STS-73 PRESS INFORMATION AND MISSION TIME LINE

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CONTENTS

MISSION OVERVIEW

This is the sixth space shuttle flight of 1995, the 18th flight of Columbia and the 72nd mission for the space shuttle.

The flight crew for the 16-day STS-73 mission is commander Kenneth (Ken) D. Bowersox, pilot Kent V. Rominger, payload commander Kathryn (Kathy) C. Thornton, mission specialists Catherine G. "Cady" Coleman and Michael (Mike) E. Lopez-Alegria, and payload specialists Fred W. Leslie and Albert (Al) Sacco, Jr. The crew will be divided into a blue team, consisting of Coleman, Lopez-Alegria and Leslie, and a red team comprising Bowersox, Rominger, Thornton and Sacco. Each team will work 12-hour shifts, allowing for around-the-clock experimentation.

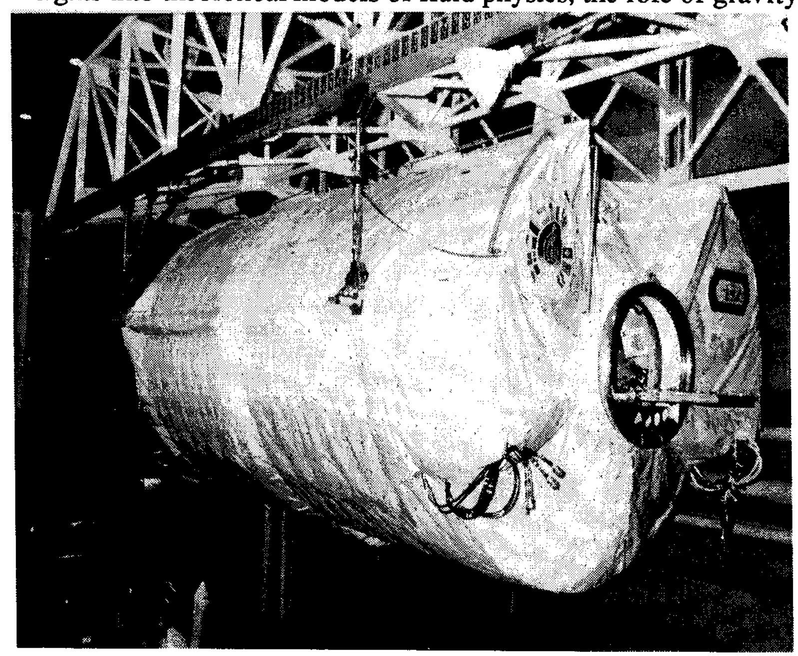
PRIMARY OBJECTIVE

STS-73's primary objective is to conduct the planned operations of the United States Microgravity Laboratory (USML) 2 payload, the latest in a series of space shuttle Spacelab missions dedicated to studying microgravity material processing technology and other science and research requiring the low-gravity environment of Earth orbit.

Designed to help the U.S. maintain world leadership in microgravity research and development, the USML mission series brings together representatives from academia, industry and government to study basic scientific questions and gain new knowledge in material science, biotechnology, combustion science, the physics of fluids and the way energy and mass are transported within them. Combining the strengths of these different research communities allows for more extensive ground-based research in preparation for flight, improved methods for microgravity experimentation, and a wider distribution of the knowledge gained in the process. The involvement of U.S. industry also means that the results of both ground-based experiments and shuttle operations can be brought down to Earth in a timely and practical manner.

The USML missions will continue development and testing of experimental flight equipment for the International Space Station and will lay the scientific foundation for extended microgravity research aboard the station.

Some of the experiments carried on the USML-2 payload were suggested by the results of the highly successful USML-1 mission, which flew aboard STS-50 in June 1992. USML-1 provided new insights into theoretical models of fluid physics, the role of gravity



NASA Photo

Spacelab Module Ready for Installation in Columbia in combustion and flame spreading, and how gravity affects the formation of semiconductor crystals.

Data collected from several protein crystals grown on USML-1 has enabled scientists to determine the molecular structures of those proteins. USML-2 builds on that foundation. That technical knowledge has been incorporated into the mission plan to enhance procedures and operations. Where possible, experiment teams have refined their hardware to increase scientific understanding of basic physical processes on Earth and in space, as well as to prepare for more advanced operations aboard the International Space Station and other future space programs.

USML-2 consists of 16 scientific experiments and associated hardware housed in a 23-foot-long Spacelab module (made up of a core segment and an experiment segment in the payload bay) and on the orbiter middeck. A long Spacelab transfer tunnel connects the Spacelab module with the orbiter middeck. Laboratory hardware includes new equipment and some equipment that has flown previously.

Research during the mission is concentrated within the same overall areas as the first USML flight. Reflown experiments will follow up on results from that mission, probing for answers to the next level of scientific questions.

The experiments being carried as part of the USML-2 payload cover a variety of scientific disciplines including fluid physics, material science, biotechnology and combustion science.

The fluid physics area is fundamental to many types of science, from the ways molten metals solidify and fuels burn to the way planetary atmospheres operate. In space, subtle and complex phenomena normally hidden by the stronger force of gravity can be revealed for detailed study.

Material science will increase insight into the relationships among the structure, processing and properties of materials. Mixtures that separate on Earth because of different component densities can be evenly mixed and processed in microgravity. This allows scientists to study the processing of such materials and to create advanced materials for study and comparison. Without the pull of gravity and the associated convective flows, more perfect crystals can be produced—an advance many believe vital for creation of advanced computer chips and semiconductors.

Biotechnology experiments in three different experiment facilities will attempt to grow protein crystals of sufficient size and perfection that scientists can determine their structure and formation process. This approach is being pursued because of the promise it holds for the development of improved drugs. Two other biotechnology experiments address the development of food crops with higher protein content and increased disease resistance.

Combustion science will aid in understanding the way a fire starts and spreads. Understanding the combustion process without the interference of gravity could lead to more efficient fuels and improved fire safety, both in space and on Earth.

Two sets of USML-2 sensors (plus the Orbital Acceleration Research Experiment secondary payload) will help scientists evaluate the quality of the microgravity environment, identifying factors that may disturb sensitive experiments.

Several USML-2 experiments will look at how the presence or absence of gravity affects living organisms. This will aid long-term space projects and provide a better understanding of life on Earth.

Commercial space processing technologies will again be demonstrated with the Commercial Generic Bioprocessing Apparatus, giving a large number of university and industry researchers access to space for their biological experiments. Techniques for plant cultivation in microgravity will be further advanced in the Astroculture facility.

Finally, several investigators will be able to view live video of their experiments at the same time, thanks to the new six-channel HI-PAC video downlink system, which will be making its first flight on USML-2.

The individual USML-2 experiments include the following:

USML-2 Middeck Experiments

The Astroculture hydroponic experiment is designed to validate a concept that was developed for supplying water and nutrients to plants growing in a microgravity environment. Because plants will play an important role in future long-duration space flights—providing crews with oxygen, food, pure water and removal of carbon dioxide from space habitats—it is important to develop an effective plant growth facility. Data will be collected on pressures, temperatures and humidity levels within the Astroculture fluid paths to aid in the evaluation of factors such as photosynthetic rates, photosynthate conversion rates, enzyme activities and morphological characteristics of starch accumulation. Potato plants will be grown. The customer is the Wisconsin Center for Space Automation and Robotics.

