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CONCEPTUAL DESIGN OF THE SPACE STATION FLUIDS MODULE

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### 1. Introduction

The purpose of this paper is to describe the conceptual design of the Fluids Module for the International Space Station Alpha (ISSA). This module is part of the Space Station Fluids/Combustion Facility (SS FCF) under development at the NASA Lewis Research Center. The Fluids/Combustion Facility is one of several science facilities which are being developed to support micro-gravity science investigations in the US Laboratory Module of the ISSA. The SS FCF will support a multitude of fluids and combustion science investigations over the lifetime of the ISSA and return state-of-the-art science data in a timely and efficient manner to the scientific communities. This will be accomplished through modularization of hardware, with planned, periodic upgrades; modularization of like scientific investigations that make use of common facility functions; and through the use of orbital replacement units (ORUs) for incorporation of new technology and new functionality.

Portions of the SS FCF are scheduled to become operational on-orbit in 1999. The Fluids Module is presently scheduled for launch to orbit and integration with the Fluids/Combustion Facility in 2001.

The objectives of this paper are to describe the history of the Fluids Module concept, the types of fluids science investigations which will be accommodated by the module, the hardware design heritage, the hardware concept, and the hardware breadboarding efforts currently underway.

## 2. Background

NASA Lewis Research Center (LeRC) received approval from NASA Headquarters to begin a definition study and conceptual design effort for a Fluid Physics/Dynamics Facility in June of 1987. The objective of this study was to assess the feasibility, effectiveness, and benefits to potential users of a modular, multi-user facility for performing fluid physics science and applications experiments aboard the Space Station Freedom [1]. Facility class hardware has been considered as an alternative to experiment specific hardware for several reasons; 1) modular, multi-user facilities can provide resources or services to users which are non-standard to space station, 2) the modular approach allows for growth in capabilities over time, 3) common subsystems developed across facilities can improve maintainability and minimize logistics requirements, 4) minimizing the individual investigators experiment hardware can reduce the individual experiment development time, and 5) the facility approach can minimize cost to the overall science discipline program while maintaining operational flexibility.

A study team worked with a facility project scientist from The LeRC Space Experiments Division (SED) fluids science group to define science requirements for formulation of a concept. The process used to define the requirements started with the Fluids Discipline Working Group (DWG), which defined fundamental areas of micro-gravity fluid physics and fluid dynamics research. A reference set of fluids experiments was developed from this definition of research areas. Some of these reference experiments were determined to be more appropriate in other facilities which were also being conceptualized for operation on the space station, such as a containerless processing facility, a fundamental science facility, a biotechnology facility, and a furnace facility. Thus the reference experiments allocated to be performed in the Fluid Physics/Dynamics Facility were deemed to have appropriate commonality and scientific significance to require a unique facility dedicated to fluids physics investigations. This initial reference experiment list contained the following experiment types [2]:

1. Surface Tension Induced Instabilities and Flows
2. Free-Surface Phenomena
3. Immersed Bubble/Droplet Dynamics and Interactions
4. Multi-component/Coupled Flow (Moderate temperatures and pressures)
5. Multi-phase Flow
6. First-Order Phase Transitions (Moderate temperatures and pressures; no externally induced flow)

These were then appropriately combined into what was considered the reference categories of micro-gravity fluids science:

- I. Iso-thermal/Iso-solutal Capillary Phenomena
- II. Capillary Phenomena with Thermal/Solutal Gradients
- III. Thermal/Solutal Convection and Diffusive Flows
- IV. First Order Phase Transitions in a Static Fluid
- V. Multi-phase Flow

The study team held interviews with NASA funded fluids Principle Investigators (PI's) and project scientists to develop the specific experimental requirements for each of the above listed categories. These experiment specific requirements were then used as the basis for this team to develop a conceptual design of a Space Station Freedom based Fluids Physics/Dynamics Facility.

It was at this point in the effort, in 1990, that a Space Station Freedom Fluid Physics/Dynamics Facility Assessment Workshop was held at the Lewis Research Center. The purpose of the workshop was to obtain science and engineering assessments of the Fluid Physics/Dynamics Facility design and operational concepts as well as the selected micro-gravity fluids science requirements used to develop those concepts.

As a result of this workshop, the study team further developed the experiment specific requirements with example science requirements documents for the following experiments [3]:

1. Free Surface Phenomena
2. Bubble/Droplet Migration
3. Surface Tension Driven Convection
4. Surface Tension Induced Instabilities
5. Adiabatic Multi-phase Flow
6. Pool Boiling
7. Non-Adiabatic Multi-phase Flow
8. Thermal/Solutal Convection

The conceptual design effort continued by focusing on accommodating these eight experiments in the Fluid Physics/Dynamics Facility until the release of the 1992 NASA Research Announcement (NRA). This NRA resulted in the selection of six potential PI's for the Fluid Physics/Dynamics Facility. During this time the Space Station Freedom Program was evolving to become what is currently known as the International Space Station Alpha (ISSA). Changes also occurred in the organization of the Fluid Physics/Dynamics Facility in that it was now envisioned as a combined facility with the Modular Combustion Facility, sharing common functions, such as data handling, communications, and carrier interfaces. These combined facilities are now called the Space Station Fluids/Combustion Facility (SS FCF) which houses a Fluids Module for performing micro-gravity fluids science, and a Combustion Module for performing micro-gravity combustion science, with shared resources for both.

### **3. Fluids Science Accommodations**

In order to design the SS FCF Fluids Module such that a broad range of fluid physics research areas are accommodated, a fluids science requirements "envelope" was established. This fluids science envelope currently consists of six flight definition experiments and five potential flight experiments from the 1992 NRA. These five potential flight experiments are currently in the ground-based fluids experiment program at NASA in the science areas emphasized by the Fluids DWG and the workshop described above, and are expected to be representative of future flight experiments. Five of the six flight definition experiments were selected from the 1992 Fluids NRA process. The sixth flight definition experiment is from the 1991 Materials NRA process. This materials investigation is believed to have enough commonality with the fluids investigations in the science envelope to be considered for manifesting on the Fluid Module. These eleven science experiment areas have been summarized and forwarded through NASA Headquarters to the Fluids DWG for formal approval as the Fluids Module science requirements envelope. This science envelope consists of the following investigations:

#### Flight Definition Experiments:

1. Evaporation from a Meniscus within a Capillary Tube in Micro-gravity
2. Microscale Hydrodynamics Near Moving Contact Lines
3. The Extensional Rheology of Non-Newtonian Materials
4. Dynamics of Hard Sphere Colloidal Dispersions
5. Colloidal Physics in Micro-gravity
6. Reverse Micelle Based Synthesis of Microporous Materials in Micro-gravity

#### Envelope Experiments:

1. Interaction of Bubbles and Drops in a Temperature Gradient
2. Phase Segregation Due to Simultaneous Migration and Coalescence
3. Interfacial Transport and Micellar Solubilization Processes
4. Studies in Electrohydrodynamics
5. Thermocapillary and Double-Diffusive Phenomena

The bulk of the eleven investigations listed above can be traced back to the five reference categories of micro-gravity fluids science mentioned in section 2. In addition, several investigative research areas have either been added to the SS FCF fluid science envelope or have been shifted to other carriers. For example, electrohydrodynamics has been added, while multi-phase flow has been shifted to larger carriers (ex. Shuttle cargo bay pallets) due to size and scaling factors required for this research area.

