY TCS DESIGN PARAMETERS

Maximum heat load, kW	
MCF	30
Rack	15
Heat exchangers	
Maximum heat input, kW	
From MCF	16
Per unit	8
Design flow through, kg/hr	499
PMMS temperature, °C	
Inlet	24
Outlet	38
User temperature, °C	
Inlet	39
Outlet	25
Size (h by w by d), mm	457 by 203 by 102
Cold plates (3)	
Design heat load, W (nominal)	1000, 600, 400
Flow, kg/hr	454
Maximum heat flux, W/cm ²	1
Sizes, mm	513 by 769
	513 by 385
	513 by 308
Avionics cooling, W/rack (nominal)	1500

Assumptions and constraints.—The operation of the imaging systems will depend on careful planning and scheduling of the available S.S. Freedom resources, including electric power, data transfer, and crew time. Crew members are expected to be available to change modular camera heads and to load and unload film and imaging cassettes. However, automation and control of experiments from the ECWS or from the ground with telescience will minimize the use of crew members. The imaging system control panel, located in the facility rack, will also provide some control.

A study sponsored by the Intercenter Systems Engineering Team will identify three or four cameras that satisfy imaging requirements common to all six Code EN facilities on the S.S. Freedom. The MCF will use the chosen cameras when possible. However, combustion experiments require unique imaging capabilities that press the limits of existing technology. The question of which specific camera (film, standard video, or nonstandard video) and associated optics will satisfy the science requirements remains an open issue.

Many operating and control functions are common to imaging systems. A proposal has been made that the MCF provide the common supporting controls and electronics, including the storage and transmission of video information. These functions will also interface with the Freedom station bulk storage and processing for workstations and telemetry. Figure 25 categorizes some of the possible imaging systems that an experimenter may want to consider when defining the imaging requirements of an experiment.

The high-rate data link, which has a data rate of 100 Mb/sec, is expected to be available to the imaging system. At best,

only 75 to 100 Mb/sec of the Tracking and Data Relay Satellite System capability will actually be available for real-time (or near real-time) downlinking of all science data. The Freedom program is expected to provide adequate data storage and data transmission for the MCF. Based on microgravity user requirements, requests have been made to handle 1 TB of storage and a 1-Gb/sec data rate.

Note that the onboard video system provided by the Freedom program is standard National Television Standards code (NTSC) video. Many of the combustion experimenters desire instrumentation imaging (nonstandard video) systems such as the high-resolution, high-frame-rate video technology (HHVT) system, which is currently under development at the Lewis Research Center. Higher resolution, higher frame rate, subframing and tracking, and pretriggered imaging would offer distinct advantages over standard NTSC video for better understanding the science. Also, as envisioned by the concept of telescience, HHVT could provide near real-time monitoring and interactive control by the experimenter. Film cameras can provide high resolution and high frame rates, but significant amounts of film may be required and up to 90 days could pass before the film could be returned to Earth for processing and analysis. Also, as currently used, film lacks the sensitivity and resolution for many low intensity flames in microgravity. Table V shows a comparison of the imaging performance and the imaging logistics characteristics to be considered when choosing a system.

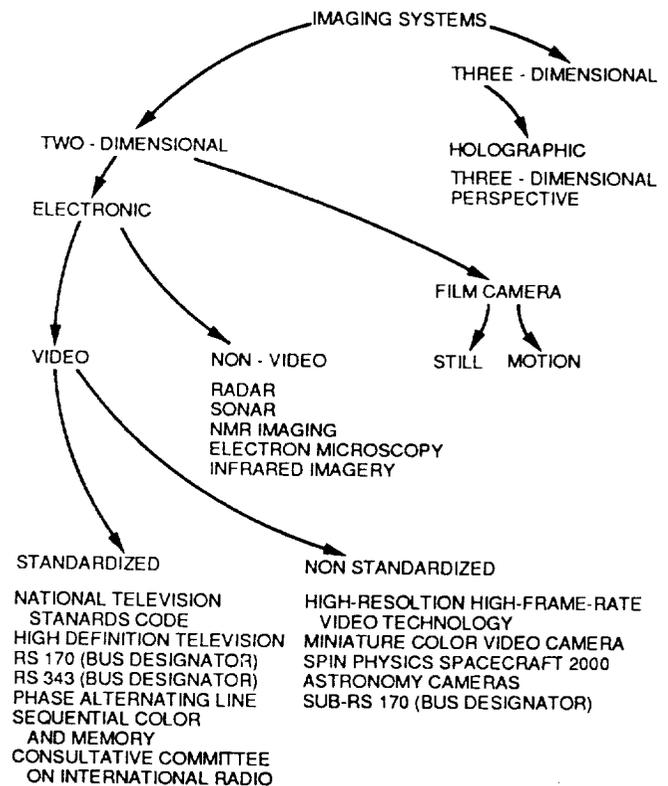


Figure 25.—Categorization of imaging systems.

Imaging subsystem control panel.—For specific experiment functions, the MCF will provide local control of imaging equipment. These control functions will be specific to an individual imager. In addition, the Facility will contain a local video monitor. The monitor signal will come from the standard video or image processing system. Hardware for digital image processing, storage, and telemetry will reside in another location within the laboratory. The Facility will communicate with this remote equipment across the Freedom station high-data-rate bus. At a minimum, the control panel will have a video monitor and will provide manual control of

the imaging system. One of the main purposes of the video monitor and control panel will be to monitor the experiment process in the MCF. More advanced possibilities for this panel could include a keyboard input to enable control of all aspects of the imaging system operation.

The control panel, which resides in the facility rack, will communicate with cameras, which reside in the experiment rack, by the MCF local bus. The control panel will also provide status words to the facility rack MDM, which will also store and provide configuration information. Built-in self-testing and self-calibration of the panel will be activated on

TABLE V.—COMPARISON OF IMAGING PERFORMANCE AND LOGISTICS CHARACTERISTICS

Advantages	Disadvantages
Imaging performance	
<ul style="list-style-type: none"> • Excellent resolution • Excellent frame rate • Variable sensitivity • Good storage capacity • Image enhancement • Variable sensitivity <ul style="list-style-type: none"> — Absolute — Gray scale • Variable frame rate • Variable resolution • Image enhancement • Excellent storage capacity • Image enhancement • Flexible frame sizes and frame rate <ul style="list-style-type: none"> — Efficient use of memory capacity — System adapts to each experiment requirement — Pretriggering capability for high-frame-rate/long duration applications — Can image/trace an area of interest within the total field of view 	<ul style="list-style-type: none"> • Constant sensitivity • Low storage capacity, bulky • Must anticipate events for high-frame-rate applications • Limited frame rate • Limited resolution • All images captured at same frame rate and resolution <ul style="list-style-type: none"> — Inefficient use of memory capacity • Cannot achieve simultaneous high frame rate and high resolution, unless subframing is employed
Imaging logistics	
<ul style="list-style-type: none"> • Many 16-mm/35-mm flight-qualified cameras exist • Low power required • Requires minimal astronaut support • Real/near-real-time downlink, immediate analysis of data • On board viewing/data manipulation capability • Ease of capturing additional experiment runs • Good telescience capabilities • More efficient use of S.S. Freedom experiment facilities 	<ul style="list-style-type: none"> • Requires astronaut support between experiment runs • Film must be physically transported to PI from S.S. Freedom • Up to 90-day delay in data analysis • No onboard viewing of images • One-shot media, more film required for additional experiment runs • Minimal telescience capabilities • Requires a video process unit to achieve telescience • A complete video system requires significant power, space, and weight allowance

power-up and on software request from the facility rack MDM. The panel will allow control of functions that are specific to either a video or film camera and to those that are common to both. Common functions include camera placement, camera operation, mirror placement, and subsystem features.

Although movement of cameras during experiments is unlikely, the control panel can provide an effective way to align the cameras during setup. When the cameras are enclosed in the experiment rack, the crew can position cameras via remotely controlled pan- and tilt-platforms, which will be an integral part of the camera mount.

Video- and film-camera operation possess some common features. The control panel will allow setting zoom, iris, and frame-rate as well as power and recording start and stop functions. White-balance, back-focus, and targeting will also be controllable; these functions may be part of the self-testing and self-calibration for cameras. All of these functions will be controlled through the facility-rack MDM to permit automatic variations of camera parameters as an experiment progresses.

Often, experimenters use mirrors to provide multiple views of a combustion experiment. This need has been anticipated, and a remotely controlled method of placing and maintaining the position of the mirrors has been included in the control panel design concept. This operation will be similar to the camera mount control.

In anticipation of a common set of imaging devices and an automated operating mode, the panel will provide a means of configuring the imaging subsystem. One can choose a recording mode to dynamic RAM, video cassette, or no-recording. Also, the panel can be programmed to specify which video signals will be downlinked. A means to configure data annotation for both recording and downlinking can be included. For film cameras, a very practical device would be an indicator of the amount of remaining film. A switch will select which video source appears on the control panel screen. A hardware enable/reset switch will be able to lock out the video section when it is not in use. Power to the control panel will come from the facility rack power distribution; the cameras or imaging devices will receive power from the experiment rack power distribution.

The imaging systems will be controlled and configured in one of three modes: telescience, workstation, or local (the control panel already discussed). In the telescience mode, the imaging system will be controlled by a ground-based experimenter. Commands issued from the ground will be displayed for the crew on the ECWS video screen. The crew will have an option to override the system manually if needed. In the workstation mode a crew member has access to the imaging system through the ECWS. For this mode, communication with the imaging subsystem controller is through the facility-rack MDM. Configuration settings would be made from the ECWS, yet control and communication could come from both the ground-based experimenter and the crew member working as a team. Finally, control of the

imaging system could reside at the local control panel, which contains the controls that manipulate the equipment inside the experiment rack.

The imaging subsystem controller will address the peculiar features of a variety of imaging devices and cameras. It will also link with other systems through the facility-rack MDM to facilitate automation and remote (telescience) control of the system. The imaging subsystem controller also will provide a convenient and common interface for the Freedom station crew members to prepare, run, and monitor combustion experiments.

Because of significant power, weight, and volume requirements of the HHVT system, the main image-processing hardware will be located outside the MCF. Only the camera heads will be located within the experiment rack; camera control will be in the facility rack.

Imaging system capability.—If the MCF were to provide the imaging system, a three-tier system being considered might be adopted (see figs. 26 and 27). The characteristics of each imaging system are defined as follows:

- (1) High-resolution, high-frame-rate video technology (HHVT)
 - (a) Phase I features
 - Tube-type or solid-state sensor
 - 40 Mpixels/sec
 - Dynamic RAM data transfer rate of 320 Mb/sec
 - Technology to record and reproduce high-resolution, high-frame-rate video images in dynamic RAM (128 MB)
 - Subframing
 - Opportunity to design, develop, and gain experience with the basic building blocks needed

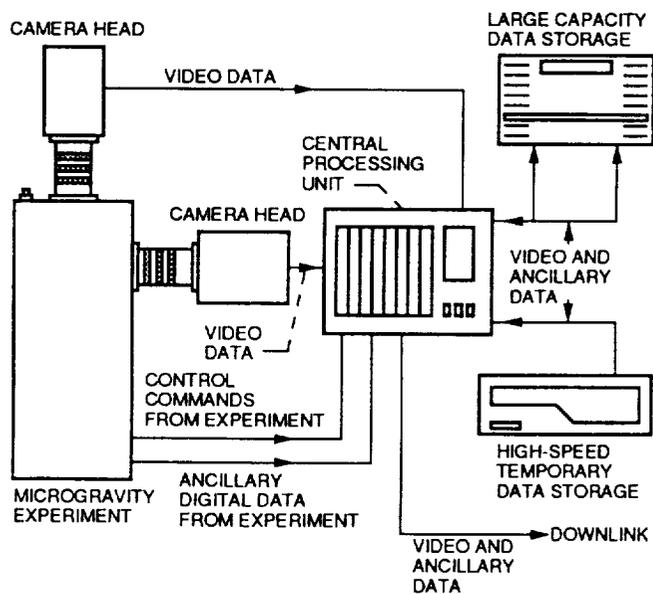


Figure 26.—High-resolution, high-frame-rate video technology (HHVT) to provide recording and transmission of high-speed detailed optical data from microgravity science experiments.

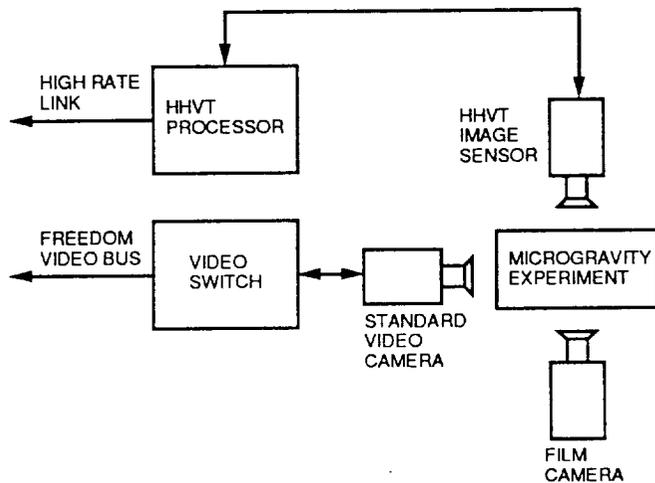


Figure 27.—Tentative three-tier imaging system capability of MCF.