The Commercial Generic Bioprocessing Apparatus incubation and processing unit (I&PU) payload is designed as a passive, self-contained mixing and heating module used to process biological fluid samples in a microgravity environment. It will conduct experiments to determine how the assembly of biological molecules is affected by microgravity. Areas of investigation include biomedical testing and drug development, ecological system development, and biomaterial products and processes. CGBA will support up to 132 individual experiments on small quantities of samples ranging from molecules to small organisms. The hardware consists of the incubation and processing unit and a stowage unit located in several middeck lockers and lockers in the SMIDEX rack of the Spacelab module. Refrigerated samples will be kept in the CGBA refrigerator/incubator module located in the middeck.

Single-Locker Protein Crystal Growth/Single-Locker Thermal Enclosure System I and II is a set of refrigeration and incubation modules designed to conduct experiments that will supply information on the scientific methods and commercial potential of growing large high-quality protein crystals in microgravity. One SPCG experiment uses the Protein Crystallization Apparatus for Microgravity Devices for vapor diffusion crystal growth. The other uses a new experiment chamber called the Diffusion-Controlled Crystallization Apparatus for Microgravity, which grows model proteins through a combination of liquid-liquid diffusion and dialysis. Each SPCG-STES is mounted to one SSP-provided panel, equivalent to one middeck locker. More than 800 protein samples will be processed.

The Commercial Protein Crystal Growth-Commercial Refrigerator/Incubator Module experiment is a refrigeration and incubation unit for experiments designed to ascertain the feasibility of growing large, high-quality protein crystals in microgravity environments. The three experiments are housed in separate CRIMs that are mounted in one orbiter middeck locker. One CRIM contains three vapor diffusion apparatus trays. A second CRIM contains vials of protein solutions for the Protein Crystal Growth Glovebox investigation. The third CRIM contains the protein crystallization facility. The experiment consists of automated minilab units able to mix samples at precise time intervals. The results will increase scientific understanding of material structure development and help identify commercial advantages of space-based processing.

The Zeolite Crystal Growth experiment will evaluate zeolite crystallization and growth in microgravity in order to achieve high yields of large, nearly perfect crystals in space. Zeolites are complex arrangements of silica and alumina that occur naturally as well as synthetically. Because of their molecular sieve characteristics, zeolites are used in the chemical processing industry as highly selective catalysts, absorbents and filters. They are also used in life support systems, petroleum refining, waste management and biomedical equipment to purify fluids. High-quality, near-perfect zeolites may one day lower the cost of refining gasoline, oil and other petroleum products. The experiment consists of three types of assemblies: the furnace module, the zeolite experiment control system, and 38 sample containers. The experiment occupies two middeck lockers, plus part of a third for equipment storage.

USML-2 Spacelab Experiments

The Crystal Growth Furnace will grow crystals from materials (primarily semiconducting material, metal and alloys) that form the basis of electronic devices. The directional solidification and vapor crystal growth methods will be used. The experiment consists of a large structure that has three furnaces (high temperature, low temperature and adiabatic) and a carousel mechanism that places material samples into the processing mechanism. The CGF, which can process multiple large samples at temperatures above 1,000 degrees Celsius, dictates the orbiter's attitude because the long axis of the furnace must be pointed along the velocity vector. Five different samples will be processed.

The Advanced Protein Crystallization Facility is the first facility in which protein crystals can be grown by three techniques: liquid-liquid diffusion, vapor diffusion and dialysis. The fifteen experiments in growing large, highly ordered crystals may enhance understanding of biological processes and lead to advances in medicine and agriculture.

The Drop Physics Module is an instrument that manipulates free-floating liquid drops in microgravity to test and expand current fluid physics models and theories while measuring the properties of liquid surfaces. It will study several fluid physics phenomena: a simple surface like a sphere formed by a liquid drop in the absence of gravity, the reaction of a drop to different forces, and the interaction of surfaces and compound drops (a drop of one liquid surrounding a drop of a different liquid). The module uses acoustic waves to hold a drop of material in the middle of the container.

The experiment will advance fundamental knowledge that can benefit a variety of industries on Earth, from pharmacology to industrial chemistry. For example, scientists hope to gain new insights into processes such as cell encapsulation, which involves surrounding living cells with a membrane to protect them from harmful antibodies. This method could have tremendous potential in the treatment of several diseases, including diabetes.

The purpose of the Surface-Tension-Driven Convection Experiment is to measure, by video photography and subsequent digital analysis, how thermocapillary flow (the fluid motion generated by surface tension variations from temperature differences along the interface of a fluid) affects containerless material processing in the microgravity environment. The knowledge gained may assist in improving production of glasses and ceramics, semiconductor and protein crystals, metals, and alloys. Thermocapillary flows also affect space applications such as bubble and droplet migration, fuel management and storage, and life support systems, as well as material processing methods like crystal growth from liquids, containerless processing and welding. Understanding and controlling the effects of these flows will become increasingly important as space flights become longer and International Space Station operations begin.

In the experiment, three sizes of containers holding silicone oils of different viscosities will be heated and data will be collected on the velocity profile of the cross sections of the oils. Two different methods of heating will be used—surface heating by a carbon dioxide laser and internal heating by a heater cartridge—and the effects of both will be studied.

The Geophysical Fluid Flow Cell experiment will study how fluids move in microgravity as a means of understanding large-scale fluid dynamics in oceans and the atmospheres of planets and stars.

The Glovebox, provided by the European Space Agency, will be used to conduct experiments, test scientific procedures and develop new technologies in microgravity. It enables crew members to handle hardware and materials in ways that are impractical in the open Spacelab. The facility can contain fluids, powders, bioproducts, and even toxic or irritating materials, which are prevented from entering the Spacelab environment. This closed environment will house seven complementary experiments in fluid dynamics, protein crystal growth and combustion science, as well as technology demonstrations.

The Space Acceleration Measurement System is a microprocessor-driven data acquisition system used to measure and record the Spacelab microgravity acceleration environment. Acceleration information will be compared with vibration levels encountered in the shuttle to help scientists better understand their flight experiments. This information will also assist engineers as they design equipment and plan the placement of sensitive experiments on future missions. Sensors will be placed on the STDCE, CGF and Glovebox USML-2 experiments.

The Three-Dimensional Microgravity Accelerometer will measure the effects of microgravity deviations on the USML-2 experiments.

The Suppression of Transient Accelerations by Levitation Evaluation experiment will test a device designed to isolate a small science experiment from high-frequency accelerations, including shuttle operations and crew activity.

The High-Packed Digital Television Demonstration is the first flight demonstration of a new digital television system to operate from the Spacelab. It will digitize and compress up to six video input signals from experiments and Spacelab cameras aboard USML-2 and downlink them all simultaneously. Without HI-PAC, only one video signal can be sent to the ground at any given time. HI-PAC will increase science return from the USML-2 mission, since a number of science teams will be able to monitor and modify their experiments simultaneously.

USML-2 experiments are sponsored by NASA and managed by NASA's Marshall Space Flight Center in Huntsville, Ala.

SECONDARY OBJECTIVE

STS-73's secondary objective is to perform the on-orbit operations of the Orbital Acceleration Research Experiment. OARE is designed to acquire accurate measurement data of low-level aerodynamic acceleration along the orbiter's principal axes in the free-molecular-flow flight regime. It will measure microgravity levels caused by atmospheric drag of the shuttle, changes in orbiter velocity, vibrations of on-board machinery, and shuttle and crew operations. OARE data will support advances in orbital drag prediction technology by increasing understanding of the fundamental flow phenomena in the upper atmosphere. Data from OARE will complement information gathered from the SAMS instrument. OARE data will be sent in real time to the ground. OARE has flown on six previous shuttle missions.

Students at four sites in the U.S. will interact with Columbia's astronauts on flight days 12 and 13 to discuss and compare on-board microgravity experiments with similar ground-based experiments. The goal is to involve students as participants in shuttle investigations in an effort to generate interest in physical science and chemistry.