The SS FCF Fluids Science Requirements Envelope Document (SRED) has been drafted based on individual experiment Science Requirement Documents (SRDs), NRA proposals, and requirements gathered from current ground-based research projects. The primary purpose of the SS FCF fluids SRED is to document the envelope of science requirements from which the SS FCF Fluids Module is designed. The fluids SRED will be used in the engineering specification development process, along with combustion science and Space Station carrier and safety requirements. As specific investigations are assigned to the Fluids Module, investigation-specific requirements will be accommodated in the system specification and the hardware design.

#### **4. Hardware Heritage**

The design of the SS FCF will draw upon the design of as many previous space experiments as possible. Since the science requirements envelope includes many investigations that have previously been performed on orbit or are being developed, it only makes sense to utilize the previous development efforts to minimize cost and design effort. The hardware heritage for the Fluids Module of the SS FCF can be broken into two areas, that of diagnostics and that of test apparatus.

**A. Diagnostic Heritage:** There is one experiment that is currently in development which the SS FCF design team plans to utilize as a basis for a facility diagnostic system. The Physics of Hard Spheres Experiment (PHaSE) project at LeRC, is currently developing a laser light scattering instrument (LLSI) that will be used in an experiment to fly aboard the Shuttle. The PHaSE LLSI, shown in figure 4.A-1 is designed to provide some early science data, but due to schedule constraints, cannot accomplish all of the science that the SS FCF LLSI will be required to accomplish. The SS FCF will use the PHaSE design as the basis for a LLSI that will meet all of the diagnostic requirements for such an instrument in a facility. Further information on the SS FCF LLSI is provided in section 5.B.

There are a number of other flight and ground experiments that have flown or are being developed for flight that may serve as a basis for design of facility diagnostic systems. Other than the LLSI instrument discussed above, the rest of the diagnostics have been evaluated only at the conceptual level. As these facility diagnostic concepts develop into detailed designs, the design from these other experiments will be evaluated to see if they meet the facility requirements. Some of these other experiments are the Surface Tension Driven Convection Experiment (STDCE) I & II, the Bubble Droplet Particle Unit (BDPU), Microscale Hydrodynamics Near Moving Contact Lines, The Extensional Rheology of Non-Newtonian Materials, Evaporation from a Meniscus within a Capillary Tube in Micro-gravity, and the Drop Physics Module (DPM).

**B. Test Apparatus Heritage:** Design of the test apparatus will be very specific to the science investigation that will be performed. As these specific investigations become manifested in the facility, the design of the apparatus will certainly draw on that of previous experiments, including those identified above.

## 5. Hardware Description

The concept for the SS FCF has been developed based on the envelope of science requirements discussed in section 3 and those for the Combustion Module portion of the project. The concept is a three rack facility as shown in figure 5-1. The left hand rack contains the hardware required to support combustion experiments. The right hand rack contains the hardware required to support fluid physics and dynamics experiments and the central rack provides core functions and control to the other two racks. A Hardware Capabilities Document (HCD) is being drafted that will provide details on capabilities of the SS FCF. The HCD will be kept current so it can be used as a source of information for potential users. The discussion that follows will address only the central, or core rack and the fluids rack. The hardware in the racks can be grouped into three categories: level 1, 2 and 3.

Level 1 hardware is that hardware which, although designed for change out for maintenance or upgrade, is planned to be a permanent feature of the facility. The rack structure of the fluids rack, a number of packages in the lower portion of the fluids rack and the entire core rack are included in this category.

Level 2 hardware is that hardware which supports a large number of the flight and envelope experiment and/or promotes future use of the facility. For the SS FCF Fluids Module, this hardware is comprised of experiment modules (EMs) which can be inserted into and removed from the rack and are supported by the level 1 hardware. Currently three EMs have been conceived. One, called a LLSI EM, supports a group of experiments which have small test volumes and require a LLSI. A second one, called a Thermo-capillary/Thermo-solutal (TCTS) EM, supports a group of experiments that require moderate test volumes with orthogonal imaging. The third EM supports a group of experiments that require large test volumes and have little common hardware.

Level 3 hardware is that which is experiment specific. The majority of this hardware consists of test cells and unique diagnostics or test set-up and is supported within the EM that is accommodating the investigation. This hardware is generally provided by the project team responsible for the specific science and not by the SS FCF project. This hardware could become part of a level 2 EM if a future need for the same hardware develops.

**A. Level 1 Capabilities/Description:** The level 1 hardware concept and interfaces are shown in block diagram form in figure 5.A-1. Level 1 hardware provides the primary interface to space

station systems and the crew. The level 1 hardware also provides space for, interfaces to, and control of the level 2 hardware. Following is a description of the various functions performed by the level 1 hardware.

Structural Support: The Level 1 hardware provides structural support for all of the level 1 packages and the level 2 EMs. This support is accomplished through the use of two International Standard Payload Racks (ISPRs) which directly mount into the space station U.S. Laboratory Module.

Facility Control and Data Acquisition: Facility control and data acquisition will be accomplished by implementing a distributed control, Versa Module Europe (VME) bus system architecture. One VME bus system will be located in the core rack to provide facility level control and one will be located in the fluids rack to provide control to the level 1, 2 and 3 hardware located in that rack. A Fiber Distributed Data Interface (FDDI) system has been chosen for inter-rack communications due to the high data rates that will be required. The control and data interface with space station will be via a Mil-1553 B interface system. Data storage will be stored on 120 mega-byte, replaceable media units.

Crew Interface: The crew interface will provide a system for the crew to view digital and video data and control the facility. This system will include a video monitor and a laptop computer.

Video Image Control, Processing and Storage: Level 1 will provide for routing, processing and storage of video images generated by the facility. Another VME bus system will be used to provide this control, digitization and compression of images so that the images can then be stored. Digitization and compression of images is required so the data can be stored on a reasonable size drive and sent to the ground within a reasonable time frame.

Electrical Power: Level 1 hardware will provide for conditioning, conversion and distribution of 120 VDC power provided by space station. The core rack will provide for 28 VDC and 120 VDC to the fluids rack and the fluids rack will additionally provide 5 VDC and 12 VDC.

Thermal Control: Level 1 hardware will interface with the space station low and moderate temperature water systems to reject excess heat. Both the core and fluids rack will have an avionics air system tied into the water systems to provide forced air convection cooling. In addition, the core rack will contain heat exchanger/pump assemblies to route cooled water to specific hardware in levels 1, 2 and 3 that require large amounts of cooling.

Vibration Data Processing: A Space Acceleration Measurement System II (SAMS II) Remote Triaxial Sensor Electronics Enclosure (RTS-EE) will be located in the core rack to provide data processing and measurement support for sensor heads that will be located in level 2 hardware.