- for an advanced HHVT system
 - Available August 1990
- (b) Phase II features
 - Solid-state sensor
 - 80 (or more) Mpixels/sec
 - Dynamic RAM data transfer rate of 640 Mb/sec
 - 512 MB dynamic RAM storage capacity
 - Automatic subframe tracking
 - Automated burst mode driven by image content (i.e., pretriggered imaging)
 - 99 GB of resident archive storage capacity
 - Available December 1992
- (c) Phase I and II shared features
 - Monochrome
 - 1024 by 1024 pixel resolution
 - High-resolution, pixel-addressable camera
 - Image intensification
 - System flexibility (i.e., ability to trade-off frame rate, pixels/frame, and gray scale resolution)
 - Variable gray scale resolution by using up to 8 b/pixel
 - Ancillary experiment data and video system control information recorded with each frame
 - Wide variety of image enhancement capabilities
 - Remote control of video system via digital command
- (d) Capabilities beyond phases I and II
 - Color, IR, UV
 - Data compression (lossless or nearly lossless) to reduce storage and downlink requirements
- (2) Standard National Television Standards Code video
 - Utilizes S.S. Freedom video system capabilities: record/playback, downlink, and workstation viewing
 - Used for operational information (experiment viewing)
 - Augments HHVT system

- (3) Film
 - Augments HHVT and standard NTSC video systems
- (4) Near- and Far-Term Advanced Technology Developments (ATD)
 - (a) Marshall Space Flight Center's miniature color video camera (MCVC)
 - 760 by 488 pixels
 - 60 frames/sec
 - 3 charge-coupled device (CCD) color
 - Small size (approximately 2 by 3 by 7 in.)
 - Flight-qualified commercial hardware available June 1991.
 - (b) Marshall Space Flight Center's high-resolution camera
 - 2048 by 2048 pixels
 - 1 to 10 frames/sec
 - Black and white
 - X-ray detector
 - Date available to be determined
 - (c) Johnson Space Center's 8-mm camcorder
 - 380-line resolution
 - 768 by 493 pixels
 - 30 frames/sec
 - 1 CCD format
 - 4 by 6 by 13 in.
 - Date available to be determined

Special Instrumentation

Optical diagnostic system support.—The optical measurement system, also called the laser diagnostic system, will serve as a nonintrusive evaluation tool for combustion research. Quantities to be measured can include temperature, spatial extent, density, species identification, and velocity. The intention is for the MCF to provide peripheral support for optical systems that will be designed by the experimenter. Much interaction with experimenters lies ahead. At this time, on the basis of information available so far, known constraints, and reasonable assumptions, only some of the options that have been considered can be offered.

During the definition-study phase for the MCF, the study team sought to determine the need for and experimental requirements of an optical measurement system. The findings of this study, tabulated in the database, indicate that potential users definitely need such a system and that the most-requested measurements are velocity and temperature.

The study team considers an optical measurement system to be a very important support system of the MCF. Unfortunately, this type of system is, by nature, extremely experiment-specific. A one-size-fits-all support system is therefore difficult to devise. The approach being considered would have the MCF house a master light source, located in the facility rack, whose emitted light would be transmitted to the required location within the experiment containment enclosure by fiber optics or light-beam tubes. The MCF would

also provide imaging systems, including computer support for analysis of images.

At this time, a single master laser light source that could provide all the power levels at all the required wavelengths for all possible experiments is not available. With today's technology, severe trade-offs in available power levels and wavelength selection would probably have to be made. Whatever laser system is chosen will be limited by the available power and space. Also, not all wavelengths will be available for use. The choice of wavelengths will be determined by the state of the art in laser technology in the near future; on the positive side, the state of the art in lasers is advancing very rapidly. The outlook is encouraging enough to plan for a set of interchangeable units, some tunable over a band of frequencies such that a broad range of useful wavelengths can be achieved.

Other light sources such as arc lamps, which are not constrained by rigid specifications on coherence, wavelength, and dimensional tolerances, do not seem to be a problem at this time, although some safety considerations may need to be resolved.

The experimenter is expected to gain some latitude in design by being able to place light sources outside the experiment module. Since the experiment rack is to be outfitted on the ground, along with necessary alignment, calibration, and checkout procedures, experiment-specific variations can be accommodated within limits.

Gas chromatograph and mass spectrometer.—The MCF requirements-definition phase made apparent the need for an in-line, or processing, gas chromatograph and mass spectrometer (GC/MS) as an MCF support system. The principal use of this device will be to analyze products of combustion. The proposed GC/MS will be capable of determining quantitatively the atomic and molecular species present in a sample—a sample that may be the experimental sample, the effluent from an experiment, or the ambient atmosphere within the chamber or enclosure. The system will be able to work as a mass spectrometer alone or with the gas chromatographic section providing the input to the mass spectrometer.

Assumptions and constraints: The proposed GC/MS system will have certain constraints. The mass range will be limited to approximately mass 12 to mass 200. The resolution is envisioned at this time to be approximately 10 percent (a 10 percent valley at mass 200). The system will be located in the facility rack, and thus the sampling will be somewhat remote since it will have to traverse from the experiment rack. Any reactive species will be lost by the time of entry into the GC/MS. Sample size will be limited by the pumping speed of the vacuum ion pump.

Hardware description: The mass spectrometer is envisioned as a two-stage double-focusing instrument that is electrically scanned. The first stage 90° electric sector is to be followed by a 90° magnetic sector. An electron-bombardment ion source with electron energies of 45 and 70 eV will provide

ionization, and a 500-cm/sec ion pump will maintain a vacuum. The gas chromatograph will be a micropacked column 2 m long with a 0.75-mm inner diam. The system will have a total volume on the order of 1 to 2 ft³ and a weight of 50 to 100 lbs. The total power needed during operation should be on the order of 150 to 300 W.

Hardware capability: The system not only will be able to analyze gas samples from the experimental apparatus, but it also can be used to continuously monitor gases in the chamber, tunnel, containment enclosure, and PMMS effluent. In addition to being an analytical tool, therefore, the GC/MS system will serve as a safety quality control instrument as well.

In general, gas chromatography requires that the gas sample be transported as a slug of material in a carrier gas stream, usually helium. Where close-coupling is possible, carrier streams may not be required for mass spectrometry, but close-coupling is an unlikely possibility in the MCF concept. The MCF fluids system will supply helium to the GC/MS interface. The GC/MS system will distribute it to the sampling system.

At present, all that can be said to describe the sampling system is that its valves will be controlled by computer. Whether this computer function will be a part of the GC/MS system or a part of the MCF computer system has not been decided, although the thinking seems to be leaning toward location in the GC/MS system.

To what extent leakage, from valves in particular, must be taken into account remains to be determined. A tentative assumption is that the quantities of samples will be so small that the avionics air system will eliminate any potential hazard. Final determination will require experimenter-provided information on the nature of the material in the sample, for example, its toxicities, flammability, corrosiveness, propensity to leak, ease of removal from the avionics air stream, and quantity required for analysis.

Facility safety systems.—As fire detection and suppression design controls, the atmosphere inside the experiment containment enclosure and the facility containment enclosure will be gaseous-nitrogen rich, and a gaseous-nitrogen purge will be available in the event of a fire. Both containment enclosures will vent into the PMMS gas waste vent. Also, the GC/MS will sample the volume inside the containment enclosures to check for leaks into the enclosure.

A fire and smoke detector will be placed inside the experiment and facility containment enclosures (see fig. 22) in addition to the existing USL module-supplied rack detectors and extinguishment systems (see fig. 28). The USL module-supplied caution and warning (C&W) detection system was found to be sufficient for the facility rack, where the primary hazard may be an electrical fire.

This C&W monitoring capability will be linked into the Freedom station data management system (DMS), which will provide command and control and health monitoring of properly interfaced payloads. The Freedom station DMS will also provide the capability for integration of onboard operations functions associated with the C&W system.

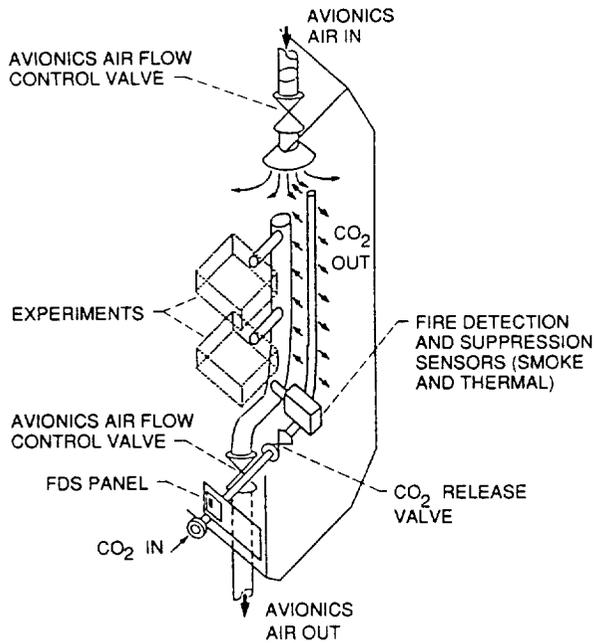


Figure 28.—Facility safety systems; rack fire detection and suppression concept.

Software Systems

Software functional description.—The software will perform the functions of real-time control, data acquisition, computation, data processing, input/output, safety, and self-testing that are necessary to conduct a microgravity combustion experiment. The software will interface with the Freedom station DMS.

Assumptions and constraints.—Two assumptions have been made relative to the software system. The first is that the Freedom crew's involvement with the MCF must be kept to a minimum. In general, crew involvement will be restricted to prestart activities (setup, etc.), emergencies, and postrun activities. A second assumption is that hardware constraints imposed on the software will be minimal. The choice of an

Intel 80386 microprocessor will allow the use of a high-level language for much of the coding and will allow considerable latitude in the design.

Software functional requirements.—For conceptual purposes, the software functions are allocated to the facility rack, the experiment rack, and the necessary interfaces. The software functions are listed in figure 29.

Experiment software functions: These software functions will depend primarily on the experiment. The following functional descriptions are general and may not be required for all experiments:

(1) **Timeline control.** The timeline control function will control those devices or quantities that interact with the experiment timeline, such as the power profile.

(2) **Device control.** Devices will be controlled through the timeline control or by comparison of sensor output with preestablished values, in accordance with experiment specifications. Control will be overridden by the safety function or by priority-interrupt through the DMS interface.

(3) **Data acquisition.** Data acquisition software will allow the interpretation and buffering of raw data received from the analog-to-digital converters.

(4) **Data processing.** Linearization and calibration of sensors will be accomplished by software.

(5) **Computation.** Data analysis is expected to be done by ground software. However, some quantities may have to be derived from on-going experiment data in order to determine control parameters. The experiment software will have the capability of performing this function.

Facility software functions: The MCF software functions are expected to change very little from one experiment to another. They are as follows:

(1) **Program control.** The Facility software will have overall program control, with the exception of timeline control details. This control includes experiment start and stop, data sampling for safety tests, emergency shutdown, and so on.

(2) **Input/output.** Included under the input/output function will be conversion of data to Systeme Internationale (SI) units, formatting the data for onboard display, a menu system

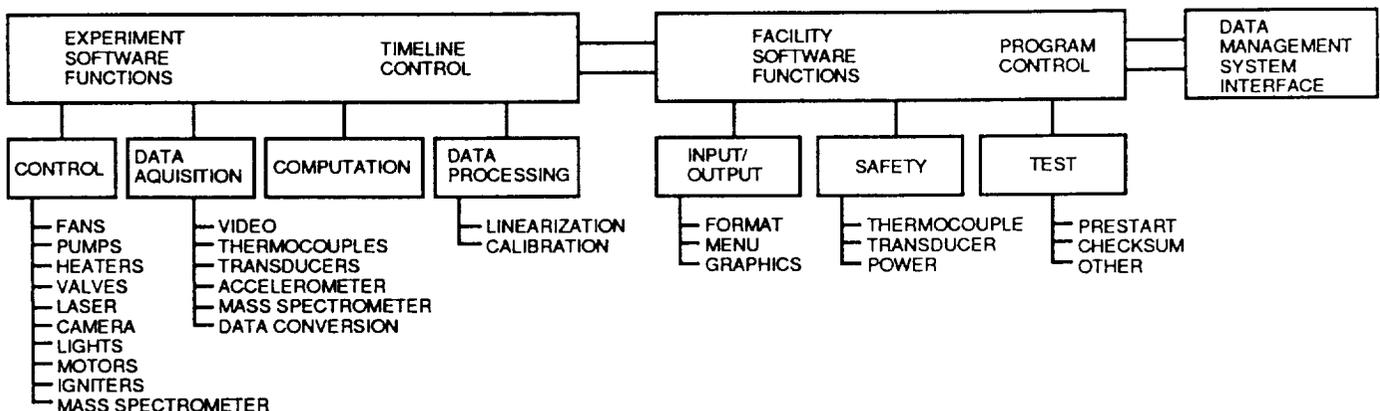


Figure 29.—Software functions.

dedicated to onboard display and limited onboard input of commands, a two-dimensional graphics system (to be determined) for onboard graphics display of data, and time-tagged video.

(3) *Safety.* The Facility safety function will include comparisons of thermocouple pressure transducer outputs and power level with predetermined maximum values and the institution of appropriate action; this action, in an emergency, may include warning messages and alarms, a memory dump to mass storage, and saving quantities indicating an alarm condition.

(4) *Test.* The test function will include software tests, such as a prestart checksum, and prestart device tests selectable by menu and/or by an automated runthrough.

Software structural design.—The design effort will be to make the software as modular as possible. A distributed software concept will be used, as shown in figure 30.

The subsystem software modules provide the functions necessary for control and/or data acquisition unique to those subsystems. Subsystems include, but may not be limited to, the gas mixing, fluid supply, waste conditioning, thermal control, and optical systems. The subsystem software modules may also perform certain safety functions assigned to them. Status words will be maintained for each subsystem. The experiment modules will consist of the timeline control module and any modules necessary for functions not provided by the system modules.

The MCF software module will consist of the program control module, which will comprise the operating system, providing startup, shutdown, and the DMS interface. The MCF software module will define the environment and control execution and safety. Modules for handling input/output, MCF software safety functions, and prestart tests will be included to complete the modularity.