Some of the scheduled STS-73 detailed supplementary objectives (DSOs) will provide additional information for use in ongoing medical studies that support the EDO Medical Project, which is designed to assess the impact of long-duration space flight (ten or more days) on astronaut health, identify any medical concerns, and test countermeasures for the adverse effects of weightlessness on human physiology. The EDO Medical Project DSOs aboard STS-73 are sponsored by the Medical Sciences Division of the Johnson Space Center in Houston.

STS-73 is the second flight of the new Block 1 space shuttle main engine. SSMEs 1 (engine 2037) and 3 (engine 2038) feature improvements that increase reliability and safety margins while reducing maintenance requirements. SSME 2 is the current Phase II design. The first scheduled flight of all Block 1 engines will be STS-77 in May 1996.

The Block 1 engine features a new liquid oxidizer turbopump, produced by a casting process that eliminates all but 6 of the 300 welds in the current pump. A new two-duct power head improves fluid flows within the engine to decrease pressure and loads. A new single-coil heat exchanger in the power head eliminates all seven weld joints inside the engine to reduce wear, maintenance and post-flight inspections. The new engine also has a baffleless main injector and start-sequence modifications.

STS-73 is also Columbia's first flight following six months of scheduled maintenace, inspections and modifications at Rockwell's Orbiter Modification and Manufacturing Facility in Palmdale, Calif. (see notes in Mission Statistics section for a detailed description of the work performed on Columbia).

Thirteen development test objectives and 14 detailed supplementary objectives are scheduled to be flown on STS-73.

MISSION STATISTICS

Vehicle: Columbia (OV-102), 18th flight, 103rd U.S. human space flight

Launch Date/Time:

9/28/95	9:35 a.m., EDT (day) 8:35 a.m., CDT 6:35 a.m., PDT

Launch Site: Kennedy Space Center (KSC), Fla.—Launch Pad 39B

Launch Window: 2 hours, 30 minutes (crew-on-back constraint)

Launch Period: Approximately 4 hours, 22 minutes, opening on end-of-mission lighting and closing on 4-hour range constraints and the lighted constraint at the latest transatlantic abort landing site, Ben Guerir

Mission Duration: 15 days, 21 hours, 55 minutes

The capability for two additional days will be provided for weather avoidance and contingency operations.

Landing: Nominal end-of-mission landing on orbit 256

10/14/95	7:30 a.m., EDT 6:30 a.m., CDT 4:30 a.m., PDT

Runway: Nominal end-of-mission landing on runway 15, KSC, Fla.; alternates are Edwards Air Force Base (EAFB), Calif., and Northrup Strip (NOR), White Sands, N.M.

Transatlantic Abort Landing: Ben Guerir, Morocco; alternates: Moron, Spain; Zaragoza, Spain

Return to Launch Site: KSC

Abort-Once-Around: EAFB; alternates: KSC, NOR

Inclination: 39 degrees

Ascent: The ascent profile for this mission is a direct insertion. Only one orbital maneuvering system thrusting maneuver, referred to as OMS-2, is used to achieve insertion into orbit. This direct-insertion profile lofts the trajectory to provide the earliest opportunity for orbit in the event of a problem with a space shuttle main engine.

The OMS-1 thrusting maneuver after main engine cutoff plus approximately two minutes is eliminated in this direct-insertion ascent profile. The OMS-1 thrusting maneuver is replaced by a 5-foot-per-second reaction control system maneuver to facilitate the main propulsion system propellant dump.

Altitude: 150 nautical miles (173 statute miles)

In the event of an abort to orbit, an altitude of 129 nautical miles circularized will support a full-duration mission (112 nautical miles for a minimum-duration flight plus 2 days' contingency). Mission duration is more important than altitude for underspeed cases.

Primary Attitudes: -XLV, -YVV, -ZVV

Scheduled EVA: none

Crew provisions will support the performance of three two-crew member EVAs to accomplish the following unscheduled and contingency EVA requirements:

- A contingency EVA to realign the Ku-band antenna
- A contingency EVA to close/latch the payload bay doors

Payload Deployments/Retrievals: none

Rendezvous: none

Space Shuttle Main Engine Thrust Level During Ascent: 104 percent

Space Shuttle Main Engine Locations:

No. 1 position: Engine 2037†
No. 2 position: Engine 2031
No. 3 position: Engine 2038†

External Tank: ET-73

Solid Rocket Boosters: BI-075

Redesigned Solid Rocket Motors: RSRM-50

Mobile Launcher Platform: 3

Cryo tank sets: 5 plus 4 EDO

Software: OI-24 (fourth flight)

Editor's Note: The following weight data are current as of September 20, 1995:

Total Lift-off Weight: Approximately 4,521,539 pounds

†Block 1 SSME (first shuttle flight with two Block 1 SSMEs)

Orbiter Weight, Including Cargo, at Lift-off: Approximately 257,162 pounds

Orbiter (Columbia) Empty and 3 SSMEs: Approximately 182,428 pounds

Payload Weight Up: Approximately 33,622 pounds

Payload Weight Down: Approximately 33,622 pounds

Orbiter Weight at Landing: Approximately 230,164 pounds

Payloads—Payload Bay (* denotes primary payloads): United States Microgravity Laboratory (USML) 2,* Orbital Acceleration Research Experiment (OARE), EDO pallet

Payloads—Middeck (all part of USML-2): Zeolite Crystal Growth (ZCG), Astroculture (ASC), Single-Locker Protein Crystal Growth (SPCG)—Single-Locker Thermal Enclosure System (STES), Commercial Protein Crystal Growth (CPCG)—Commercial Refrigerator and Incubation Module, Commercial Generic Bioprocessing Apparatus (CGBA) Incubation and Processing Unit (I&PU)

Flight Crew Members:

Red Team:

Commander: Kenneth (Ken) D. Bowersox, third space shuttle flight
Pilot: Kent V. Rominger, first space shuttle flight
Payload Commander (Mission Specialist 3): Kathryn (Kathy) C. Thornton, fourth space shuttle flight
Payload Specialist 2: Albert (Al) Sacco, Jr., first space shuttle flight

Blue Team:

Mission Specialist 1: Catherine G. "Cady" Coleman, first space shuttle flight
Mission Specialist 2: Michael (Mike) Lopez-Alegria, first space shuttle flight
Payload Specialist 1: Fred W. Leslie, first space shuttle flight

Workshift: Dual shift

Ascent and Entry Seating:

Ascent:

Flight deck, front left seat, commander Kenneth (Ken) D. Bowersox
Flight deck, front right seat, pilot Kent V. Rominger
Flight deck, aft center seat, mission specialist Michael (Mike) Lopez-Alegria
Flight deck, aft right seat, mission specialist Catherine G. "Cady" Coleman
Middeck, payload commander Kathryn (Kathy) C. Thornton
Middeck, payload specialist Fred W. Leslie
Middeck, payload specialist Albert Sacco, Jr.

Entry:

Flight deck, front left seat, commander Kenneth (Ken) D. Bowersox
Flight deck, front right seat, pilot Kent V. Rominger
Flight deck, aft center seat, mission specialist Michael (Mike) Lopez-Alegria
Flight deck, aft right seat, payload commander Kathryn (Kathy) C. Thornton
Middeck, mission specialist Catherine G. "Cady" Coleman
Middeck, payload specialist Fred W. Leslie
Middeck, payload specialist Albert Sacco, Jr.