**B. Level 2 Capabilities/Description:** Each EM is designed to

interface in the same manner with level 1 hardware. The structural interface consists of slide rails that allow the EMs to be installed easily and fasteners to fix the EMs to the ISPR corner posts. All fluid and electrical interfaces are then made through a common interface panel. This configuration is shown in figure 5.B-1 for the LLSI and TCTS EMs. The EM itself provides one level of containment for any hazardous materials located within it.

LLSI EM: The LLSI EM is designed to perform full angle static and dynamic laser light scattering. As discussed previously the instrument to do these measurements is based on the design for the PHASE instrument. The instrument is shown configured in the EM in figure 5.B.1-1. The laser source, detectors and other hardware that make the measurements are mounted in a fixed location and a carousel allows eight test cells to be moved into position for data collection. These test cells are the level 3 hardware that would be provided by the specific science investigation team. Rheology and variable volume fraction could be accommodated in these test cells. Details of a generic test cell and the measurement system are shown in figure 5.B.1-2. The LLSI is located in the central portion of the EM which will be thermally controlled to maintain a desired temperature. Electronics and other heat sources will be located behind a thermal barrier to ease thermal control of the test cells. Space is also provided to store additional carousels and test cells. The usable internal volume of the EM is approximately 450 mm. high x 900 mm. wide x 600 mm. deep. Each carousel, including test cells, is estimated to have a mass of 7 kg. The level 3 test cells are approximately 70 mm. diameter by 100 mm. tall.

TCTS EM: The TCTS is designed to perform microscopic and macroscopic orthogonal imaging and laser interferometry of a test cell or multiple test cells. These options are shown in figures 5.B.2-1, -2 and -3. The level 2 hardware provided within the EM consists of two video cameras mounted on 3-axis translation stages for test cell imaging and tracking of bubble, drops, or fluid interfaces that are of interest; two sets of microscopic and macroscopic lenses for the cameras; appropriate lighting for the camera images; an interferometry system; six dispenser mechanisms to provide a supply source for bubbles and drops; two deployment mechanisms to deploy the bubbles and drops; a translation stage to provide any required test cell motion, including aspect ratio changes; and thermal control hardware to reject heat and support test cell thermal boundary condition maintenance. The usable internal volume of the EM is approximately 550 mm. high x 900 mm. wide x 850 mm. deep. Space allotted for the test cells, which are level 3 hardware, is approximately 125 mm. square by 300 mm. tall, with a mass of less than 16 kg.

Large EM: The large EM is configured to support a variety of experiments which require larger test volumes and have less

diagnostics commonality. At this time, the only hardware envisioned to be provided within this EM by level 2 is general thermal control. The rest of the volume would be allocated to level 3 hardware. Level 2 hardware developed for other EMs may be used in this EM if it meets the needs of the specific science investigation being performed. The usable internal volume of the EM is approximately 1000 mm. high x 900 mm. wide x 600 mm. deep.

Future EMs: The three EMs described above have been configured for the classes of experiments that are currently in the SRED. As specific science investigations are identified that will operate in the facility, these may require modification. At that time additional EMs will be designed to meet the needs of the science. These EMs will utilize as much of the design of the other EMs as possible and could range in size up to the large EM size.

**C. Software:** The SS FCF project will provide the majority of the software required to perform the science investigations. This software will reside on the VME bus systems that are part of the level 1 hardware. There are two cases where this is not true: 1) if there are specific control algorithms/software required that have been developed by a specific science investigation team and which can be integrated with the facility software, and can be loaded into the VME bus system in the fluids rack, and 2) if a controller is included in the level 3 hardware, then the specific science investigation team could write software that would reside on the controller and interface with the facility.

**D. Logistics Scenario:** A logistics scenario is the concept for getting experiments to the space station, operating them in the SS FCF, and bringing them back to the ground. The current concept for getting experiments to the space station is launch as cargo aboard a space vehicle. Once on-orbit, an EM would be installed into the Fluids Module by an astronaut. Installation of the EM would include making all hardware connections with the FCF (e.g. power, data, vacuum/vent, nitrogen), verifying these connections, and performing functional check-out of the EM, including hardware and software. The astronaut would then install the experiment specific hardware into the EM, by making all hardware connections between the experiment specific hardware and the EM, verifying these connections, and performing functional check-out of the experiment specific hardware.

The operations of the experiments are very dependent on the experiment being performed and the EM into which it is installed. The concept for operations is to maximize the effectiveness of the crew time by automating experiment functions when it is experimentally and technologically practical as well as cost efficient.

Resources which need replenishment will be planned for and the resupply of these will be negotiated with the ISSA and the resupply vehicle programs.

Experiments which are completed will be removed by an astronaut and packed for return to Earth in the appropriate carrier. However, the EMs may remain installed in the FCF and another PI's experiment installed for operation in the EM. This could continue as long as there are experiments planned for operations in that EM. These experiments could all be on-orbit at the same time or could be taken up on consecutive flights.

When all planned operations for an EM are complete it will be de-integrated from the FCF and packed for shipping back to Earth. Another EM will be installed into the FCF in its place, or possibly, if a large EM is removed, two EMs may be installed in it's place. This concept of continual resupply of experiments and EMs for the FCF will ensure that the NASA micro-gravity fluids science program has a consistent and constant platform for performing micro-gravity fluid physics research.

## 6. Breadboard Plans/Accomplishments

The SS FCF Project is currently in the process of capturing all of the requirements that it will have to meet to perform the science described in the SRED. A necessary part of this conceptual phase of the project is to demonstrate that systems can be designed to meet key performance parameters. This may include development of new technologies to meet these needs. Most often, this is addressed by breadboard testing of systems that potentially will be used in the final design. Three breadboards are currently in work and another is being planned to support the SS FCF project. In addition, other projects are currently performing breadboards which are associated with the specific type of investigation they are considering for flight in the SS FCF. These breadboards are described below.

**A. Automated Positioning and Tracking (APT):** The envelope of science requirements includes a number of investigations where high resolution images of small features (on the order of 0.01 mm.) in the test cell are required. A high resolution camera with a microscopic lens is required to adequately image these features. As part of the science investigation, these features will be in motion. The simplest approach to image this would be to have a fixed camera with a large field of view, however the resolution could not be obtained within the volume constraint of the facility. The current imaging concept to accomplish has the cameras mounted on translation stages. The cameras translate to keep the desired feature in the field of view. An option to this has been proposed where the camera is fixed and a scanning mirror is adjusted to keep the feature in the field of view.

Although these both appear to be feasible, there are many challenges which have to be met. It was therefore decided that this system would require a breadboard to demonstrate that it could meet the science requirements. Some of the functions that the breadboard must prove the feasibility of are: 1) recognize

the feature that is desired, 2) determine the camera/mirror motion required to keep it within the field of view, 3) translate the cameras/mirrors while keeping the image in focus and retaining image resolution, and 4) maintain knowledge of the camera image relative to a fixed point of reference.