There are several advantages to using the modular software design: changes can be made with minimum impact on the rest of the software; breadboard testing of the hardware subsystem prior to integration will be facilitated; the commercial and Freedom station software packages may be

utilized where applicable; and program debugging can be more easily accomplished.

Interfaces.—The MCF and experiment software module interface will be accomplished by global declaration of variables and argument passing. The subsystem software interfaces will be in accordance with subsystem software specifications (to be determined).

The DMS interface will be accomplished through the network interface unit.

Software life cycle.—The software life cycle will consist of four phases, as shown in figure 31. Software engineering and qualification encompasses all four phases and the configuration control functions shown.

Configuration control will be maintained by a system that uses engineering notebooks, planning and scheduling, monitoring, meeting support, and documentation.

Software products.—The following software products will be developed:

(1) *Conceptual design document.* The conceptual design document will detail the functions to be performed by the software of the MCF and of the microgravity experiment. This document will be produced for the breadboard testing and evaluation.

(2) *Detailed design document.* The first part of the detailed design document will describe the functions to be performed and the algorithms required for the MCF. The second part will describe the functions and the algorithms for the experiment.

(3) *Software test plan.* The software test plan will detail the tests to be performed on the software for validation and verification. These may include (a) tests with MCF and experiment hardware to validate the software control and data acquisition functions and (b) tests with software emulation of MCF and experiment hardware to validate the software safety function.

(4) *Executable code.* The product of the final development phase will be code-compatible with the DMS interface and meet USL specifications and requirements.

(5) *Flight qualification documents.* All documents required for flight qualification will be produced.

(6) *Programmers guide.* The programmers guide for an experiment will consist of the final detailed design document for that experiment.

(7) *Users manual.* The users manual will describe the program requirements in general and the program input/output requirements in particular, including status words and messages, in a format that can be easily understood by the person who will be running the experiment.

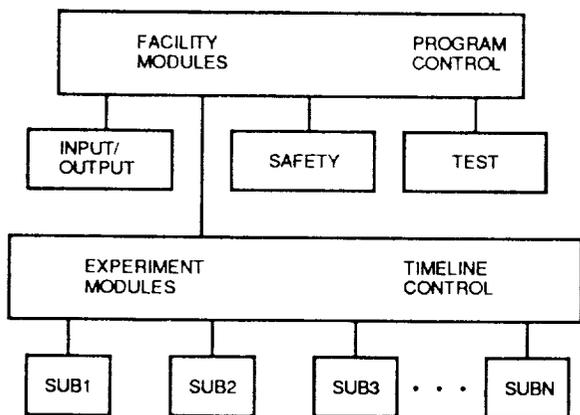


Figure 30.—Program hierarchy.

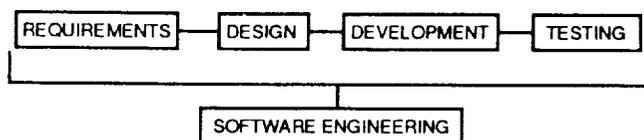


Figure 31.—Four phases of the software life cycle.

Acceleration Environment and Measurement

As previously mentioned, one of the unique features or services to be provided by the Freedom station, and thus by the MCF, is a near-zero-gravity environment. This environment, measured as an acceleration parameter, consists of a steady-state and a dynamics component. Both of these components will be disturbed by the crew's presence onboard the station and by natural effects as Freedom orbits the Earth.

The steady-state component will be affected by three disturbance forces. These are gravity gradient effects, pitch-torque equilibrium attitude effects, and station aerodynamic drag. Of these three, the first two appear to be dominant and affect the microgravity environment in the range of 0.5×10^{-6} to $4 \times 10^{-6} g_0$ (where g_0 is gravity at sea level on Earth).

The dynamic component will also be affected by crew activities inside and outside the Freedom station, including such activities as a crew member exercising on the treadmill or pushing off one wall and floating over and impacting another wall, extravehicular activities on the station truss, and control console operations; even coughing and sneezing have been analyzed for their effects on the microgravity environment. Two major disturbing forces will be the periodic docking of the space shuttle at the Freedom station and the periodic altitude reboost. The reboost will be needed to raise the Freedom station to a higher orbital altitude, since the altitude degrades because of atmospheric drag forces. The shuttle-caused disturbance will occur about once every 90 days, which is the current revisiting schedule. The reboost disturbance is scheduled to recur about once every 90 days, just after the space shuttle leaves the Freedom station.

The current S.S. Freedom program baseline microgravity requirements are frequency-dependent. At low frequencies, less than 0.1 Hz, the level required is $1 \times 10^{-6} g_0$ or less. At intermediate frequencies, 0.1 to 100 Hz, the requirement varies from $1 \times 10^{-6} g_0$, at 0.1 Hz, to $10^{-3} g_0$, at 100 Hz. At high frequencies, greater than 100 Hz, the required level is $10^{-3} g_0$. These target levels will be maintained continuously for periods of 30 days or more, for more than 50 percent of the operational year. There is also an impulse-type disturbance requirement of less than $10^{-6} g_0 \cdot \text{sec}$, which is to be measured over a 10-sec interval.

Recent analysis of the effects of some of the crew-caused disturbances listed above has shown that they greatly exceed the baseline microgravity requirements; however future development in program hardware design may minimize some of these crew-caused disturbances. With respect to the MCF, the analysis points out the possible need for experiment isolation by mechanical means. In addition, it points out a possible problem with experiments requiring quiet microgravity periods of durations that exceed 90 days.

Current S.S. Freedom program plans include an acceleration measurement system for the USL module. This system will monitor accelerations to $10^{-8} g_0$, from 0 to 1 Hz, and to $10^{-7} g_0$, from 1 to 500 Hz, in three axes and with a resolution

of measurements to $\pm 10^{-9} g$. The system will provide a map of acceleration levels, below 1 Hz, throughout the USL module.

Facility and Experiment Integration and Operations Scenarios

Background

Operations and integration activities needed to support the microgravity combustion experiments planned for the Freedom station are described within this section. Each phase of facility-rack, experiment-rack, and experiment-specific equipment integration on the ground and on orbit is identified. Typical experiment integration will start at the Lewis Research Center Science and Technology Center (S&TC) with rack-level testing to verify operational integrity. Final integration will be achieved at the orbiting MCF by crew members. Operations activities identified include assembly, setup, run, recycle, de-integration and stowage of experiments, and associated crew time required to perform these activities.

Assumptions and Constraints

Experiment facility definition and development activities will have been performed at the experiment developer's facility. These activities will include experiment definition, hardware development, and certification.

Integration

Two types of racks will be required to run a typical combustion experiment. These are the facility and experiment flight racks, which will be assembled and tested at the S&TC. The experiment modules will then be integrated into the racks for further extensive testing. After flight certification acceptance, the facility and experiment flight racks will be shipped to Kennedy Space Center for integration into the space shuttle. There, further testing will be performed to insure compatibility with the space shuttle systems. On orbit, the facility and experiment flight racks will be moved to Freedom's USL module and integrated into the MCF. When required combustion tests have been completed, the experiment rack will be de-integrated from the MCF and returned to Earth for posttest analysis. The facility rack will remain in orbit and will be refitted as necessary to support multiple experiment racks.

Science and Technology Center.—Personnel at the Lewis S&TC will physically integrate experiment and facility hardware into flight racks and then conduct the necessary testing and verification activities. The primary functions to be performed at the S&TC are (1) flight rack staging and integration and (2) flight rack testing and verification. The duties inherent in these functions are as follows:

- (1) Flight rack staging and integration
 - Experiment hardware receiving, inspection, and functional testing
 - Racks and integration hardware receiving, inspection, and checkout
 - Form, fit, and function testing
 - Rack staging
 - Experiment hardware-to-rack interface tests
 - Integration of experiments into racks
 - Testing and verification of integrated experiments and racks
 - Stowage verification
 - Procedures verification
 - Verification of analytical integration predictions
 - Testing remote interfaces
- (2) Flight rack testing and verification
 - Simulator testing of integrated racks-to-module interface
 - Preparation and shipment of training hardware to payload integrated training facility
 - Preparation and shipment of integrated racks, resupply, stowage items, and equipment hardware
 - Verification of data packs

These activities are expected to begin approximately two years before launch and be completed one year before launch.

Facility rack integration.—The facility rack integration process involves required assembly, checkout, and shipment of the MCF rack that will support the experiment racks on orbit. Space Station Freedom program-furnished racks will be received at the S&TC with the following standard options installed:

- Equipment attachment hardware
- Cable and wire assemblies
- Backplane tubing and ducting
- Drawer slides
- Cold plates
- Rack-release mechanisms
- Fire suppression hardware
- DMS multiplexer/demultiplexer equipment

Following inspection and acceptance testing, the MCF systems and subsystems previously described will be integrated into the program-furnished rack to form the facility rack.

Subsequent to component installation into the facility rack, S&TC personnel will perform hardware and software verification testing to ensure on-orbit facility rack integrity. Facility rack-to-experiment rack and facility rack-to-DMS interfaces will be verified, along with exhaust and gas supply system pipe and ducting networks. Housekeeping interfaces (i.e., electrical, thermal, and mechanical) will also be verified.

After S&TC checkout and certification, the facility rack will be shipped to Kennedy Space Center for space shuttle integration and testing in preparation for launch. Facility rack integration at Kennedy will consist of a two-step process. The first step is integration of the rack into the logistics module, which is a type of canister that will be used to simplify the transfer of payload

items from the space shuttle to Freedom. Rack-to-logistics module integration includes rack functional testing, rack installation into the logistics module, rack-to-module interface testing, module closeout, and software end-to-end verification testing. The second step in the process logistics is module-to-space shuttle integration, which includes any late access stowage support required, monitoring of critical hardware status, and preflight baseline data collection and archival.

In orbit, integration of the facility rack from the space shuttle to S.S. Freedom will consist of physically inspecting and transporting the rack from the logistics module to the USL module. After unpackaging the facility rack and visually inspecting it, crew members will begin the task of physically integrating the rack hardware with the associated Freedom mountings and interconnects. These interconnects, consisting of fluid and electrical connections to the module, will be made through flexible hoses and cables connected to the standoff Freedom interface plate. Rack cabinets will be secured within the Freedom station by means of pin-latching mechanisms on the top and bottom of the rack. After the facility rack has been completely integrated into the USL module, crew members will complete a predefined rack powerup and self-testing calibration run.

Experiment rack integration.—The experiment rack integration process is similar to the process described for the facilities rack. Components associated with the experiment rack will be installed on a mission- or experiment-unique basis. The S&TC personnel will process multiple experiment racks over the expected life of the MCF project. The experiment rack can be modified to support new experiments in two ways: changeout of the experiment-specific hardware from the experiment rack and changeout of the entire experiment rack. Science and Technology Center integration activities for the experiment rack begin with the same Freedom program-furnished racks, with standard options as described earlier.

The types of components that will be integrated into the experiment racks differ. The experiment-specific components may include, but are not limited to, the following:

- Accelerometer
- Burners
- Cameras (35-mm film, 16-mm film, and video)
- Cup fuel holder
- Flowmeters
- Gas bottles
- Heaters
- High-speed droplet release mechanism
- Holographic equipment
- Lasers
- Lights
- Probes
- Radiometer
- Robot arm
- Signal conditioners
- Specialized test chambers
- Transducers
- Video recorder

In the case of the combustion tunnel or combustion chamber, one of these will be installed into the experiment rack along with some of the listed components to make up a complete experiment rack for a specific set of experiments. Any vibration-isolation equipment and/or methods necessary to conform to experiment-unique restrictions will be

incorporated. Followup integration will require connecting the electricity, gas, and venting between the experiment-specific hardware and the experiment rack. In addition, any experiment-unique interconnections will be made. Verification testing will be performed to ensure that the flight experiment rack functions properly. This integrated test of the facility rack verification unit along with the experiment rack flight unit will demonstrate the compatibility between hardware and software elements, thus ensuring on-orbit operational integrity.

After S&TC checkout and certification, the experiment rack will be shipped to Kennedy Space Center, where it will undergo the same prelaunch integration and testing process as explained previously for the facility rack, that is, integration of the rack into the logistics module and then from the logistics module to the Freedom station. The experiment rack and the facility rack will be interconnected through the between-rack interface plate. Any experiment-unique connections or additions to the experiment rack will be made at this time. After the experiment rack has been completely physically integrated into the Freedom station module, crew members will complete a predefined MCF powerup and self-testing calibration run.

As required, the experiment rack will be de-integrated from the Freedom station in preparation for the installation of another experiment rack. This process will involve disconnecting, securing, packaging, and stowing the rack in preparation for a logistics module return flight. When back on Earth, the experiment rack will be shipped back to the S&TC for posttest analysis, data removal, and refurbishment for future missions.

Operations

Operations for the MCF include pre-mission planning of the on-orbit experiments, crew and ground personnel training, and on-orbit operations. These activities will be supported concurrently at the Discipline Operations Center (DOC) at Lewis.

Discipline Operations Center.—The DOC is a NASA Lewis facility that will provide support to the combustion experimenters in the MCF on Freedom. Operations activities to be performed at the DOC include, but are not limited to, the following:

- Mission planning and replanning
- Training of ground personnel
- Providing procedures for experiment-specific crew training and real-time operations
- Supporting integrated tests and simulations
- Monitoring data flow, processing user-specific data, and managing data distribution
- Providing ground video interface
- Troubleshooting of user-provided equipment
- Providing uplink services, including real-time video uplink capability, camera control, voice system interfaces, and command generation and issue
- Providing short-term scientific data storage

- Recalling from long-term data storage
- Providing short-term storage and real-time recall for users

Planning.—Planning operations for the MCF fall into two categories—increment planning and execution planning. An increment is defined as the period between space shuttle visits to S.S. Freedom, nominally 90 days in length. The increment will be the basic unit for coordinating the development, shipment, and on-orbit installation of racks with respect to the space shuttle manifest. Increment planning will establish which experiment will be run during the increment.