Extravehicular Activity Crew Members, If Required:

Extravehicular (EV) astronaut 1: mission specialist Michael (Mike) Lopez-Alegria
EV-2: mission specialist Catherine G. "Cady" Coleman

Intravehicular Astronaut: payload commander Kathryn (Kathy) C. Thornton

Entry: Automatic mode until subsonic, then control stick steering

Flight Directors:

Ascent/Entry: Rich Jackson
Orbit 1: Bryan Austin
Orbit 2/Lead: Al Pennington
Orbit 3: Rob Kelso
Orbit 4: John Shannon

Notes:

- The extended-duration orbiter pallet, EDO nitrogen mission kit, regenerable carbon dioxide removal system and EDO waste collection system with dual vane are installed on Columbia for this mission.

- The remote manipulator system, spare manipulator controller interface unit, spare payload data interleaver, mainpulator positioning mechanisms, treadmill, and trash compactor are not installed on Columbia for this mission.

- The middeck accommodations rack, cycle ergometer, four-tier operational sleep stations, shuttle orbiter repackaged galley, middeck utility panel, payload recorder, cabin air cleaner, Spacelab utility kit, long Spacelab transfer tunnel, airlock tunnel adapter and four empty hard ballast compartments are installed on Columbia for this mission.

- Reduced Freon flow through the radiators due to the cold attitude profile will result in cold radiator panel temperatures, which will necessitate frequent nozzle dumps. Nozzle dumps will be performed in the experiment attitudes.

- The modular auxiliary data system (MADS) pulse code modulation (PCM) and MADS wide band will be recorded during ascent and entry. All of these data will be recorded on the MADS/orbiter experiments recorder.

- With a nominal end-of-mission weight of 230,164 pounds, STS-73 will be the heaviest scheduled orbiter landing to date.

- Significant first-flight orbiter items:

  — Payload bay door shear pins with improved dry film lube

  — Redesigned main propulsion system 17-inch disconnect valve actuator (actuator linkage improved to prevent structural failure)

  — Redesigned main propulsion system gaseous hydrogen pressurization/prepressurization system (modified to minimize contamination-induced flow control valve failures)

  — Redesigned waste collection system with dual-vane compactor assembly to allow a second compaction of the commode (a single-vane compactor provides a net to sweep the contents of the commode to one side of the tank, which clears the transport tube for further use). For long missions (14 or more days), a second vane compactor is now provided so the commode tank may be swept twice, thereby reducing the difficulty in using the commode when it is nearly full, eliminating the need for the crew to manually clear the transport tube as often, and reducing the risk of fecal waste escaping from the commode.

  — First use of ground-to-air TV (uplink only)

- RTV backfilling of both of Columbia's solid rocket boosters was performed on September 5, 1995.

- The CGBA, CPCG-TES, CPCG-CRIM, and SPCG-STES samples must be replaced if launch is delayed 48 hours or longer. The SPCG-STES module must be replaced if a 96-hour launch delay occurs. The ZCG samples must be replaced if launch is delayed 72 hours or longer. The ASC payload must be removed and its water replaced for launch delays of 24 hours or more. The APCF payload must be replaced if a nine-day launch delay occurs.

- The STS-73 flight plan originally called for approximately 150 hours of flight in a -ZVV (payload bay forward) attitude to meet sample processing attitude requirements for the CGF USML-2 payload. Due to orbital debris concerns, this plan was amended to 10 hours of -ZVV attitude (the Space Shuttle Operational Flight Design Standard Ground Rules and Constraints—Level B states that it is desirable to fly less than 48 hours cumulative in this attitude).

- Drag chute deployment will be per nominal flight rules unless the crosswind DTO is likely to be performed. In that case, drag chute deployment will be delayed until after nose gear touchdown to allow for pilot handling evaluation of the orbiter alone without any complications that drag chute dynamics may induce.

- NASA Television is available through Spacenet-2, Transponder 5, Channel 9, located at 69 degrees west longitude with horizontal polarization. The frequency is 3880 Mhz; audio is 6.8 Mhz. Most of the NASA TV will originate from MSFC due to the use of digitized video downlink (HI-PAC).

- Nineteen televised special events are scheduled for STS-73, including the crew press conference and two interactive educational events with various schools.

- Beginning with the STS-74 mission, the Rockwell press information and mission time line publication for each shuttle flight will be available via Internet through the Rockwell Space Systems Division Home Page.

Columbia Orbiter Maintenance Down Period (OMDP)

STS-73 will be Columbia's first mission since STS-65 in July 1994. Rockwell Aerospace conducted a scheduled six-month period of maintenance, inspections and enhancement modifications on Columbia at the company's Palmdale, Calif., Orbiter Modification and Manufacturing Center from October 13, 1994, to April 10, 1995. The effort, known as OMDP 1, J02, was designed to maintain Columbia's structural integrity, keep the shuttle fleet configuration uniform and technologically up-to-date, and reduce overall shuttle program costs. Each orbiter typically undergoes an OMDP every three years.

Four significant activities were performed at Palmdale:

- 1,459 Orbiter Maintenance Requirements and Specifications Document requirements
  - 869 that were baselined
    - 488 structural inspections (469 X-rays and 19 visual)
    - 381 revalidation/storage/transportation items
  - 590 additional requirements
- 80 modifications
- 32 chits (nonstandard work items)
- 143 deferred work items

Work on Columbia was designed to improve performance, meet mission requirements, increase safety, and reduce turnaround time. The following is a list of significant work accomplished.

Forward Fuselage

- Crew module closeout panels
- Accommodations for new carbon dioxide partial pressure sensors
- Environmental control and life support system flexible tube assembly replacements
- Mechanically attached vent doors 1 and 2 thermal barriers
- Lithium hydroxide container convertibility
- Pulse code modulator master unit lap-top computer provisions
- Removal and replacement of hydrogen separators
- Replacement of cabin heat exchanger
- Waste and potable water tank installation
- Deletion of inactive environmental control and life support system line

Midbody

- Bay 8 and 9 heat sink additions

- Payload bay door pushrod rod-end replacement
- Debris screens at payload bay door drive rod penetrations
- Payload bay door shear pins with more durable dry lube
- Attach points for liner restraints
- Xo 1307 feedthrough connectors to support PDAP installations
- Payload bay door torque box instrumentation
- Thermal protection system life instrumentation
- Installation of acre sleeves at damaged payload bay door strongback attach locations
- Removal and replacement of fifth power reactant storage and distribution tank set filter
- Removal and partial reinstallation of payload bay door switch modules
- Water dump nozzle measurements
- Boron aluminum strut inspection
- Payload bay door radiation inspections and repair

Wings

- Wing leading edge corrosion protection
- Reinforced carbon-carbon panel and T-seal inspection
- Elevon corrosion and repair
- Inboard/outboard elevon sealing and drainage provisions
- Flipper door hinge bearing inspections and replacement
- On-orbit tire temperature monitoring
- Right-hand elevon actuator removal and replacement
- Main landing gear door mechanically attached thermal barrier (left-hand side)

Aft Fuselage

- Gaseous hydrogen flow control valve modification
- Improved auxiliary power unit water valves
- External tank door corrosion protection
- Improved orbiter/space shuttle main engine hydraulic quick disconnect
- Hydraulic quick disconnect (PD27) with in-line filter
- Noninstrumented vertical tail bolts
- External tank door latch fitting redesign
- Umbilical keel beam bracket notch
- Orbiter/external tank separation debris containment
- Hydraulic main pump depressurization piston cap redesign
- Liquid hydrogen/liquid oxygen actuator beef-up
- Water spray boiler electric heaters

- Orbital maneuvering system oxidizer high-point bleed line heater circuit redesign
- Rudder speed brake bead blasting and repaint
- Body flap actuator torque check
- Removal and replacement of water spray boiler 2
- Removal and replacement of water spray boiler valves
- Main propulsion system fill and drain valve verification
- Main propulsion system manifold relief valve removal and replacement
- Hydraulic bootstrap accumulator removal and replacement

During Columbia's structural inspection, engineers and technicians entered the orbiter to perform nondestructive and visual inspections with borescopes, ultrasonic devices, eddy currents and X-rays to search for evidence of fatigue, corrosion, stress cracks and broken rivets or welds. The inspection did not cause any new concerns regarding corrosion or degradation that may have resulted from flight environmental factors.