The current effort on the breadboard is to test the baseline concept of translating camera and is shown schematically in figure 6.A-1. The scanning mirror concept will be added in the near future. The breadboard consists of two cameras mounted on 3 axis translation stages, a 486 PC, an image processing workstation, video monitors and video recorders. The effort will focus initially on control of a single camera in two axis. Once this is demonstrated, a second camera will be added for tracking in three dimensions.

Once the camera acquires an image, it is then sent to a monitor for real time visual indication of tracking, to a video recorder for post test analysis to determine success, and to the image processing workstation. The workstation must process the image to recognize the desired feature and then send the location of the feature to the 486 PC. The PC then determines the required relative motion of the camera and commands the motion.

Hardware is currently being delivered and configured for this breadboard. The algorithms needed to recognize and track the desired feature are currently being developed. The current schedule has the initial software developed by the end of July 1994, testing with a single camera complete by the end of September 1994, and testing with two cameras complete by the end of October 1994.

**B. Data Compression and Image Processing (DC/IP):** Most experiments in the SS FCF science envelope rely heavily on video images for quantitative science data. Storing and transmitting all of these images to the ground is a major challenge. Current Spacelab and shuttle experiments rely primarily on video tapes to store the data. This is a feasible approach because the shuttle returns to the ground within a relatively short period of time. For experiments on Space Station however, the opportunity to return tapes to the ground in a short time will be severely limited. Alternatives to this are being developed. Digitizing of the images is the approach being taken. These images are also required to be compressed to avoid having excessively large files created, transmitted and stored. Once on the ground the images then need to be processed to return them to usable form, without losing the video data of interest.

Many methods have been developed in the recent past for image compression. The challenge is to select a method that will allow the video image information to be of sufficient quality to extract the required science data on the ground. Within the SS FCF science envelope, there are needs for several different types of video images to allow different data to be extracted. These types of data vary from microscopic to macroscopic views which

require illumination configurations that include incident, backlit, and scattered lighting with both lasers and white light sources. The SS FCF will need to have a number of compression methods available so that the best method can be selected for each type of science data required.

The breadboard is shown schematically in figure 6.B-1. It consists of a video source, a 486 PC, digital storage, and a video output recording system. The video source provides video images to the 486 PC which digitizes, compresses, and stores the images on the digital storage device. The digital data is then sent back to the 486 PC which de-compresses it, regenerates the video image, and sends it to the output system. These images, in contrast to the input image, will be used to determine if the data in the input image was maintained adequately.

The majority of the hardware and commercial software needed for this breadboard has arrived and has been assembled. Testing of compression algorithms is expected to continue into July 1994. The image processing portion is expected to be complete by the end of August 1994.

**C. Data Management:** The concept of the SS FCF as presented has data processing and storage functions along with central control functions located within the core rack on a VME bus system. In addition, this system is the interface to the Space Station control and data systems. There is also a VME bus system located in the fluids rack that passes data to the core VME bus system and controls the lower level functions. With the quantity of data and control that is required to pass between the various systems it was determined that a breadboard was needed to make sure that the hardware can be integrated and to benchmark the system performance. This breadboard will demonstrate the implementation of Mil-1553 B interface hardware operations and protocol for use as a data and control bus, and the FDDI system operation and protocol for use as a high speed data bus for rack to rack communications.

The breadboard system is shown schematically in figure 6.C-1. It consists of two VME bus systems connected by fiber optics and one of the VME bus systems connected to a 486 PC via a Mil-1553 B interface. Initial testing will consist of sending simple commands and data across the systems. Once this is working and understood, the communications will be made to be more and more complex, to the point where a large amount of traffic including the data and commands being transferred in the APT and DC/IP breadboards can be accommodated. Initial testing is expected to be complete by the end of July 1994.

**D. Fluid Handling:** The method to handle the various fluids to configure a test cell for testing and to allow it to be used for more than one test point is a key development issue. These methods will be common to a number of experiment types. This breadboard is in the initial stages. It will initially focus on

the generation of a drop(s) or bubble(s) in a test cell completely filled with a liquid and the removal of the same drop(s) or bubble(s). Most of the experiments that fall in the class that utilize this require that a linear thermal gradient be established in the test cell before deployment. This requires that the bubble/drop deployment does not disturb the liquid, destroying the thermal gradient. Results from this breadboard are expected by the end of 1994. Once methods are developed, they will be evaluated to see which functions will become part of the facility design.

**E. Vector Alignment:** A number of experiments in the science envelope are affected by even the low levels of micro-gravity that will exist on Space Station. By aligning the experiment with the gravity gradient, the effects can be minimized. Active control/alignment systems may be required, depending on the criticality to the science objectives. The SS FCF project is currently evaluating the criticality of this capability to the experiment apparatus. If it is decided to provide such a system, a breadboard is planned to support the concept development.

**F. SS FCF Breadboard Integration:** As SS FCF breadboards meet their individual objectives, many will be combined to test a larger system. This is currently planned for the APT, DC/IP, Data Management and Fluid Handling breadboards. The Fluid Handling breadboard will provide a feature for the APT system to track and send an image to the DC/IP system, all under the control of the Data Management system. This complete system should be up and running by the end of 1994.

**G. Vibration Isolation:** The SS FCF project is currently gathering vibration environment requirements from the envelope science requirements and comparing them to expected environments. If the predicted environment does not meet the requirements, vibration isolation, either active or passive, will be required. Currently the ISSA program is evaluating vibration isolation at the rack level, which includes the SS FCF. A great deal of breadboard work on vibration isolation has been performed at LeRC by Grodsinsky [4].

**H. External Breadboards:** There are currently a number of projects which fall into the SS FCF science envelope that are testing independent breadboards. Although the exact science may not be performed in the SS FCF, many of the techniques developed in the breadboards may be applicable.

Extensional Rheology: One of these projects is looking at the extensional rheology of fluids. This project has three major areas that are being breadboarded. The deployment of a column of both high and moderate viscosity liquid, the stretching of this column at constant strain rates and the measurement of the force required to do so.

3-Dimensional Particle Image Velocimetry (3-D PIV): Another project plans to evaluate three dimensional flows by tracking particles in a fluid. A technique to do this is currently under development in a breadboard. Lighting of the test cell and processing of the video image are the areas of focus.

## 7. Summary

A conceptual design of a Fluids Module, which is part of the Space Station Fluids/Combustion Facility, has been presented. The concept was developed to maximize use of common hardware and software in order to minimize development time and effort for a large number of fluids science investigations, and to provide maximum scientific return.

These objectives are met through provision of standard experiment modules (EMs) which support like experimental investigations. The EMs provide a maximum of common hardware and software with clearly defined interfaces and standard data acquisition and control capabilities.

The Fluids Module concept supports all of the classes of fluid physics and dynamics scientific investigations currently envisioned by the NASA Fluids Discipline Working Group to be performed aboard the International Space Station Alpha.