Execution planning will detail the steps required to perform each experiment run. Support equipment requirements, consumables, and the associated specimens for each experiment will be determined, and a complete list developed. The following functions will be performed during an increment:

- (1) Weekly planning
 - Generate short-term plan
 - Update payload operating sequences
 - Update payload procedures
 - Update software data tables
- (2) Data management
 - Schedule and coordinate data networks
 - Coordinate onboard data systems operations
 - Distribute data
 - Archive and store data
- (3) Operations control and support
 - Execute the short-term plan
 - Execute payload procedures and sequences
 - Manage payload and intersystems
 - Command MCF operations
 - Coordinate crew communications
 - Monitor payload and systems interface
 - Assess, coordinate, approve, and implement plan deviations

Training.—There are two types of training—increment dependent and increment independent. Increment-independent training will include familiarizing the crew with the setup and checkout of the facility rack, support equipment, glovebox, and any other nonexperiment-specific equipment associated with the facilities module. Crew facility rack calibrations and data transfer exercises among the Freedom station, the S&TC, and the DOC will be simulated. Increment-dependent training will include familiarizing the crew with the setup and checking out the experiment-specific equipment in the experiment rack. Experiment runs will be simulated to ensure crew efficiency in specimen changeout, equipment reconfiguration, and interactions between the USL module and ground-control centers. Both types of exercise will train the principal investigator (PI), facility systems engineers, and facility operations engineers with simulated data and video flows. These training exercises will ensure the compatibility of operating the Facility, running an experiment, transferring science data to the Earth, and allowing PI interaction with the operation.

On-orbit operations.—The operation of the Facility will be experiment-dependent. Several factors need to be considered in defining a given operation. These include crew time, experiment class (exploratory or matrix test), on-orbit characterization of samples, telescience capability (PI interaction), and automation.

The crew will operate the Facility primarily through the Freedom ECWS, which is a centralized workstation in the USL module that will be used to initiate and monitor the experiment operation. The Freedom DMS will handle all of the data storage and data downlink for the Facility.

Facility operations: Typical Facility operations will entail setting up the rack and interconnecting the experiment and facility racks. Hookups between these racks and the Freedom station power, computer, gas, cooling and thermal, venting, and hazard and fire detection systems will be made as described in the discussion of the particular system in this section. During the setup and interconnection of the racks, ground personnel will be available to assist crew members as needed. The following list shows the required Facility operations and the estimated crew time for their performance:

- Initial visual inspection of racks upon receipt (30 min)
- Material handling (1 to 2 hr)
- Facility rack installation (½ hr)
- Experiment rack installation (½ hr)
- Interconnections of racks (3 hr, maximum)
- Interconnections of racks and the Freedom station (3 hr)
- Rack software loading and checkout (1 to 2 hr)
- Rack checkout and calibration (2 hr for both)
- Rack-to-ground interface testing (1 to 2 hr)
- Experiment setup (1 to 3 hr)
- Experiment run (5 min to 7½ hr)
- Experiment resetup (5 min to 3 hr)
- End experiment, secure and/or “safe” rack, and power down (30 min)
- Cleanup (15 min to 2 hr)
- Experiment rack and module de-integration (1 to 2 hr)

For example, an operation could proceed as follows: The payload scientist would install and test the hardware and software associated with the experiment; next, the scientist would load a sample and do any manual setup required. The experiment would then be ready to run, so startup would be initiated through a command issued by the payload scientist at the ECWS or by a ground operator at the DOC. Experiment process parameters could be adjusted via instructions to the payload scientist or by commands sent directly to the experiment computer from the DOC. After the experiment had been run, the payload scientist would shut the experiment down and do such posttest activities as retrieving samples or storing hazardous materials. The PI could evaluate the data and take whatever actions might be necessary before the next test run.

Experiment-specific operations: Consider an operational scenario for one MCF experiment—droplets combustion. This experiment will provide an understanding of the mechanisms influencing and controlling the ignition, burning, and

extinction of single droplets of pure and multicomponent liquid fuels. The facility rack and the experiment rack equipped with the droplet combustion chamber are assumed to have been installed and be ready to support experiment operations. Experiment assumptions and estimates are as follows:

- Nine hundred tests in a 90-day period
- Much crew interaction expected (setup and observation)
- Ten to thirty different fuels required
- Glovebox required
- High-speed droplet release mechanism required
- Telescience plays important operations role
- Video with zoom capability required
- Dual cameras needed for three-dimensional depth effect
- Potential hazard from fuel leakage exists
- Chamber atmosphere sampling required (MS or GC)

The experiment scenario begins with Facility startup, which includes powering up systems requiring warmup time (approximately 1 hr). A portable glovebox is used to access fuel stored in the chemical storage locker and to fill small reservoirs with the selected fuel. Any fuel mixing required at this stage, including the mixing of liquids with solid particles, is done inside the materials science glovebox. By using the portable glovebox, the fuel reservoirs can be transported to the MCF and installed inside the experiment module. Any necessary gas bottles are installed, and leak checks are performed. Calibration checks are performed on the transducers and the gas sample analyzer. A test of the high-speed droplet release mechanism is performed by forming and deploying (but not burning) a droplet. Cameras and video equipment are installed and checked out.

Next, the experiment is prepared. The chamber atmosphere is sampled and analyzed. One evacuation and refill cycle is performed, and the chamber pressure is measured. Evacuation and refill cycle requirements are computed. Data from the transducers are checked, and cameras and videos are configured. To initiate an experiment run, the data acquisition system is activated; then the automated droplet formation, deployment, and ignition sequence begins. Droplet formation should last 1 to 2 sec, deployment and ignition should last 1 sec, and the burning cycle should take up to 2 min (maximum) for the largest drops. Normally, extinguishment is not necessary, since droplets will evaporate; however the chamber may need to be flooded with nitrogen in multiple droplet tests. During this period, crew members are required to observe and report the following experiment characteristics: (1) initial droplet size and droplet size as a function of burning, (2) flame diameter change with time, and (3) soot formation.

Observations are made with the cameras and video equipment. Video zoom capability is used as the droplet decreases in size. A single experiment should last 5 min or less. After the experiment run, the data acquisition system is deactivated. The chamber atmosphere is sampled with a mass spectrometer or gas chromatograph. The level of decay is computed, and a decision is made about whether an atmosphere changeout should be made or a new test should be run with

the same (only marginally degraded) atmosphere. This decision is arrived at through a teleconference between the PI on the ground and the payload scientist in charge of the test. After this decision is made, data reduction and downlink procedures are executed. Then either an atmosphere changeout is performed in preparation for another sample run, or another test is run with the same atmosphere. The chamber should be vented after several runs, depending on oxygen consumption, fuel vapor accumulation, or combustion product concentration.

Modular Combustion Facility Development Plan

Planning Assumptions and Approach

The plan for the development of the MCF evolved from some basic assumptions about how the project will be managed, who will develop the MCF, when it will be flown, what S.S. Freedom program- and Code EN-provided facilities will be available, and where those facilities will be located.

For this plan the following assumptions have been made: NASA Lewis will manage the project and will also develop the MCF; the MCF will be launched and transported to the Freedom station via the space shuttle in late 1997 (or early 1998), and it will be made operational shortly thereafter; the Freedom program will provide a set of USL module emulators, flight racks, and other miscellaneous equipment to accommodate integration of the MCF into the Freedom station; a Lewis Science and Technology Center (S&TC) and a Discipline Operations Center (DOC) will be established at or near NASA Lewis to support MCF integration and operations activities. Most importantly, the plan assumes that there are a sufficient number of combustion science experiments to justify the MCF and that the MCF can accommodate them.

To define the development plan, an MCF development scenario that identifies the activities of the project has been prepared, based on typical NASA project milestones and current assumptions. The major elements of this plan are (1) an MCF development scenario, (2) an MCF development schedule, and (3) a preliminary work breakdown.

Facility Development Scenario

This plan addresses the development of the MCF from conceptual design through operations of flight hardware. The MCF development scenario (see fig. 32) has four phases: (1) the breadboard phase, (2) the brassboard (engineering model) phase, (3) the prototype phase, and (4) the operations phase.

Each of these phases and the nature and purpose of the hardware developed during these phases are described in the following sections. The end products of the development are (1) MCF and experiment modules, (2) verification units, (3) ground support equipment (GSE), (4) advanced technology enhancements (ATE), and (5) experiment-specific hardware.

Breadboard phase.—Assuming that a decision to pursue a flight development project has been made and that ground-based research and testing have demonstrated that a space experiment is justified, this phase addresses the earliest part of flight-experiment development. The main objectives of this phase are to develop a conceptual design of a flight experiment and to validate the concepts by fabricating and testing engineering breadboard versions before committing to full-scale development. Breadboards are typically made up of a mix of commercial-grade, readily available components and specially fabricated hardware. The breadboard phase starts with requirements definition and concludes with the conceptual design review.

Sequence of activities: The general sequence of breadboard phase activities is as follows:

(1) *Requirements definition.* The preliminary science requirements, the safety requirements for the Freedom station, the reliability requirements of the experiment apparatus, and the interface requirements, including mission-specific requirements, are determined.

(2) *Conceptual design.* Design concepts to meet the science and safety as well as the engineering objectives of the project are developed and evaluated. Early structural, thermodynamic, thermal, and electrical analyses are performed to determine the functional envelope of the designs and to determine if the design concepts can be accommodated within Freedom's physical and operational constraints.

(3) *Breadboard design.* Breadboards of systems and subsystems are designed to provide development test-bed designs for validation of the design concepts and analyses. The breadboard design is also used to verify system compatibility and to gain insight into system performance characteristics.

(4) *Procurement and fabrication.* The breadboards are fabricated and assembled to the specifications of the breadboard design, and the necessary components are procured.

(5) *Breadboard test.* The breadboards are tested as individual subsystems but may also be integrated with other subsystems and emulators of USL module utilities.

(6) *Conceptual design review (CoDR).* This is the first major design review. The design concept, with supporting analyses and test data, is reviewed to ensure that the original science requirements of the project are being met and that the project can meet its mission schedule and achieve its mission objectives.

Development hardware: Engineering breadboards serve as models for evaluating design concepts. They may be a combination of both off-the-shelf and custom-built hardware, and often they are only temporary setups that may be discarded once their purpose has been served (see fig. 33). Initially, breadboards permit experiment designers to explore different concepts and design approaches. They provide flexibility and accessibility, which minimizes the time and cost of evaluating alternative concepts, and they also provide insight into the concept characteristics and operational behavior, which may

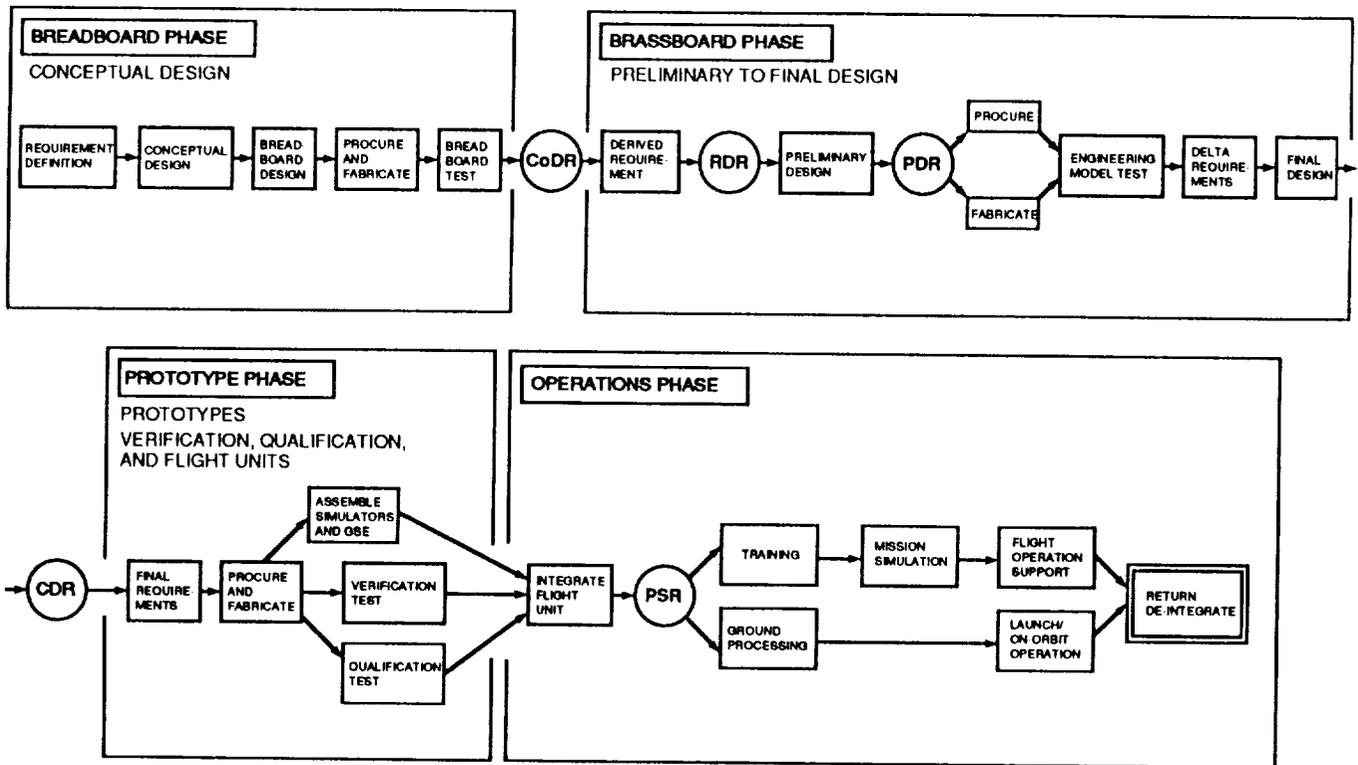


Figure 32.—Phases of MCF development.

otherwise be overlooked in a strictly analytical approach. Breadboard models of Facility and module subsystems will vary in levels of complexity depending on the breadboard test objectives, technical risk of achieving design objectives, and the availability of equivalent off-the-shelf hardware. Breadboards will also be used to determine if design concepts with high technical risk, such as systems that operate only in microgravity, are feasible—by testing models in short-duration microgravity facilities such as the program drop towers or aircraft such as the Learjet and KC-135.