Columbia first rolled out of Rockwell's Palmdale facility in March 1979 and flew its first mission in April 1981. Its 17 missions included the first five shuttle flights, five Spacelab missions, one Department of Defense (DOD) flight, and four extended-duration missions. Altogether, Columbia has flown more than 62.6 million miles and 2,341 orbits (not including the classified DOD flight, for which such data are unavailable). This was Columbia's third visit to Palmdale, it previously went through inspection/modification periods there in 1984-85 and 1991-92.

MISSION OBJECTIVES

- Primary objective
  - Payload bay
    - United States Microgravity Laboratory (USML) 2 operations
  - Middeck
    - Zeolite Crystal Growth (ZCG) operations (USML-2)
    - Commercial Protein Crystal Growth (CPCG)—Commercial Refrigerator and Incubation Module (CRIM) operations (USML-2)
    - Commercial Generic Bioprocessing Apparatus (CGBA) Incubation and Processing (I&PU) operations (USML-2)
    - Astroculture (ASC) operations (USML-2)
    - Single-Locker Protein Crystal Growth (SPCG)—Single-Locker Thermal Enclosure System (STES) operations (USML-2)
- Secondary objective
  - Payload bay
    - Orbital Acceleration Research Experiment (OARE) operations
- 13 development test objectives, 14 detailed supplementary objectives

STS-73 CREW ASSIGNMENTS

Commander: Kenneth (Ken) D. Bowersox

- Overall mission decisions
- DTOs/DSOs—DTOs 623,* 667,* 679, 682,* and 913*; DSOs 605 and 624
- Other—ascent/entry, crew safety, mission success, Earth observations*

Pilot: Kent V. Rominger

- DTOs/DSOs—DTOs 623, 667, 679,* 682 and 913; DSOs 604, 611, 624,* 901, 902 and 903
- Other—ascent/entry, orbiter systems, Earth observations

Payload Commander (Mission Specialist 3): Kathryn (Kathy) C. Thornton

- Payload—Spacelab subsystems, USML-2 operations
- DTOs/DSOs—DTO 655; DSOs 603C and 626
- Other—intravehicular astronaut

Mission Specialist 1: Catherine G. "Cady" Coleman

- Payload—USML-2 operations
- DTOs/DSOs—DTOs 312 and 655*; DSO 802
- Other—EV2, Spacelab deactivation

Mission Specialist 2: Michael (Mike) E. Lopez-Alegria

- DTOs/DSOs—DTOs 312, 679, 682, and 913; DSOs 604, 611, 901, 902 and 903
- Other—ascent/entry, orbiter systems, Earth observations, EV1, Spacelab deactivation*

Payload Specialist 1: Fred W. Leslie

- Payload—USML-2 operations
- DTOs/DSOs—DSOs 603C, 621 and 626
- Other—Spacelab deactivation

Payload Specialist 2: Albert Sacco, Jr.

- Payload—USML-2 operations
- DTOs/DSOs—DTO 655; DSOs 603C, 626 and 802
- Other—Spacelab activation

NASA photo

STS-73 crew members are (from left) mission specialist Catherine Coleman, payload specialist Albert Sacco, commander Kenneth Bowersox, pilot Kent Rominger, payload specialist Fred Leslie, mission specialist Michael Lopez-Alegria, and payload commander Kathryn Thornton.

FLIGHT ACTIVITIES OVERVIEW

Flight Day 1

Launch
OMS-2 burn
Payload bay doors open
Unstow cabin
HUD calibration
Spacelab activation
Trim burn
USML-2 operations

Flight Days 2–14

USML-2 operations
DTOs/DSOs

Flight Day 12

Educational TV event with students in Bozeman, Mont., and Las Cruces, N.M.

Flight Day 13

Educational TV event with students in Worcester, Mass., and Louisville, Ky.

Flight Day 15

USML-2 operations
DTOs/DSOs
Crew press conference

Flight Day 16

USML-2 operations
DTOs/DSOs
FCS checkout (Red team)
RCS hot fire (Red team)

Flight Day 17

Cabin stow (Blue team)
Spacelab deactivation (Blue team)
Ku-band antenna stow (Blue team)
Deorbit preparations
Deorbit burn
Entry
Landing

Notes:

- Each flight day includes a number of scheduled housekeeping activities. These include inertial measurement unit alignment, supply water dumps (as required), waste water dumps (as required), fuel cell purge, Ku-band antenna cable repositioning, and a daily private medical conference.

- Off-duty periods for the Spacelab crew are scheduled for flight days 6 and 12 for the Red team and flight days 7 and 13 for the Blue team. One crew member will be off duty at a time in order to continue USML-2 operations. The pilot's off-duty periods are on flight days 8 and 11; MS2's are on flight days 9 and 14. The commander has off-duty periods on flight days 6 and 12.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