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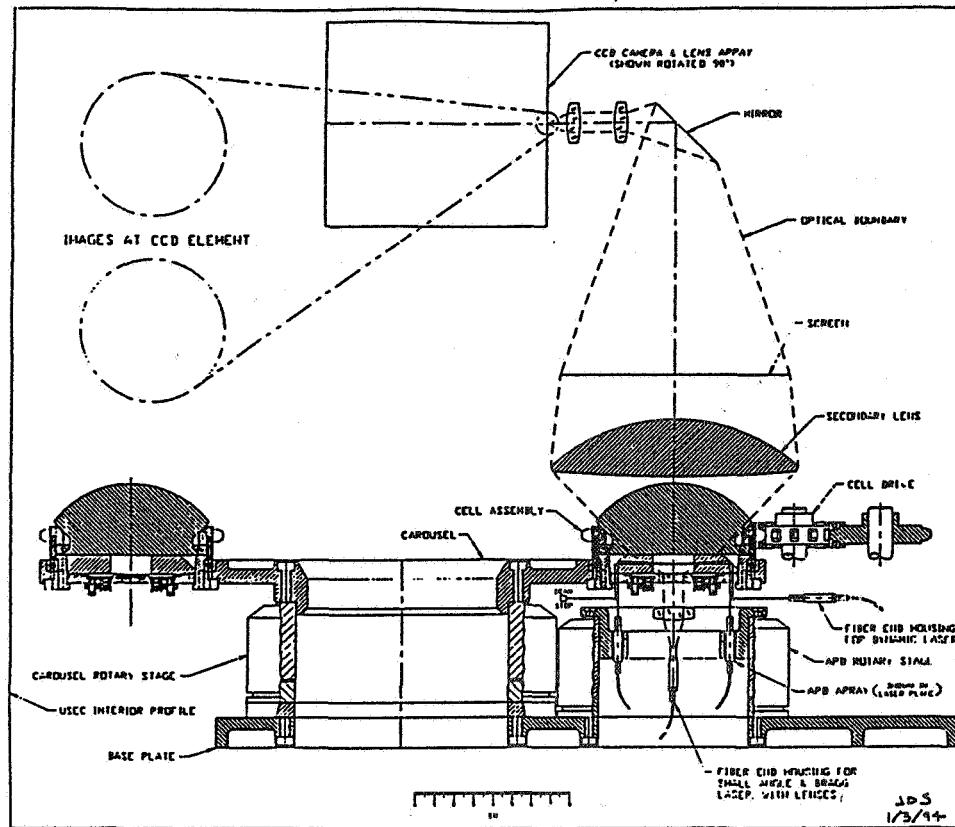