Subsystems are breadboard-modeled individually to validate subsystem design concepts; they can also interface with other subsystems to verify compatibility. Breadboards often have nonflight or development-only instrumentation and test points to aid in system characterization. Furthermore, they may be both manually and electronically controlled. Long after the

MCF development is complete, breadboards will continue to provide service by supporting experiment-specific hardware development, advanced technology enhancements, and flight operations.

The following is a list of breadboard applications in the MCF development:

- Designing evaluation test bed for components and subsystem
- Characterizing components and systems
- Identifying failure modes
- Fault-tolerance testing and redundant system isolation
- Component life-cycle testing
- Verifying compatibility between systems
- Verifying interfaces with USL module and experiment emulators
- Supporting the development of control algorithms

The MCF and experiment module breadboards will continue supporting the development of hardware after the initial breadboard phase in the following ways: interface development between Facility and module subsystems and space experiments, breadboard-level development and evaluation of GSE, and breadboard-level development of ATE.

Since full-scale development of the MCF and the support facilities will require emulation of USL module systems and their interfaces, the Freedom program will create emulators of the USL module systems. In the early phases of Freedom's development, USL module emulators may not be available, so Lewis-built USL module emulator breadboards may be required to support development until those supplied by the

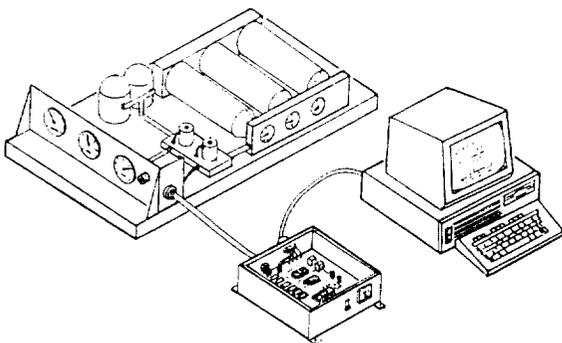


Figure 33.—Engineering breadboards.

program are made available. The USL module emulator will emulate the following systems: power, process materials management, fluid management, environmental control and life support, and data management.

Brassboard phase.—During this phase the bulk of the project's engineering design is performed, starting with the outcome of the CoDR and concluding with the critical design review (CDR). Both the preliminary and final design phases are completed, the flight design is fixed, and all aspects of the design come under configuration control. Engineering models of subsystems are fabricated and then utilized in the development of the integrated MCF. As a final design is derived, the engineering models are also used to solve design problems not encountered in the previous design phases. Some of the subsystems are developed entirely by vendors; therefore, the design reviews of those subsystems must occur prior to the design milestones of the overall MCF.

Sequence of activities: The brassboard phase stages are as follows:

(1) **Derived requirements.** These are requirements that are derived from the conceptual design as well as safety, reliability, and carrier interface requirements, functional requirements, and the software requirements defined and documented in the project plan. These derived requirements along with initial requirements are the basis of the preliminary and final design process.

(2) **Requirements definition review (RDR).** The RDR is a review of all the science and engineering requirements that have been derived from original science requirements. The purpose of the RDR is to ensure that all requirements have been identified and are being properly addressed by the development plan.

(3) **Preliminary design.** Once the latest requirements have been established, the preliminary design of the MCF begins. With more definitive design goals, emphasis is on the design of an integrated system, which includes emulators of carrier interfaces and development support equipment.

(4) **Preliminary design review (PDR).** This milestone is a review of the preliminary design, along with results from the supporting analyses, prior to committing the design to hardware or major procurement.

(5) **Procurement and fabrication.** These two activities occur in concert. Some systems are fabricated in-house and others are procured from commercial sources or subsystem contractors. In many cases the procurement of the flight hardware and the procurement of engineering models occur as part of the same effort. This is typical when hardware developed by a vendor requires a long development lead-time.

(6) **Engineering model (brassboard) tests.** Components, subsystems, and, eventually, completely integrated engineering models of the experiment system are tested to verify that the design is capable of meeting the project design requirements and mission objectives. The need for design revisions becomes evident as characteristics of the integrated system become known.

(7) **Final design.** The final design incorporates design and performance information gathered from engineering model testing; it represents the flight design. At this point, configuration control and safety, reliability, and quality assurance (SR&QA) become more significant, and the fidelity of engineering models increases in importance as interfaces between systems and the carrier become fixed.

(8) **Critical design review (CDR).** This milestone marks the review of the final design; science requirements; test and analyses data; GSE and test plans; safety, integration, qualification, and verification plans; and flight operations plans. The detailed schedule of activity through flight is also reviewed.

Development hardware: The brassboard subsystems are a first attempt at a flight design; generally, engineering models are another step in the evolution of a flight design. Although the engineering models have greater fidelity than the forerunner breadboards, they generally consist of nonflight hardware (see fig. 34).

The Facility and/or module subsystems are integrated and packaged into a unified system occupying the intended flight envelope. The primary function of the brassboard is to support MCF and experiment-module development, but it will also serve as a prototype for derivative models such as the simulation model, the GSE, and the validation units.

All MCF mechanical and electrical subsystems are integrated into an MCF double-rack envelope. Hardware is integrated and configured in a manner that supports software development. Interfaces with USL module emulators are supported, and thus, the MCF can be controlled through an emulated DMS workstation.

In addition to flight instrumentation, built-in, development-only instrumentation is included to support ATD and next-generation module development.

The engineering brassboards will support the integration of MCF and experiment module systems as follows:

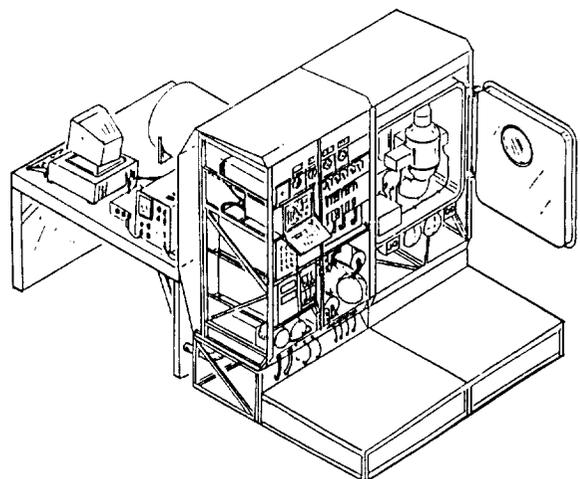


Figure 34.—Brassboard system ground rack.

- (1) Verifying that the mechanical fluids systems, electronic control and data systems, and structural support mechanisms can physically fit in the MCF and experiment module envelopes
- (2) Verifying that operation of the packaged system meets design requirements in the following areas:
 - DMS compatibility
 - EMC
 - Thermal stability
 - Accessibility and maintainability
 - Static and dynamic structural integrity
 - Fluid system stability
 - System reliability and safety
 - Ergonomics
- (3) Developing and testing software
- (4) Characterizing the integrated system
- (5) Verifying failure mode and effects analysis (FMEA) as well as failure tolerance and fail-safe operation
- (6) Verifying module and Facility compatibility

The engineering models may continue to provide program support beyond the development phase by acting as troubleshooting tools in the following ways:

- Simulating failures with closely controlled and heavily instrumented system models
 - Isolating subsystems faults
 - Isolating redundant or failure-tolerant subsystems and components
 - Evaluating the system impacts of failed components
- Brassboards will support the development of experiments and also ATE (from the ATD program) as follows:
- Verifying experiment and module interfaces
 - Verifying that the packaged system operation conforms with Freedom Station payload design requirements
 - Supporting development of experiment-specific software
 - Characterizing the experiment or ATE integrated system
 - Verifying FMEA

Prototype phase.—In this report the term “prototype” refers to hardware that represents the flight design, but it does not always refer to the specific flight hardware. In this phase the emphasis is on fabrication and integration, as well as verification and qualification, of the flight design. Once the final flight design has been established by the CDR, any design changes will have major schedule and cost impact on the project. This happens because multiple sets of prototype hardware are being fabricated, integrated, and tested virtually in parallel. Therefore, configuration control is essential so that coordination and control of the unavoidable changes is assured.

Sequence of activities: The prototype phase progresses as follows:

(1) *Procurement and fabrication.* For the most part, the procurement of prototype hardware should already have been done in the brassboard phase, leaving only hardware necessitated by contract changes or revisions of requirements to be procured at this point. Miscellaneous prototype hardware is fabricated in-house or is locally procured.

(2) *Verification, integration, and testing.* Each modular subsystem is tested and then integrated into the verification unit. The assembly or integrated verification unit, is tested at the system level to verify requirements for operation, compatibility, safety, and science. This is the first opportunity to verify that the final flight design will meet subsystem- and system-level requirements. Failure to meet requirements will mandate corrective action that will affect the qualification unit and the flight unit.

(3) *Qualification.* Qualification refers to the testing and analysis that shows that a design meets the requirements for flight-qualified hardware dictated by the Freedom station and the space shuttle programs. The single most important set of requirements pertains to mission safety. Qualification is needed primarily at the subsystem level, but ultimately the entire system will be qualified. In this development scenario, system qualification occurs concurrently with verification testing, but the completion of qualification is planned to follow completion of verification, with enough of a time lag to accommodate a minor design change. With this approach the need to repeat an entire qualification test sequence is avoided.

(4) *Simulator and GSE fabrication.* After the design for the flight system is fixed, simulators are fabricated and assembled. These simulators will be provided to other NASA centers for use in training and in mission simulation. The GSE is fabricated to verify flight hardware interfaces, and it will be used in the integration activity at the S&TC as well as in the postreceiving inspection and prelaunch checkout at the launch site. Since the GSE hardware interacts directly with flight hardware, special attention to interface configuration is required.

Prototype hardware: Three basic prototypes will be built to represent the flight design: (1) the verification unit, (2) the qualification unit, and (3) the flight unit. Each of these will have its own special function in the program. The qualification and flight units will be built for both the MCF and the experiment module. However, only the MCF requires a verification unit, because once on orbit, the MCF is not available for integration and verification.

The first set of hardware representing the flight design will be the MCF verification unit (see fig. 35); this will be used initially to verify the flight design requirements. Once that function has been served, the MCF verification unit then becomes a means to integrate and verify future experiment modules, experiments, and ATE upgrades while the flight unit is onboard the Freedom station. In addition, the MCF verification unit will support operations training and simulations by acting as a high fidelity simulator. This verification unit will be identical to the flight hardware, but it will not necessarily be built from flight-grade components. Because the experiment modules will return to Earth periodically, a verification model of every experiment module is not necessary.

The MCF verification unit will be maintained as a physically and functionally identical twin of the flight unit and will be

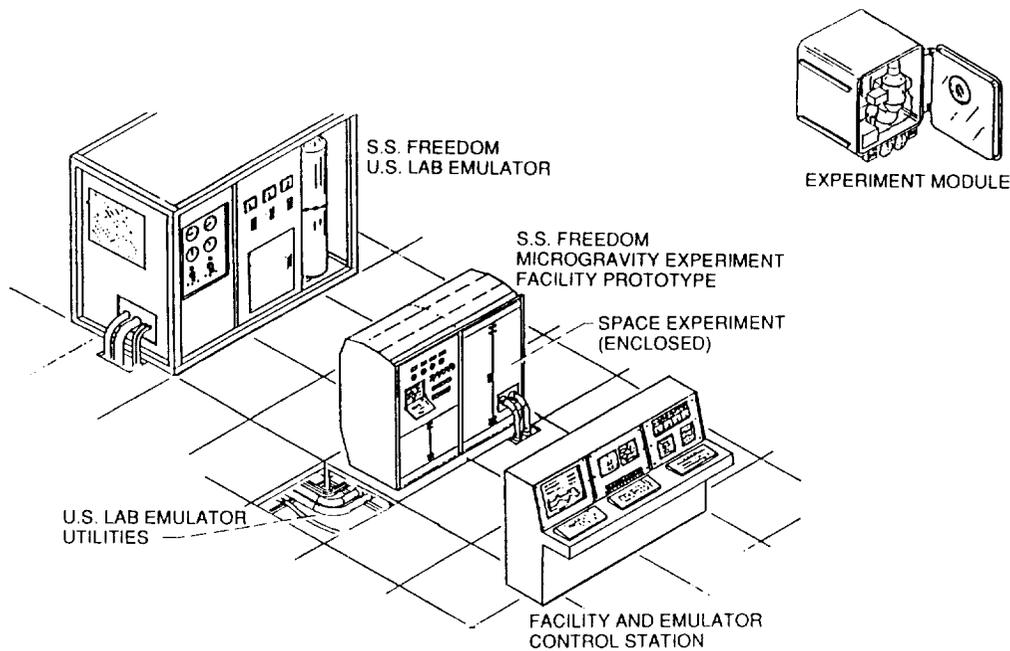


Figure 35.—Modular Combustion Facility verification unit.

operated in a clean-room environment located at a S&TC integration laboratory. The verification unit will operate in conjunction with the integration GSE once the flight unit is operational on Freedom; it will be under configuration control wherein the configuration changes only when the flight unit changes. Since software installed in the verification unit is identical to that of the flight unit, it can also be linked to the communications network and thus can support telepresence.