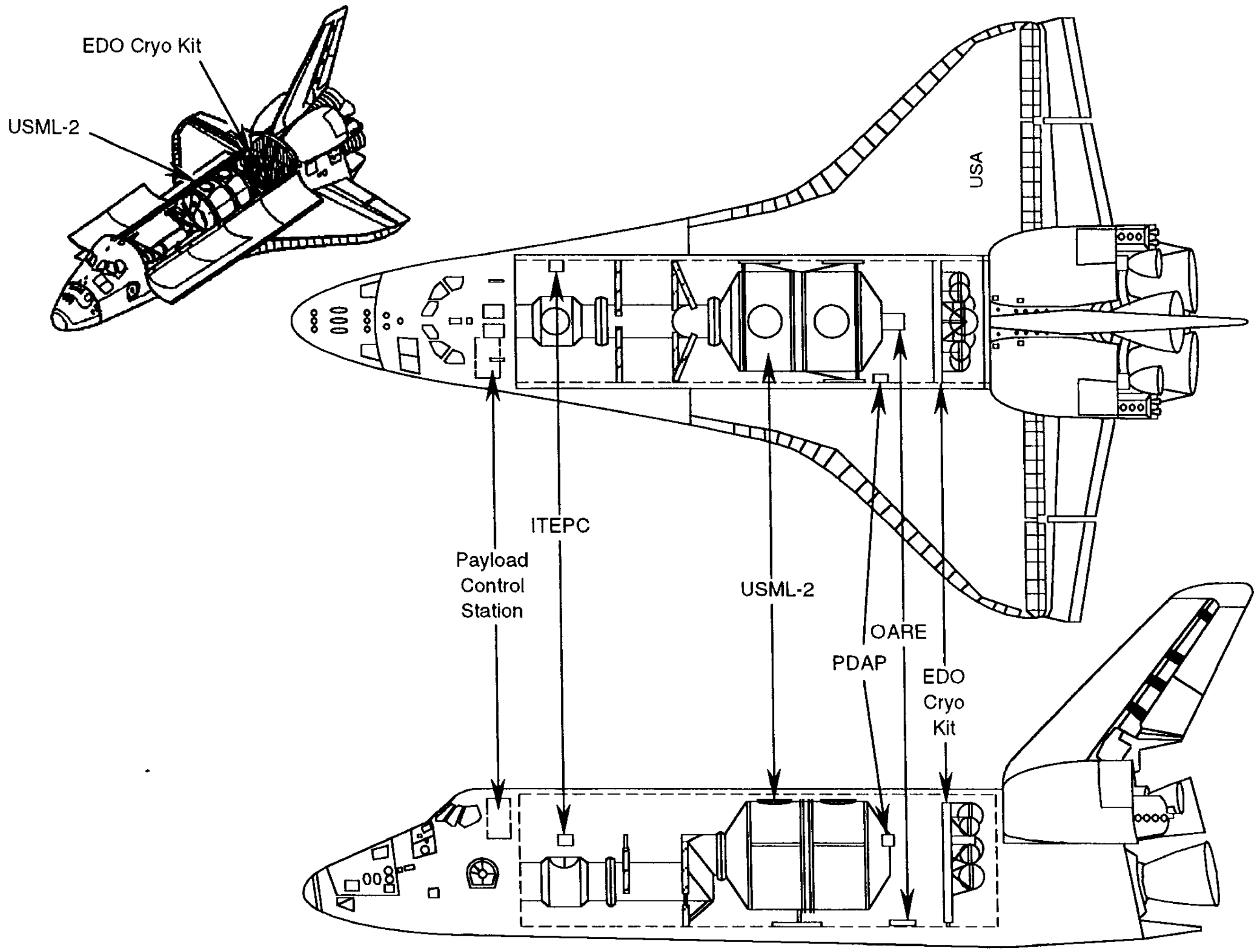
DTOs

- Ascent structural capability evaluation (DTO 301D)
- Entry structural capability evaluation (DTO 307D)
- ET TPS performance, methods 1 and 3 (DTO 312)
- Shuttle/payload low-frequency environment (DTO 319D)
- APU shutdown test, sequence B (DTO 414)
- Cabin air monitoring (DTO 623)
- Foot restraint evaluation (DTO 655)
- Portable in-flight landing operations trainer (DTO 667)
- Ku-band communications adapter demonstration (DTO 679)
- Inertial vibration isolation system evaluation (DTO 682)
- Crosswind landing performance (DTO of opportunity) (DTO 805)
- Microgravity measuring device evaluation (DTO 913)
- Ground-to-air television demonstration (DTO 1121)

DSOs

- Immunological assessment of crew members (DSO 487)
- Characterization of microbial transfer among crew members during space flight (DSO 491)
- Orthostatic function during entry, landing and egress (DSO 603C)
- Visual-vestibular integration as a function of adaptation, OI-3C and OI-1 (DSO 604)
- Postural equilibrium control during landing/egress (DSO 605)
- Air monitoring instrument evaluation and atmosphere characterization test (DSO 611)
- In-flight use of Florinef to improve orthostatic intolerance after flight (DSO 621)
- Pre- and postflight measurement of cardiorespiratory responses to submaximal exercise (DSO 624)
- Cardiovascular and cerebrovascular responses to standing before and after space flight (DSO 626)
- Educational activities (DSO 802)
- Documentary television (DSO 901)
- Documentary motion picture photography (DSO 902)
- Documentary still photography (DSO 903)
- Assessment of human factors, configuration C (DSO 904)

STS-73 PAYLOAD CONFIGURATION



MTD 950918-5373

Since the beginning of the U.S. space program, microgravity has been the subject of exhaustive research that has often produced valuable insights into physical processes. NASA's United States Microgravity Laboratory Program, a cooperative venture of NASA's Office of Space Science and Applications and the Office of Commercial Programs, is the first major step in building a mature microgravity research program involving NASA, researchers in fundamental and engineering sciences, and private industry.

The USML is a key component in the preparations for a new age of space exploration. Flying in orbit on the space shuttle for extended periods of time, the laboratory will give researchers greater opportunities to conduct technology demonstrations and investigations of material sciences, fluid physics, biotechnology, and combustion science. Research conducted on USML-2, the second mission in NASA's vital space exploration initiative, will help prepare for advanced microgravity research and processing on the International Space Station and other advanced spacecraft.

USML-2 will build on the success of the first USML mission, which was conducted on STS-50 in June 1992. USML-1 has given researchers a better understanding of the behavior of fluids, the role of gravity in combustion and flame spreading, and the affects of gravity on the formation of semiconductor crystals. Scientists have also used data from USML-1 to identify the molecular structures of several protein crystals grown during that mission. Researchers have also used the knowledge they gained from the first USML mission to enhance their procedures and operations and refine their hardware for this mission.

USML-2 is housed in the European Space Agency's Spacelab, a pressurized module in Columbia's payload bay that provides astronauts a shirt-sleeve environment for conducting experiments.

AREAS OF INVESTIGATION

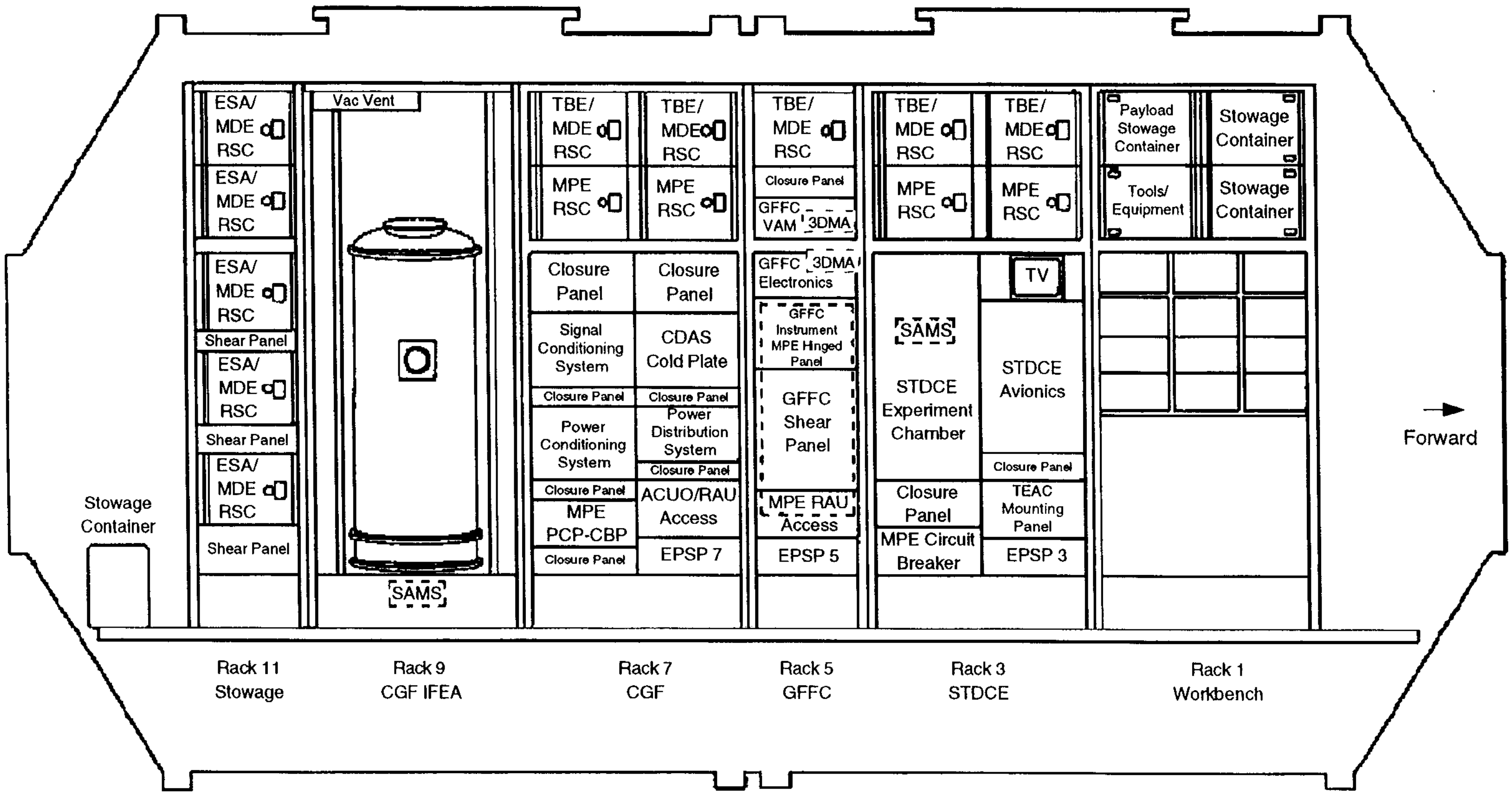
The USML-2 payload comprises investigations in the same basic areas studied on the first USML mission. Some of the USML-1 experiments are being flown again on STS-73 to follow up the results from the first mission.