Figure 4.A-1 Diagram of PHaSE Laser Light Scattering Instrument

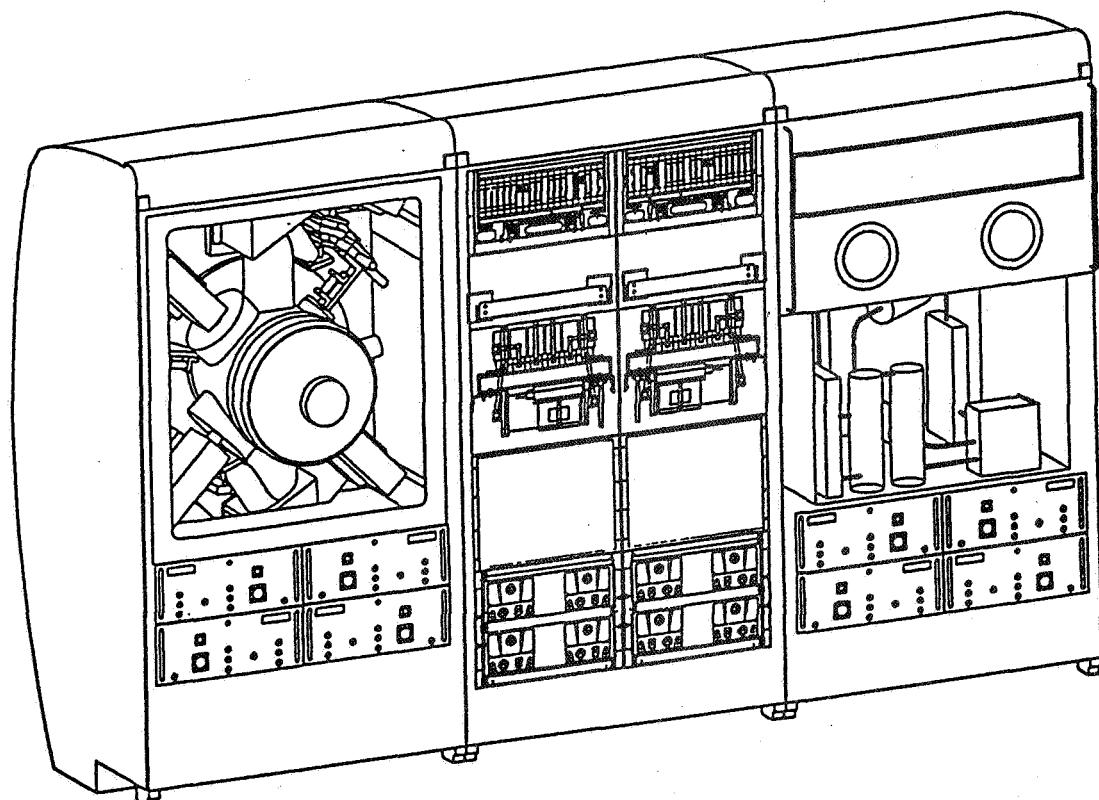


Figure 5-1 Space Station Fluids and Combustion Facility Concept

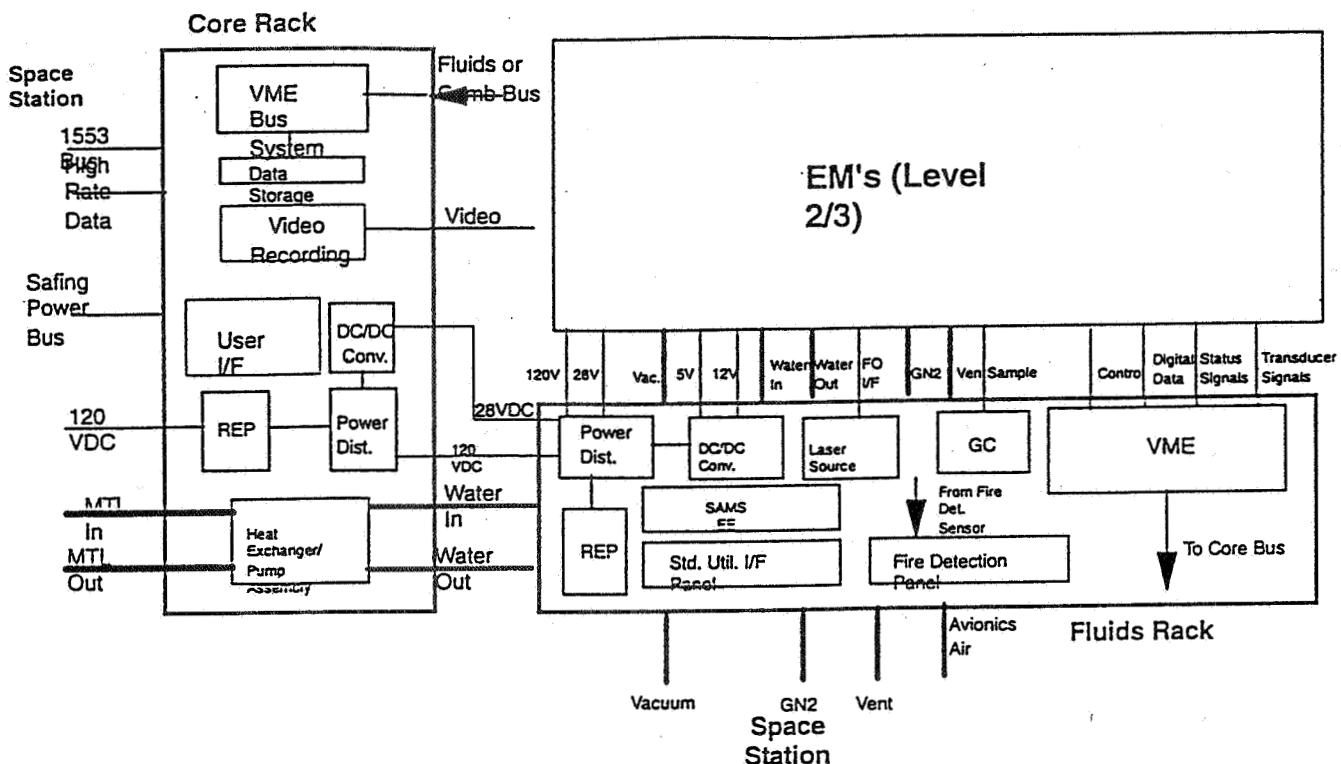


Figure 5.A-1 Level 1 Block Diagram

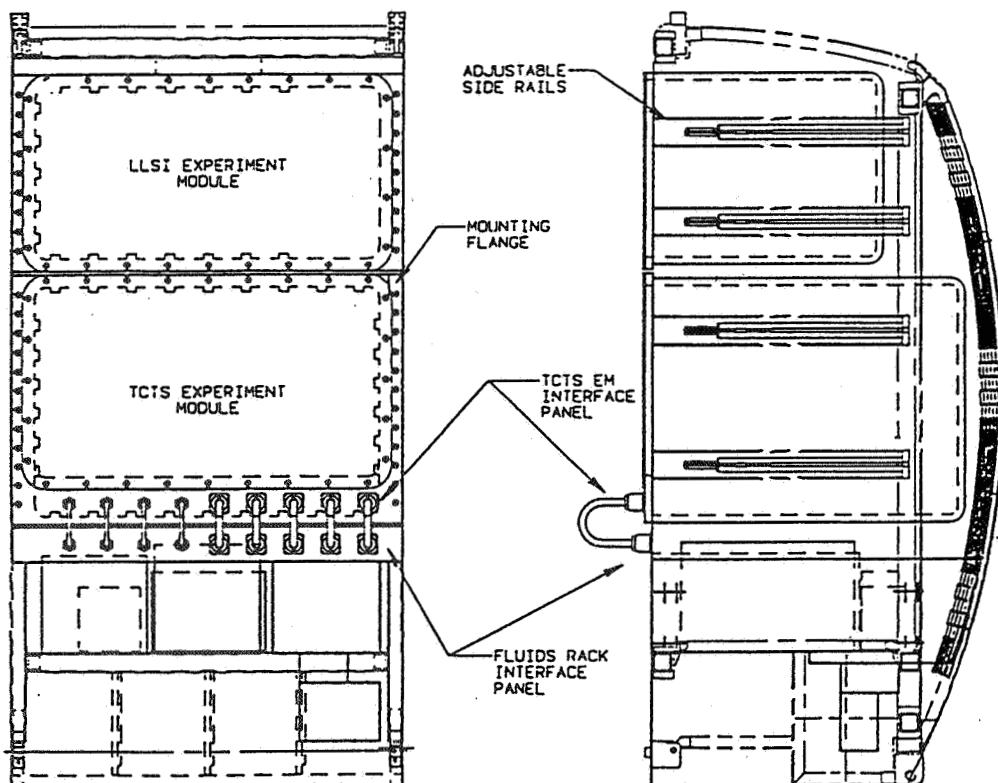


Figure 5.B-1 Fluids Rack Layout with LLSI and TCTS Experiment Modules

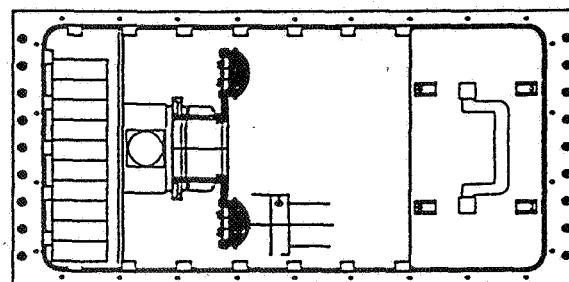
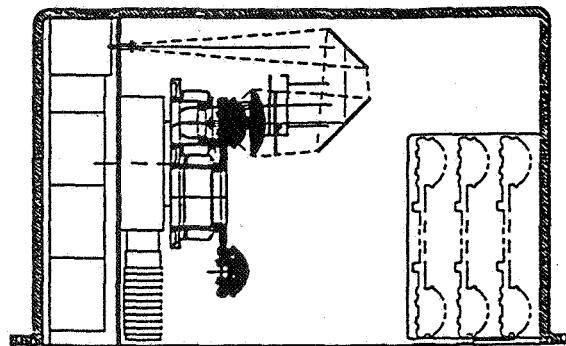