The qualification units of each MCF subsystem will be identical to the actual flight units and will be fabricated from flight-grade hardware. The complete system will undergo a series of qualification tests to demonstrate the operational reliability of the MCF and experiment module systems when subjected to the environmental extremes of the space shuttle and the Freedom station. Additional tests to verify that these systems meet the space shuttle and Freedom program requirements will be performed. Failure of a qualification test because of an inadequate design will mandate a redesign of the affected system. Design changes, such as incorporation of ATD enhancements, will compel a requalification of the design. Provided that it has not been overstressed, the qualification unit hardware becomes the backup flight unit.

The MCF qualification unit will consist largely of flight-qualified hardware in the configuration of a flight unit. Special instrumentation, installed for qualification testing, will help to determine whether qualification goals are met. The qualification unit will verify that the Facility and module subsystems designs are capable of meeting the requirements defined by payload classification, program safety, compatibility, and reliability requirements. It may also support the flight qualification of ATD enhancements and design changes.

Ultimately, the MCF flight unit is the end product of the development project; all other equipment supports the development or operation of this unit. Previous sections of this report have described the nature of the flight systems in detail. The actual flight hardware will be received at the S&TC and integrated into Freedom program-provided racks. Both the facility rack and the experiment racks with the combustion experiment modules will be integrated in the same manner, but the facility rack is expected to be integrated only once because it is expected to remain on the Freedom station for a 20-yr operational lifetime. However since the experiment rack can be used for multiple station 90-day station increments, and modules will be replaced periodically with new ones to perform new experiments, many integrations of the experiment rack are likely.

Operations phase.—The operations phase includes all activities associated with experiment operations and integrations—not only those that occur at Lewis but also those that Lewis supports at other NASA centers—such as flight hardware integration and verification, launch-site carrier integration and ground operations, flight operations, crew and support-personnel training, and MCF experiment operations.

Sequence of activities: The operations phase proceeds as follows:

(1) **Flight systems integration.** Work begins when flight subsystems are delivered to the rack-level integration laboratory (Lewis S&TC). Subsystems arrive from subsystem development contractors to be integrated and tested as a unified package. The nonflight MCF verification unit has already verified software and system design, so flight units are tested to verify the quality of their material and workmanship. In addition to flight hardware, the GSE and training simulators

are integrated and tested, both separately and in conjunction with the flight systems. Once all verification is complete, the hardware is prepared for shipment to the launch site.

(2) *Preshipment review*. The preshipment review (PSR) allows the program management to review the verification, qualification data, and all related integration documentation and to assess the readiness of the flight systems for shipment to the launch site. This review is important because of the difficulty in correcting any problems once the flight unit has been shipped and is no longer controlled by the development center. Beyond this point, activity progress along two parallel paths. The flight hardware follows the integration path, in which the flight systems are tested and integrated into a logistics module and launched via the space shuttle to the Freedom station. The operations path addresses the utilization of the flight hardware.

(3) *Ground processing (integration activity)*. The facility rack and any experiment racks are shipped from the Lewis S&TC to a space station processing facility at Kennedy Space Center. Following initial receiving inspections, the flight hardware is thoroughly tested in off-line laboratories prior to on-line integration into the logistics module. Except for unusual circumstances, the off-line laboratory is the last station where changes can be made or system anomalies can be debugged.

(4) *On-orbit operations*. During launch and transport to Freedom, the MCF, being inactive, requires minimal attention. Onboard the Freedom station the Facility is transported to the USL module and installed in a rack location. The Freedom-provided utilities are connected, and the Facility is checked out for operation. Experiment module experiment-specific hardware is installed, and the Facility is prepared for an experiment sequence. Telescience permits experiments to be performed with both flight-crew and ground-based investigators involved.

(5) *Return and postflight de-integration*. Eventually the experiments are completed. The experiment-specific hardware and, occasionally, experiment racks are removed from the USL module and returned to Earth. Here, equipment is de-integrated from the shuttle logistics carrier and returned to the Lewis S&TC. The test specimens and related hardware are then removed from the experiment module and given to the PI for data and specimen analysis.

(6) *Training (operations activity)*. Training prepares the flight crew (payload scientist), the science investigator (or PI), and the support personnel (systems engineers) to operate the MCF on the Freedom station. Individual scientists and engineers are trained to act as a team in operating the experiment. Special MCF and module training simulators will be used for this purpose at Lewis and at other centers such as Marshall and Johnson.

(7) *Mission simulations (operations activity)*. Simulations act not only as a rehearsal for flight operations but also as a system verification test. A number of mission simulations are conducted to verify the communications network between NASA centers and Freedom. These simulations test network

effectiveness, establish command and communications protocols, and verify telescience capabilities.

(8) *Flight operations (operations activity)*. Once onboard Freedom, the MCF is integrated into the USL module, checked out, and made operational. These on-orbit duties are supported from a ground-based systems engineering team at the DOC. When the MCF is fully operational and ready to perform experiments, the payload scientist, in concert with the ground-based PI, initiates the experiment. The PI can observe data and interact with the experiment via telescience.

Simulation model: The S.S. Freedom program requires that users provide a simulation module. These prototype derivatives will possess a level of fidelity necessary to provide effective payload specialist training in a Freedom station operational environment at Marshall and Johnson. The user-provided modules must be operable with the USL module and experiment simulators and be compatible with telescience; they must also support operation simulations and aid evaluation of the MCF's effectiveness in a simulated Freedom station environment. The following is a list of simulation model applications:

- Training of payload specialists
- Evaluation of flight operations and experiment procedures
- Training of technicians and systems engineers
- Supporting joint intercenter simulations
- Aiding in the development of telescience (remote interactive operation)

Integration ground support equipment: The integration GSE (fig. 36) will be utilized at the Lewis S&TC and at the launch site. It will support the Freedom station integration and the preflight checkout of both the MCF and the experiment modules, as well as system troubleshooting. The integration GSE consists of three emulators: (1) a USL-module utilities emulator, (2) an MCF emulator, and (3) an experiment-module emulator. Each emulator can be used separately for integration

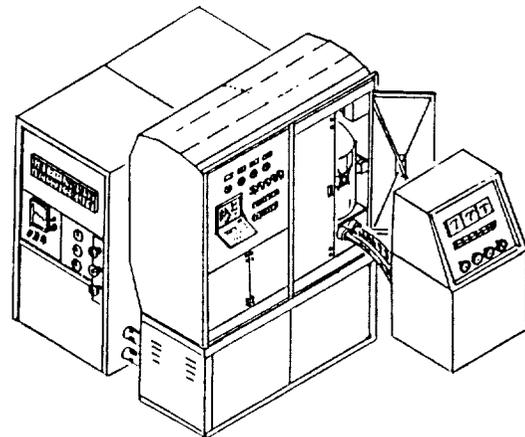


Figure 36.—Integration ground support equipment.

support and testing of its adjacent counterpart's flight hardware. The integration GSE has configuration-controlled system interfaces with high functional and interface fidelity, and it is capable of interfacing with the actual flight hardware or its emulator. It is also capable of isolating and testing individual systems. Special test controls, instruments, and displays are included for supporting Facility and module or experiment checkouts. The following is a list of integration GSE applications:

- Providing emulation support of the Facility simulator model
- Evaluating Facility or experiment interfaces
- Evaluating flight-readiness
- Providing preshipment checkouts
- Troubleshooting malfunctioning Facility and module subsystems
- Testing to verify corrective actions

Future space experiment accommodation.—The experiment module concept can provide varying levels of accommodation for experimenters who have varying levels of resources for the equipment and varying levels of sophistication in working with the space program.

Classes of experiment accommodation: The following classes are based on the equipment that the user supplies:

(1) *Experiment modules.* The user provides a complete self-contained experiment module. This approach is the most costly to the experimenter and requires considerable sophistication in experiment design and resources available; in addition the user bears much of the responsibility for safety and mission success. However, the approach does give the experimenter maximum flexibility and a greater assurance that the experimental hardware best achieves the intended scientific objectives.

(2) *Experiment-specific hardware.* In this case the microgravity program provides an experiment module with interface hardware, support subsystems, and experiment containment. The user provides experimental apparatus, experiment-specific software and instrumentation, and control algorithms. This approach reduces the cost of designing, developing, and qualifying systems with complex interface requirements by using program-developed or existing hardware. Responsibility for safety and fault tolerance shifts toward the program, but the flexibility to develop an apparatus specific to an experiment is preserved.

(3) *User-specific configuration.* The microgravity program provides the experiment module and experiment apparatus. The user provides the experiment information that affects the existing hardware configuration, such as experiment test parameters, new test specimens, and data format and acquisition rates. The cost to the user and the development time are minimized by the use of existing experimental apparatus and software. Safety and mission success are almost entirely the responsibility of the microgravity program. This option offers a minimum level of flexibility because it relies on already existing hardware.

Program support may consist of providing the experiment developers with development kits and the use of Facility engineering models, prototypes, and verification equipment. Freedom program-provided experiment module interface kits would be available through the Mission Integration Office.

In an experiment module development scenario, the MCF brassboard (engineering model) is used for verification of module hardware and software (including electronic compatibility), for fluids system stability, and for software validation, and so forth. Experiment simulators for training and evaluation are built or configured and installed in the MCF simulator. Experiment modules very likely require qualification testing to ensure that the Freedom station requirements for safety and reliability are met. The experiment module flight unit is interfaced with the MCF verification unit so that it may be certified as compatible with the actual flight MCF onboard Freedom.

In an experiment-specific hardware development scenario, all experiment-specific hardware undergoes development similar to the experiment modules, but because it is less complex, a less rigorous and time-consuming process is involved. Development testing of the hardware starts with the brassboard level and proceeds toward verification and qualification. Unlike the Facility and module development, the first set of hardware that satisfies the module verification and qualification requirements could become the flight unit with no need for hardware duplication for use in the DOC, S&TC, and so on.

Experiments based on a user-specific configuration utilize an existing apparatus that is already flight-qualified, so only configuration-dependent qualification needs to be addressed. In many cases the change in experiment configuration may be trivial, and essentially no development effort is required. If the experiment poses no safety issues or mission conflicts, providing the proper information to the Mission Integration Office offers a potential user an experiment opportunity.

Experiment development support kits: To simplify the experimenter's development effort and assure interface compatibility with the MCF, a set of experimenter interface and development kits is being considered. They are as follows:

(1) *Facility information kit.* This kit is intended to provide information that would assist the user in the conceptual design of an experiment. Such a kit would include a Facility-user handbook with guidelines for MCF operations, Facility capabilities documentation, program information and contact points, and Facility simulation model software. This kit would also provide information that would help in selecting the experiment accommodation option.

(2) *Experiment module interface kit.* This kit is intended to provide the experiment developer with both hardware and software for developing compatible experiment hardware prior to verification testing with the Facility engineering models and prototypes. Such kits would include interface requirements data, interface panels and connection hardware, and Facility control and data acquisition simulation software.

(3) *Experiment module qualification and flight kits.* To support the qualification and flight hardware phase, a set of flight-qualified hardware will be available. Depending on the experiment hardware, these kits could include a payload integration plan for the space shuttle and Freedom, an experiment containment enclosure (if required), a qualification and integration plan, a telescience and flight operations handbook, and a DOC handbook.

In addition to these development kits, the experiment developer is encouraged to utilize the in-house MCF development models, prototypes, emulators, and simulators to assure that module-Facility compatibility is established early in the development and is maintained through flight. Furthermore, users are expected to participate in and support training exercises as required.

Incorporation of advanced technology enhancements.—The ATD Program is developing technologies that have direct application to microgravity facilities including the MCF. Technologies such as laser diagnostics, high-resolution, high-frame-rate video, and other noncontact measurement techniques will have a dramatic impact on the science capabilities of these facilities, as well as on the development of telescience.

To best incorporate these enhancements, the MCF development plan includes an ATE development scenario that includes ATE in all of the following stages: breadboard development, prototype development, simulator for Facility simulator update, qualification, flight kit for flight facility enhancement, and verification kit for verification unit enhancement.

This scenario applies to the enhancement of the MCF that is assumed to be operational onboard the Freedom station and requires the on-orbit installation of the enhancements.

Modular Combustion Facility Development Schedule

The schedule in figure 37 shows the activities described in this section, indicates the four major phases, and gives the approximate duration of each activity. This schedule is based on the assumption that at least one precursor module will have been developed for use in Spacelab. The conceptual design review milestone has been shifted downstream to allow the development of this precursor to provide meaningful design information prior to the MCF design reviews. Note that the cross-hatched bars indicate integrated systems tests and that nearly 2½ years are devoted to systems-level testing.