The fluid physics experiments will examine several basic fluid phenomena that cannot be studied on Earth because of the effects of gravity. Knowing how and why these phenomena occur will enable scientists to understand how they influence material science processes and will help them develop methods of reducing or eliminating their undesirable effects in Earth-based experiments and processing.

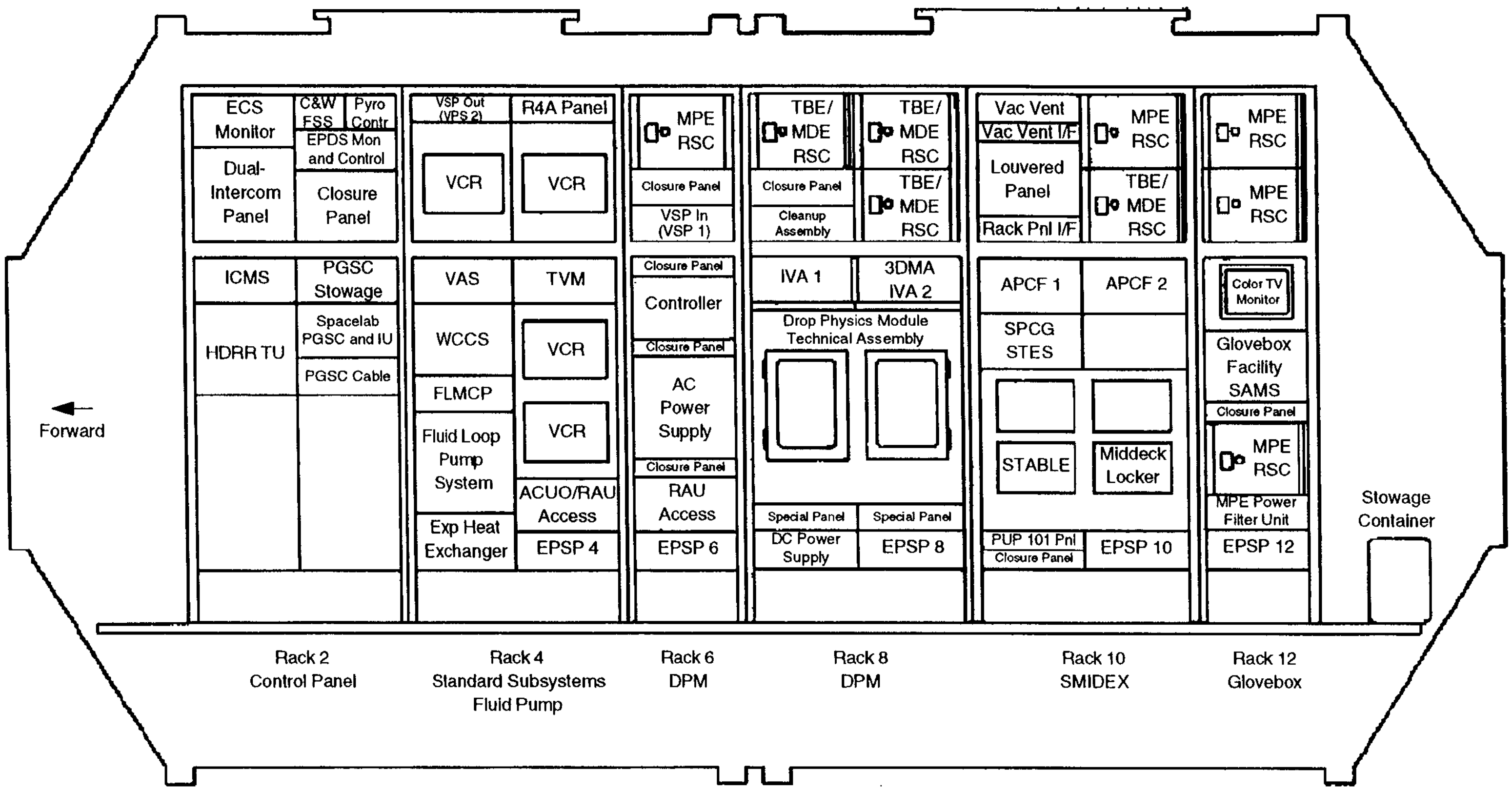
On this mission, researchers will also grow crystals as part of the investigations of the relationships of the structure, processing and properties of materials. They will study the processing of materials that cannot be evenly mixed on Earth because of the effects of gravity and will create advanced materials for study. Their efforts may lead to the production of advanced computer chips and semiconductors.

USML-2 will grow protein crystals so that scientists can learn more about growing crystals in microgravity and about the crystals themselves. Crystals play major roles in our lives, from the formation of the proteins in our bodies to their use in semiconductors in electrical appliances. The microgravity of space allows scientists to grow the nearly perfect samples they need to be able to study crystals and their uses.

On this mission, scientists will observe combustion phenomena that are not normally observable on Earth because of the influence of gravity. They will study the way a fire starts and spreads in micro-



USML Spacelab Port Configuration



USML Spacelab Starboard Configuration

gravity compared to gravity. This could lead to the production of more efficient fuels and improvements in fire safety on Earth and in space.

The technology demonstrations are opportunities to try out new procedures and facilities for future space missions.

These investigations will be conducted around the clock during Columbia's 16-day mission, which will be the longest in the shuttle program. Not since NASA's Skylab program in the early 70s have scientists had access to space for more than seven days. Extended missions will allow scientist-astronauts to explore the microgravity environment and learn how to use it more effectively for research. Scientists require longer periods in microgravity for their experiments to prepare for long-term microgravity research on the space station.

Columbia can remain in orbit longer because it has been outfitted with additional oxygen and hydrogen tanks for propulsion, extra middeck lockers, extra nitrogen tanks for cabin air, and a system for removing carbon dioxide from the cabin air. Eventually, orbiters with extended-duration kits could stay in orbit for up to 90 days.

Most of the USML-2 experiments will be conducted by the four payload crew members who are flying on this mission. Payload specialists Dr. Fred Leslie of the Marshall Space Flight Center and Dr. Albert Sacco of the Worcester (Mass.) Polytechnic Institute are scientists as well as trained astronauts. Mission specialists Dr. Catherine Coleman and Michael Lopez-Alegria have been trained to conduct the experiments. Scientists at Spacelab Mission Operations Control at MSFC will work with the astronaut-scientists while they conduct the experiments in Spacelab. Science teams at other NASA centers and at universities will also monitor and support some of the experiments.

SCIENCE EXPERIMENTS

Crystal Growth Furnace (CGF)

Scientists hope to learn more about the fundamental nature of materials by studying what happens to them when they are melted or vaporized and then form crystals. The microgravity environment of space allows researchers to study the crystallization process more carefully than they could on Earth because the gravitational factors that obscure or change the process are greatly reduced or eliminated. The knowledge gained from materials research in space may lead to the development of improved materials, processing techniques, or products on Earth.