Figure 5.B.1-1

Diagram of LLSI Experiment Module

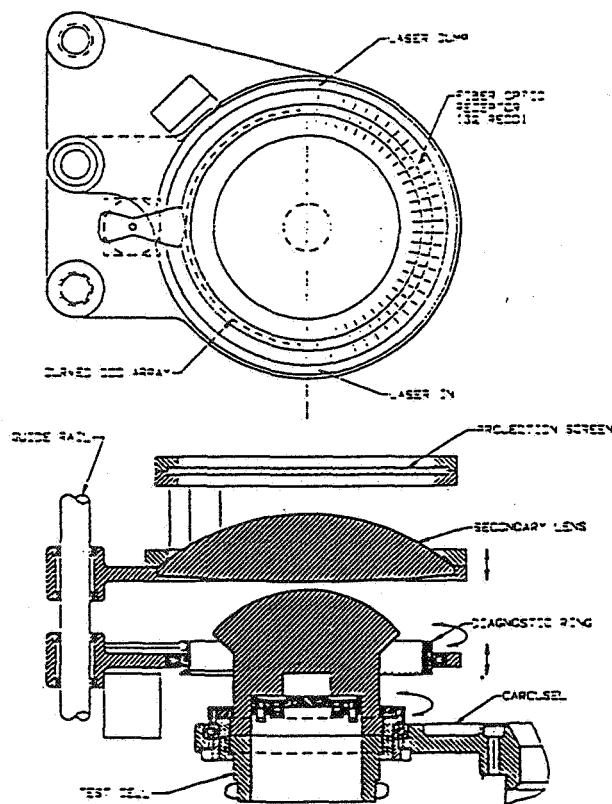


Figure 5.B.1-2

Diagram of LLSI Test Cell and Diagnostics

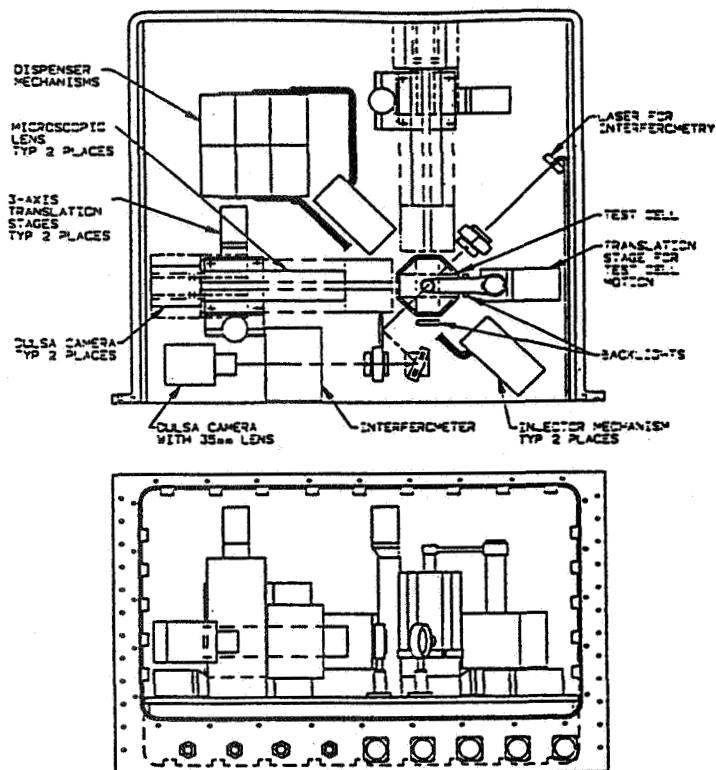


Figure 5.B.2-1 TCTS Experiment Module Layout for Microscopic Viewing

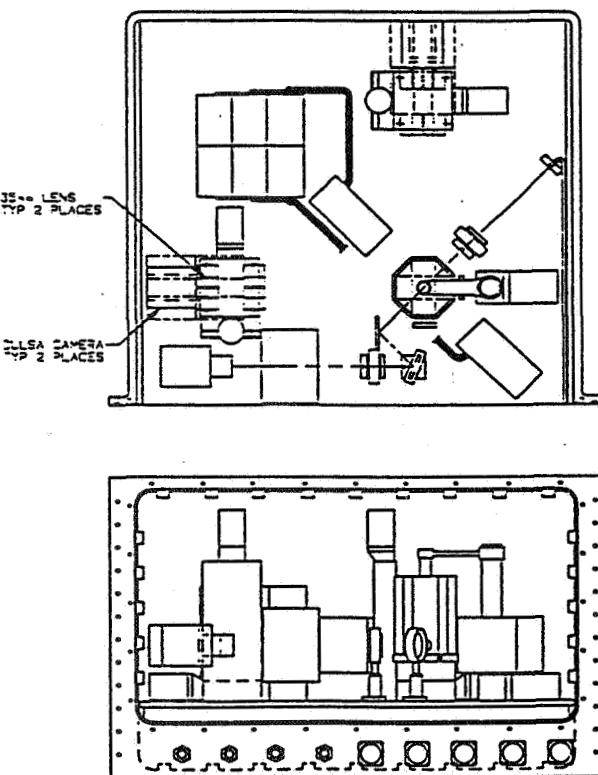
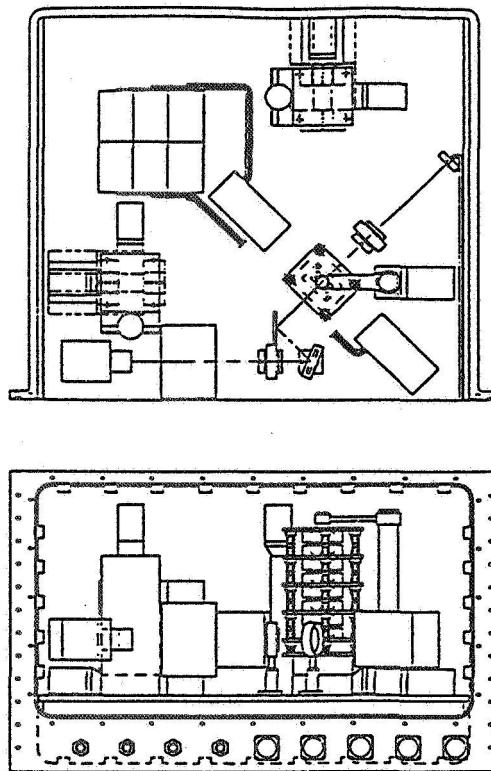
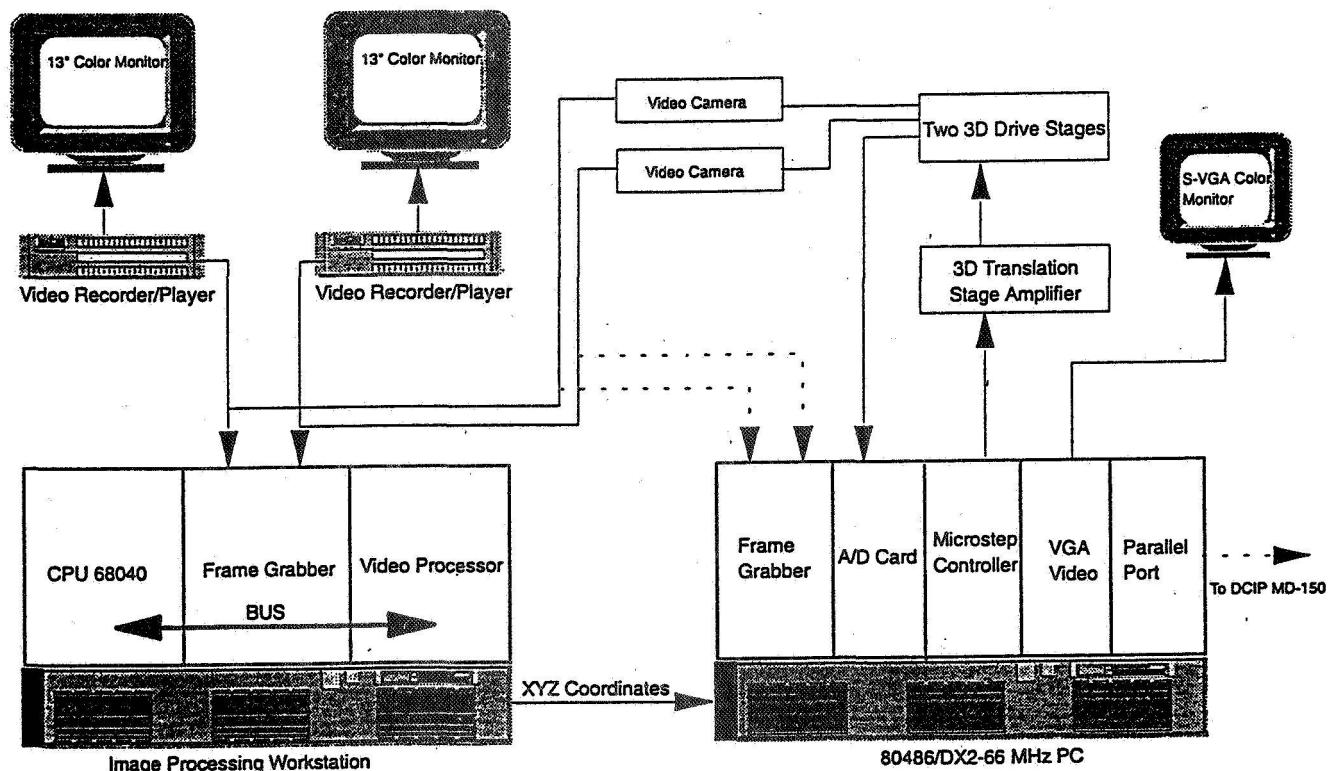