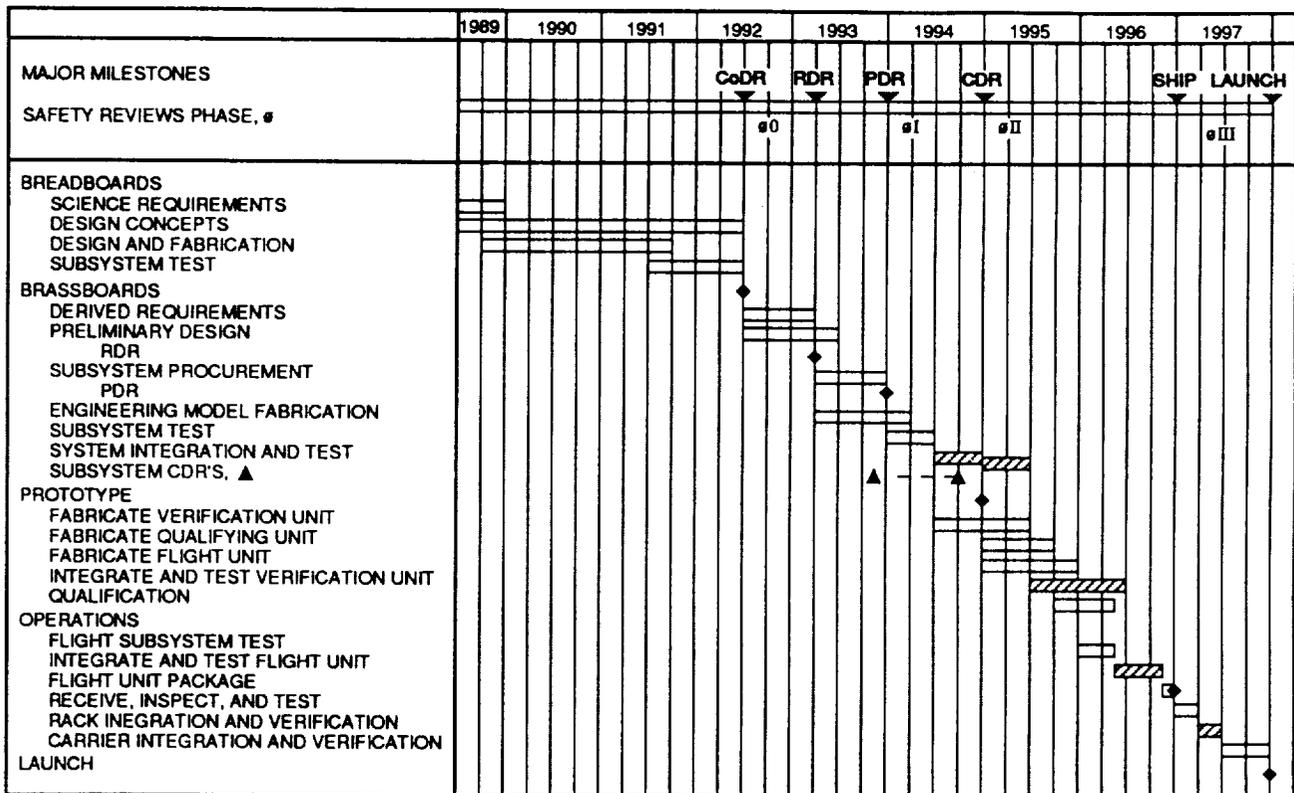


Figure 37.—Modular Combustion Facility development schedule.

Preliminary Work Breakdown Schedule

The work breakdown structure in figure 38 shows the major elements of the program organization.

Science definition is clearly the responsibility of the Space Experiments Division of the Lewis Space Flight Systems Directorate. Safety, reliability, and quality assurance are the responsibility of the SR&QA Division of NASA Lewis. The MCF hardware development will be handled by a project organization that is yet to be determined; currently it is managed by the Space Experiments Division, with project engineering provided by the Engineering Directorate with support from its support-service contractors. Because of the scale of the project and the manpower restrictions on civil service engineering, an outside contractor might perform a major portion of the development work. The exact arrangement is still to be determined. The mission-integration duties will be handled by a currently unassigned mission-integration office. Mission-integration personnel will be responsible for working with the S.S. Freedom program in the analytical integration of the MCF. They will also oversee the analytical integration between the MCF and user-developed experiment modules and experiment-specific hardware. And they will manage configuration and documentation control of the MCF. The operations office will be responsible for supporting flight operations and ground operations at other centers. Furthermore, it will handle Lewis operations at the

S&TC and DOC and develop the operational capabilities of these centers by utilizing the systems development laboratory.

Concluding Remarks

The Modular Combustion Facility (MCF) is being conceptually designed as a pressurized payload that will be located in the Freedom station's baseline U.S. Laboratory (USL) module. Because of the future integration of the MCF into the USL module, the S.S. Freedom program levies certain constraints on the current design of the MCF. These constraints come from several sources including those related to USL module and S.S. Freedom program safety requirements; those related to the capabilities and requirements of the USL module; those related to Freedom program operations and logistics requirements and capabilities; and those related to program funding and schedule.

In addition to these constraints, certain assumptions have been made by the Lewis project team for the current MCF design effort. Assumptions were required primarily because information on module systems or S.S. Freedom program operations was not available in the present early predesign phase of the program.

A summary of these constraints and assumptions, both general and structure- or system-specific, is followed by a summary of Facility descriptions and capabilities.

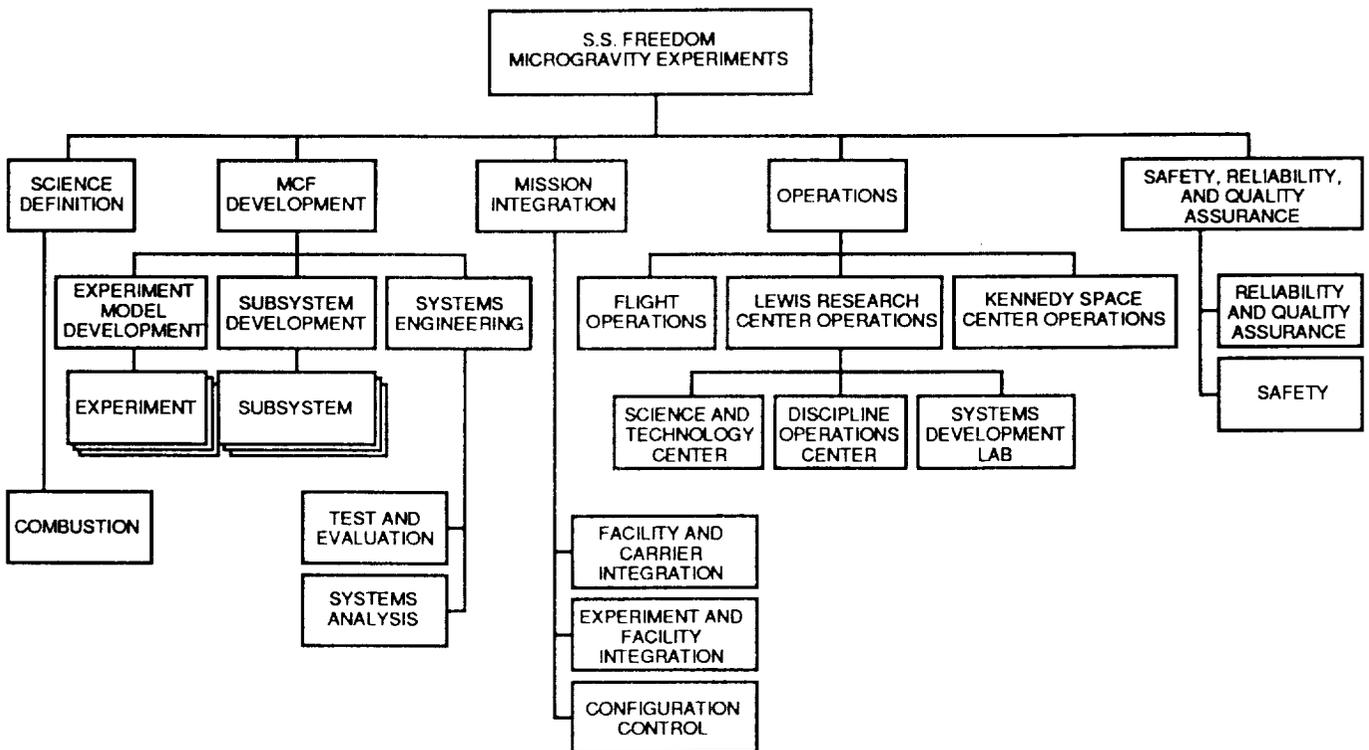


Figure 38.—Preliminary work breakdown structure.

Summary of Assumptions and Constraints

I. General

1. The Lewis charter is to conceptually design a multiuser, modular, user-friendly host facility that will accommodate experiment-specific hardware modules and provide common support systems and interfaces with the USL module utilities and subsystems.

2. The current Lewis Project Study Team is conceptually designing a host facility only (i.e., supporting systems), not experiment modules. It is attempting to define the requirements of candidate experiments to a point that is sufficient to assess experiment support systems requirements.

3. The MCF is being conceptually designed to fly in the USL module. For this study no provisions were made for possible locations in the international partners' Japanese Experiment or European Space Agency modules.

4. The MCF will not be manifested in the initial outfitting of the USL module. It will be sent to the Freedom station via a pressurized logistic module after Freedom is operational.

5. The MCF will remain onboard the Freedom station for an extended period of time. It will be designed for a 20-year life. Methods of incorporating advanced technology enhancements will be provided.

6. In defining the requirements of candidate users of the MCF, particularly in the area of consumables, the project study team made projections on the basis of a 90-day increment. In effect, the team asked users, "If the Facility were available to you for a full 90-day period, how much of each consumable would you use?" This period is consistent with the S.S. Freedom program reporting method, which is tied to the proposed 90-day cycle of shuttle visits to Freedom for logistics purposes.

II. Structure and racks

1. The Facility will be housed in two standard S.S. Freedom racks.

2. The designs of the MCF and the experiment module are constrained by the available working envelope of the Freedom station rack enclosure and by the maximum allowable payload weight of 700 kg per rack. However, portions of payloads in excess of 700 kg can be delivered separately and incorporated into racks on orbit.

3. The Freedom station racks may not be structurally modified. The MCF design must allow the racks to rotate about the lower front bottom to provide access to the back of the rack for necessary repairs to the USL module wall or for other maintenance. Flexible service lines and connectors are required to permit this rotation.

4. All experiment hardware must be designed such that it can be removed and installed on orbit without requiring removal of the primary rack structure.

5. Because the USL module hatch size allows only one rack through it at a time, each rack of the MCF must be designed to be transported to the Freedom station separately and then be assembled in place on the USL module.

6. The S.S. Freedom program will provide an interface panel at the bottom of each rack, outside the user's envelope. Mechanical and electrical connectors on this panel will provide USL module fluid consumables, power, and data connections.

7. The MCF and the experiment modules must be designed to withstand the rigors of a space shuttle launch.

8. All hardware in the MCF or the experiment module, particularly pressure vessels, must be designed to withstand a scheduled decompression and recompression of the USL module without yielding, cracking, or suffering other damage.

9. The Freedom program requires that structures be designed with an ultimate safety factor equal to or greater than 1.4. Pressure lines and fittings of less than 1.5 in. diam must have an ultimate safety factor equal to or greater than 4.0.

10. The Freedom program requires fracture analysis, stress corrosion analysis, and hazard analysis in accordance with program specifications.

11. The design of an experiment module containing a combustion experiment must provide for triple containment as required by SSP-30000, sec. 3.

12. A containment enclosure that maintains a negative pressure relative to cabin pressure will provide two of three required safety containment levels (see item 11).

13. The USL module crew members will be available to make interface connections between the racks.

III. Fluids and thermal system

1. The USL module will provide the following consumables at the interface panel at the bottom of the rack: argon, oxygen, helium, nitrogen, and ultrapure water. Hydrogen, carbon dioxide, and liquid nitrogen will be provided via bottles brought to the racks.

2. The environmental control and life support system (ECLSS) will supply cooling air to the Facility.

3. Fluids not furnished by the USL module or by the ECLSS must be furnished by the experimenter.

4. Access to the process materials management system (PMMS) will be on a scheduled basis. The MCF will be capable of temporarily storing experiment byproducts until the PMMS is available.

5. The MCF will provide storage of PMMS-supplied consumables that are not plumbed to the interface panel.

6. All MCF and experiment waste products can be exhausted into the PMMS.

7. The MCF will have the capability of supplying PMMS gases at experiment-required mixtures.

8. Fluids, including combustion byproducts of an experiment, will be transported from the experiment module, via the MCF, to the USL module PMMS. Such fluids are required to be under the constraints shown in table IV.

9. The Freedom station thermal control system will provide heat rejection of 30 kW (15 kW/rack) for the MCF.

10. Cold plates and heat exchangers will be designed and built by Marshall Space Flight Center (work package 1).

11. The vacuum vent system will be available for emergency venting of relief valves.

12. Safety requirements mandate dual shutoff valves to prevent possible unscheduled leakage into the USL module. One of these valves will be furnished by the PMMS on the PMMS side of the interface.

13. Each component and subsystem of the MCF and the experiment module will be required to be qualified for flight as per the S.S. Freedom program requirements.

14. Laboratory support equipment supplied by the Freedom program will be available for use in the MCF and the experiment setup and checkout.

IV. Electric Power

1. The USL module will distribute 120-V-dc electric power to the Facility at the rack interface panel.

2. The MCF will be required to minimize the voltage transients on startup and shutdown of equipment within it; for example, soft startup of electrical equipment such as large motors will be required. Specific requirements are not known at this time.

3. The MCF will convert USL module-provided power to other voltages and frequencies.

4. The Freedom station power management system will tightly control the use of all electric power on the station. The power to the MCF will be available on a scheduled basis.

5. The power available to any rack in the USL module will depend on the rack's location in the module. Rack locations will be rated at 3, 6, or 15 kW. The location of the MCF in the USL module (and thus the power level available) has not been determined at this time.

V. Computer System

1. There are three paths that data may take. The local bus has a data rate of 1 Mb/sec. The payload network has a bandwidth of 100 Mb and a throughput of 10 Mb/sec. The high-rate link will have a data rate of 100 Mb/sec.

2. The use of USL module crew time by the MCF or the experiment must be kept to a minimum. Automation, instrumentation, and data processing will be used to compensate for the lack of available crew time. In addition, the MCF will be run or controlled from the element control workstation (ECWS) or from the ground by using telepresence, to the greatest extent possible.

3. Sharing of resources among all of the Freedom station users will require strict scheduling of experiment run times. Resources include electric power, data transfer networks, fluid systems, and crew time.

4. The S.S. Freedom program will provide computer hardware and software whenever practical. This includes networking hardware and software, processor boards, and I/O cards of all types.

5. The S.S. Freedom program will handle all data storage and data transmission for the MCF.

VI. Diagnostics

1. The optical components of an optical diagnostic system are experiment-specific and, thus, will not be provided as part

of the MCF. However, a laser light source and imaging detector may be provided as part of the Facility.