Figure 5.B.2-2

TCTS Experiment Module Layout for Macroscopic Viewing



**Figure 5.B.2-3 TCTS Experiment Module Layout for Multiple Test Cells**



**Figure 6.A-1 Automated Positioning and Tracking Breadboard**

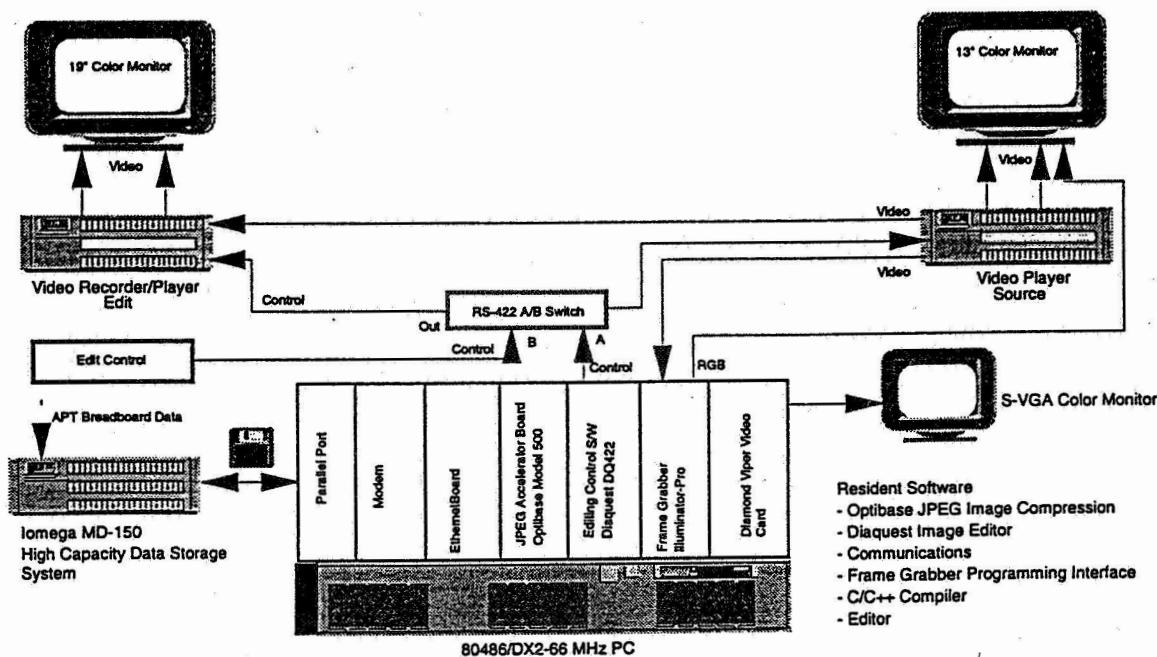


Figure 6.B-1 Data Compression and Image Processing Breadboard

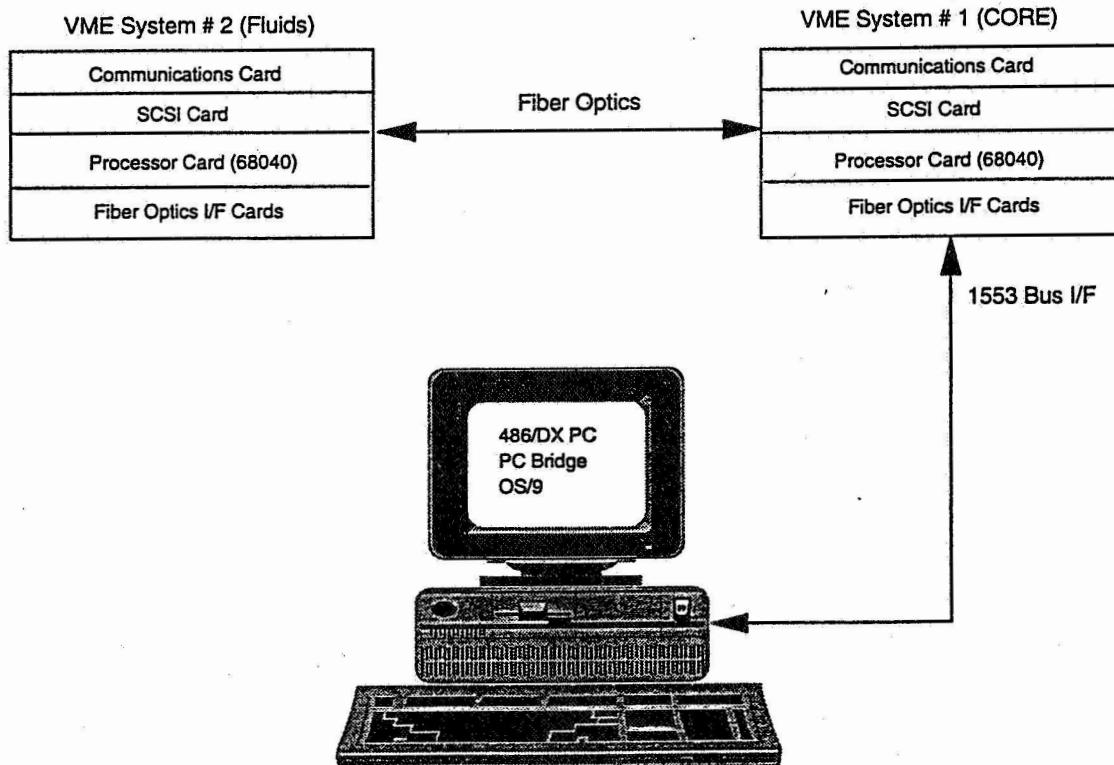


Figure 6.C-1 Data Management Breadboards