2. Imaging systems are somewhat experiment-specific; whether video and film cameras and their optics will be provided as part of the MCF or experimenters will provide their own has not yet been determined. However, the controls and electronics required to support film and video cameras, including the storage of video information, will be provided by the MCF.

VII. Controls

1. The MCF computer will be the primary controller; the software required for overall experiment control and to maintain safety will reside in the MCF computer.

2. Inhibits are required to apply power to any device in the MCF.

3. Multiple measurements will be provided for any parameter needed for safety monitoring.

VIII. Software

1. The MCF software will be modular. It will be designed to allow the inclusion of experimenter-designed software modules for those experimenters who wish to use their own software for control and data acquisition.

2. The S.S. Freedom program has adopted Ada as the computer language to be used on the Freedom station. However, software that will be used for control, data acquisition, and analysis within the MCF may be written in a non-Ada language such as C and FORTRAN.

3. The software user interface will be menu-driven and user-friendly.

Summary of Facility Descriptions and Capabilities

I. Physical description

- (1) Contained within two standard S.S. Freedom racks
 - (a) Facility rack contains support systems
 - (b) Experiment rack includes experiment containment enclosure, experiment module, and experiment-specific hardware
- (2) Facility rack remains onboard the Freedom station for life of MCF
- (3) Experiment racks interchanged periodically as required
- (4) Two strawman experiment racks with experiment modules identified
 - (a) Combustion chamber
 - (b) Low-speed combustion tunnel
- (5) Multiple experiment-specific apparatus to fit within strawman experiment modules

II. Electrical capabilities

- (1) Power available
 - (a) Facility rack: 6 kW
 - (b) Experiment rack: 3 kW
 - (c) Interchanged between racks

- (2) Voltages available
 - (a) 120 V dc, direct
 - (b) 28 V dc, by conversion
 - (c) Other voltages and frequencies as required by conversion
- (3) Computer system comprised of facility-rack computer and experiment-rack computer for data acquisition and control
 - (a) 32-b Intel 80386 microprocessor
 - (b) 4 MB of memory
 - (c) 4 MIPS (million instructions per sec)
 - (d) 10 mb/sec fiber-distributed data interface
- (4) Control system monitors and controls the electrically controlled hardware of the MCF and the experiment
- (5) Instrumentation and data acquisition system supports
 - (a) National Institute of Standards and Technology-calibrated thermocouples
 - (b) Resistance temperature devices
 - (c) Strain gage devices, including pressure transducers
 - (d) Frequency generating devices, including flowmeters
 - (e) Any transducer providing a voltage or digital output
- (6) Mechanical fluid system
 - (a) Fluids supply system
 - Available fluids: O₂, N₂, Ar, CO₂, He, H₂, and H₂O
 - (b) Gas mixing system
 - Provides custom-mixed combustion atmospheres
 - Mixes any combination of available gases except H₂
 - (c) Waste conditioning system
 - Processes experimental byproducts before passing them on to S.S. Freedom waste management system
 - Conditions byproducts as shown in table III.

- (7) Thermal control system
 - (a) Two liquid-to-liquid heat exchangers
 - Inlet temperature: 24 °C
 - Maximum outlet temperature: 49 °C
 - (b) Cold plates
 - Heat loads: 400, 600, and 1000 W
 - (c) Avionics air cooling
 - Maximum cooling by rack: 1500 W

III. Special instrumentation

- (1) Gas chromatograph/mass spectrometer
 - (a) In-line processing type
 - (b) Identifies and analyzes products of combustion
 - (c) Secondary use as a safety and quality control instrument
- (2) Optical measurement system
 - (a) Nonintrusive evaluation tool
 - (b) Experiment-specific type of system
 - (c) Facility support consists of
 - Master laser light source
 - Detector electronics

IV. Imaging systems

- (1) Cameras and optics are experiment-specific
- (2) Not determined if cameras and optics will be part of Facility
- (3) Facility support of
 - (a) Controls and electronics
 - (b) Storage and transmission of video information

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 April 15, 1989

Appendix A Definitions

A/D	analog-to-digital	MCVC	miniature color video camera
ATD	Advanced Technology Development (program)	MDM	multiplexer-demultiplexer
ATE	advanced technology enhancements (from ATD)	Mil.Spec.	Military Specification (set of standards)
C&W	caution and warning	MIPS	million instructions per second
CDU	control distribution unit	NHB	NASA Handbook
CDR	critical design review	NIST	National Institute of Standards and Technology (formerly National Bureau of Standards)
CoDR	conceptual design review	NTSC	National Television Standards Code
DMS	data management system	OSSA	Office of Space Science and Applications (NASA Headquarters)
DOC	Discipline Operations Center (Lewis)	PDCU	power distribution and control unit
ECLSS	environmental control and life support system	PDR	preliminary design review
ECWS	element control workstation	PI	principal investigator
EDP	embedded data processor	PMMS	process materials management system
EMI/EMC	electromagnetic interference/compatibility	PSR	preshipment review
EPDS	electric power distribution system(s)	RBP	reactive bed plasma
ESA	European Space Agency	RDR	requirements definition review
EVA	extravehicular activity	RTD	resistive temperature device
FDDI	fiber-distributed data interface (protocol)	SED	Space Experiments Division (Lewis)
FMEA	failure mode and effects analysis	S&TC	Science and Technology Center (Lewis)
GC/MS	gas chromatograph/mass spectrometer	SDP	standard data processor
GSE	ground support equipment	SR&QA	safety, reliability, and quality assurance
JEM	Japanese Experiment Module	TCS	thermal control system
HHVT	high frame-rate, high-speed video technology	TDRSS	Tracking and Data Relay Satellite System
I/O	input/output (usually with reference to a computer)	USL	United States Laboratory (module)
MCF	Modular Combustion Facility		

Appendix B Preliminary Hazard Analysis

Hazardous condition	Cause	Effect	Level	Controls	Applicable MCF system
Release of toxic/ combustible gases or fluids into experiment or Facility enclosures, the facility rack, or USL module	Attachment failure Pressure transducers Flowmeters Sample ports Improper assembly Combustion chamber/ tunnel leaks Improper seals Cracks in chamber Experiment or facility containment enclosure leaks Overpressurization Corrosion damage Window breaks Inadvertent opening of chamber door Lines/fittings leak Improper design and/or assembly	Fire/explosure Illness Uninhabitable atmosphere Contamination Corrosion	Catastrophic	Torque requirements for proper seal Checkout/inspection procedures Assembly per specification by trained and certified personnel Chamber designed to meet maximum expected operating pressure Meets design specifications Leak checks Chamber/tunnel within containment enclosure Relief system is two-fault tolerant Meet material compatibility requirements per MSFC-STD-527 Gaseous nitrogen atmosphere Containment enclosures connected to PMMS Windows designed to meet the Freedom station safety factor for glass Interlock system Trained personnel performing approved procedures Meet design specifications Assemble per specification and by trained personnel Leak detection	Instrumentation Fluid supply Structures
Support structures fail	Improper material selection allows corrosion Improper installation Inadequate design loads Vibration	Collision	Catastrophic	Use compatible materials with experiment fluids and gases Comply with MSFD-STD-527 Inspection of materials Test materials to meet S.S. Freedom laboratory atmospheres Installation by certified personnel Meet design specifications Design to SF = 1.5 Fracture control plan Meet appendix A vibration design and test requirements	Structures
Broken/loose objects within the facility or experiment racks damage equipment	Attachment failure Pressure transducers Flowmeters Sample ports	Collision Injury	Catastrophic	Torque requirements for proper seal Checkout/inspection procedures	Instrumentation

Hazardous condition	Cause	Effect	Level	Controls	Applicable MCF system
System components overheat	Failure of thermal control system for experiment exhaust processing system Electrical shorts Connector fails	Temperature extremes	Critical	Detection system Protect from overloads Inspection	Fluid supply Instrumentation
Overpressure of contained gases or fluids	Gas storage bottles Overtemperature in facility rack Combustion chamber Valve fails open Control failure of sensor Software error Regulator failure Experiment exhaust processing system Explosive reaction in exhaust of experiment by-products	Fire/explosion Explosion	Catastrophic	Build per design specification Vent and relief system Meet design specifications Fail-safe system Validation checks in software Meet design specifications Detection of mixtures prior to entering the experiment exhaust processing system Dilution of by-products Facility containment enclosures	Fluid supply
Electrical shock	Exposure to high voltages Regulator failure Improper procedure allows crew member to contact high voltage source Improper grounding Improper design sizing No strap included Overcurrent of power for camera Camera mounting motor field winding failure Improper connections Static discharge from CRT (under normal operations)	Injury/shock	Critical	Breakers Voltage sensors Surge suppressors Train crew members Meet design specification and requirements Follow proper installation Meet design specifications Inspection of motors Use of approved procedures by trained personnel Use of band around CRT to help dissipate static charge Maintain proper environment	Control system Power distribution Imaging system Diagnostic optical system Data acquisition
Circuit overloads causing over-temperature/fire	Improper circuit protection Fuses wrong size Circuit breaker wrong size Tranzorb wrong size, improperly installed, or fails itself	Fire	Catastrophic	Meet proper design specifications Install per specification by trained personnel	Control system Data acquisition

Hazardous condition	Cause	Effect	Level	Controls	Applicable MCF system
Exposure of frayed or damaged cable wiring	Improper installation Wear due to aging	Electrical Shock Fire	Catastrophic	Installation performed by trained and certified personnel Inspection/testing per specification and requirements	Power distribution
Sparking in combustible atmosphere	Damaged connectors Use of limit switches Use of motors	Explosion Fire	Catastrophic	Use of explosion-proof equipment Use of nitrogen-purged enclosures Design per code	Power distribution
Overcurrent	Short Improper wire sizing	Fire	Catastrophic	Use of breakers, fuses, and current limiter	Power distribution
Software system fails to operate as intended causing overtemperatures and overpressures	"Bug" in control software Command error by operator	Fire/explosion	Catastrophic	Testing to eliminate "bugs" Hardware designed to fail-safe with respect to software failure Validity checked within software to assure proper sequencing Operations performed by trained personnel	Software
Presence of ozone	Xenon arc lamp (under normal operation)	Uninhabitable atmosphere	Critical	Ozone eliminator system Venting	Diagnostic optical
Explosion of bulbs	Xenon arc lamp (common to these bulbs)	Fire	Catastrophic	Containment of broken bulb in event of explosion	Diagnostic optical
Implosion of CRT releases shrapnel/toxic compounds into experiment containment enclosure or into the facility rack	CRT may be struck during improper procedures	Contamination Injury	Critical	Trained crew Support bands will be placed around the tube to give extra structural support CRT will be flight proven Front of CRT will be enclosed to limit shattering	Imaging system
Camera system and associated lighting creates EMI and interferes with control devices	Improper design Lack of shielding	Radiation	Critical	Meet design specification and requirements Assure proper shielding Meet test requirements Electrical devices to filter out radiation	Imaging system
Generation of heat from laser	Misdirection of laser beam Laser electrical failure overheats box	Fire Radiation Injury	Catastrophic	Meet design specifications Trained crew Monitoring of the system	Diagnostic optical

Appendix C

Fracture Mechanics Plan

For the MCF, all fracture-critical hardware (mechanical, fluids, and structural) will be subject to fracture mechanics control. The purpose of this control is to ensure structural adequacy of critical components during operation on the S.S. Freedom's USL module and in related space transportation system launch and transport operations.

Electrical components, in general, will not require fracture mechanics control. Exceptions are related mechanical parts (i.e., interface panels, connectors, and mounts). Diagnostic systems (i.e., cameras, videos, lasers, etc.) will be reviewed on an individual component basis.

Fracture control of experiment-furnished parts will be the responsibility of the experimenter. Parts within the MCF that are currently identified as requiring fracture control are

- Fluid supply bottles
- Mounts for facility and experiment hardware
- Waste bottles
- Bracing structures
- Interface panels
- Diagnostic equipment mounts
- Mechanisms
- Viewing windows
- Facility containment enclosure
- Experiment containment enclosure
- Pumps
- Heat exchangers
- Fans

A fracture control plan is being prepared to define the elements of the MCF fracture control programs and the responsibility for managing and accomplishing them. The plan will be in compliance with NHB 8071.1 "Fracture Control Requirements for Payloads Using the National Space Transportation System," dated September 1, 1988. As a minimum, this plan will describe the methods and procedures to be used for the following:

- (1) Fracture-control classification of components
- (2) Analysis and/or testing and inspection to determine fracture-control acceptability of hardware
- (3) Control of materials, manufacturing processes, testing, design changes, and transportation
- (4) In-process verification and control, including nondestructive evaluation inspections, to insure proper implementation of requirements
- (5) Overall assessment of the payload fracture control activity and results

Appendix D Contributors

This document was prepared by members of the Lewis Research Center Space Station Microgravity Experiment Facilities Study Team. Team members and their areas of responsibility are as follows:

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16. Abstract A study team at NASA's Lewis Research Center has been working on a definition study and conceptual design for a combustion science facility that will be located in the Space Station Freedom's baseline U.S. Laboratory module. This modular, user-friendly facility, called the Modular Combustion Facility, will be available for use by industry, academic, and government research communities in the mid-1990's. The Facility will support research experiments dealing with the study of combustion and its byproducts. Because of the lack of gravity-induced convection, research into the mechanisms of combustion in the absence of gravity will help to provide a better understanding of the fundamentals of the combustion process. This document has been prepared as a final version of the handout for reviewers at the Modular Combustion Facility Assessment Workshop held at Lewis on May 17 and 18, 1989. It covers the background, current status, and future activities of the Lewis Project Study Team effort. It is a revised and updated version of a document entitled "Interim Report of the Concept Design for the Space Station Modular Combustion Facility," dated January 1989.					
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