The CGF is a reusable device that can use either the directional solidification or vapor transport method to produce crystals on this and future USML missions. It is one of the first furnaces produced by the United States that is capable of producing many large crystals at temperatures above 1,000 degrees Celsius.

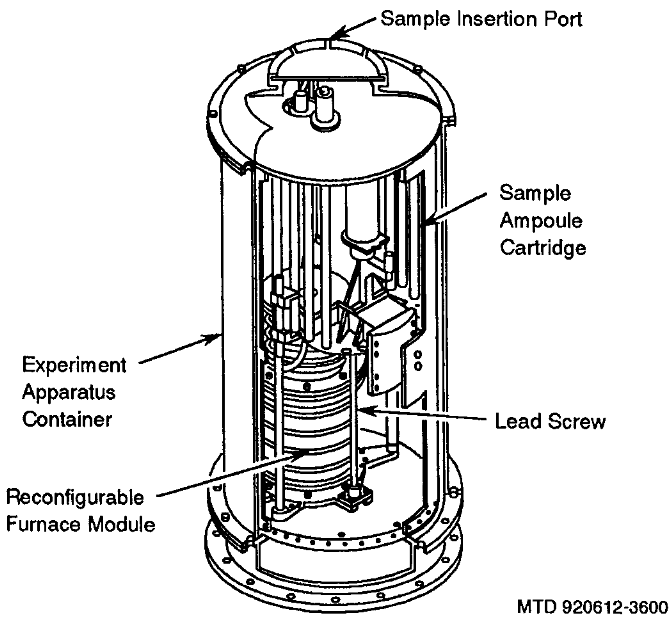
The four primary CGF experiments are continuations of USML-1 investigations. Three of the experiments will use the directional solidification method to grow crystals. In this process, the CGF melts all but one end of a sample, and a crystal grows in a particular direction as the furnace moves and the melted sample resolidifies. This process produces crystals that have fewer defects and more orderly atomic arrangements.

In the vapor transport process, crystals are formed as vaporized material is deposited on a substrate, or base, in a cooler section of the CGF.

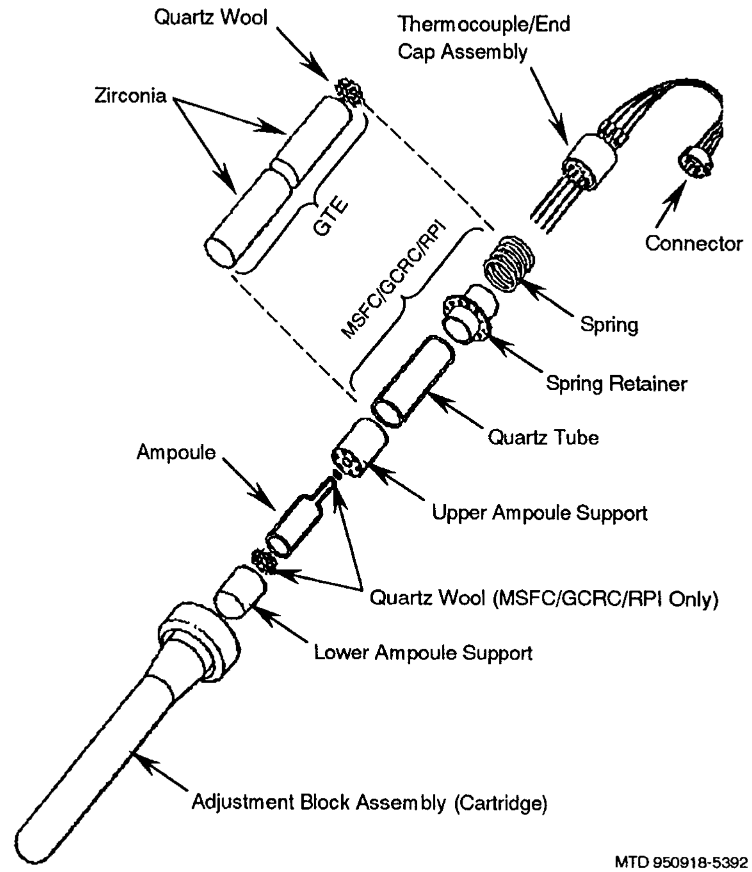
Near the end of the mission, a sample of germanium with a trace of gallium will be processed in the furnace to determine the effect of different shuttle attitudes on crystal growth. The process will begin with the shuttle in an orientation thought to be best for crystal growth. Midway through the processing, the shuttle will maneuver to the normal gravity gradient attitude with its tail to the Earth.

The CGF is mounted in the integrated furnace experiment assembly. Part of this assembly is the reconfigurable furnace module, which contains five heating zones—three hot and two cold. The heating zones pass over the experiment samples, melting them in a controlled manner and promoting optimal crystal growth. The heating levels and gradients of the module can be modified, which permits the furnace to be used on several missions to process different types of crystals.

As many as six samples can be processed automatically by the CGF. On orbit, a crew member loads the sample cartridges in a rotary carousel, which positions the sample cartridges so the furnace



The Crystal Growth Furnace



CGF Sample Ampoule/Cartridge Assembly

unit can move over them. Computer instructions in the flight software control the sample processing, but investigators on the ground can modify the processing by transmitting new commands to the onboard computer.

Dr. Martin Volz of the Marshall Space Flight Center is the project scientist for CGF.

Orbital Processing of High-Quality Cadmium Zinc Telluride (CdZnTe) Compound Semi-conductors. This experiment studies the effects of gravity on the growth and quality of doped and alloyed compound semiconductors. Researchers also will try to produce high-quality crystals of CdZnTe.

Researchers will grow a crystal of CdZnTe in the CGF for comparison with a crystal produced by the same growth method on Earth. CdZnTe crystals are used as substrates in a variety of mercury cadmium telluride (HgCdTe) infrared radiation detectors.

The alloying element, zinc, helps reduce defects in the HgCdTe crystal grown on the CdZnTe substrate by minimizing the strain where the two layers join. This allows the alloyed compound to have fewer natural structural defects than the binary compound since fewer defects can be transmitted from the substrate to the HgCdTe crystal. Like many similar materials, CdZnTe is also a relatively soft material and can be deformed during the normal crystallization process on Earth. These deformations can introduce undesired changes in the arrangement of the atoms of the crystal.

By processing CdZnTe in microgravity, scientists can demonstrate how gravity creates structural defects in the crystal system. These studies should enable them to predict the distribution of chemical components within a crystal. This information will be important to the improvement of the technology for growing crystals on Earth.

The CdZnTe crystal grown during USML-1 was most free of defects where it completely touched the wall of the sample cylinder and where it did not touch the wall at all. Therefore, the primary sample container on USML-2 has a spring-loaded piston, which will move to reduce the volume of the cylinder as the material contacts during cooling. This should eliminate air voids in the crystal and ensure that it maintains even contact with the container wall along its entire surface.

The principal investigator for this experiment is Dr. David J. Larson, Jr., of the Northrop Grumman Corporate Research and Development Center.

Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification. The purpose of this experiment is to confirm theories about how gravity influences the introduction and chemical distribution of structural defects in alloy semiconductors during the cyrstallization process. A crystal of mercury zinc telluride (HgZnTe) 2 centimeters long will be grown to determine its chemical and physical properties.

HgZnTe is being investigated for use in infrared radiation detection. Crystals of HgZnTe are classified as II-VI because of the position of their constituent atoms in the vertical columns of the periodic table.

Infrared detectors have many applications in defense, space, medicine, and commercial industry, and HgZnTe has qualities that theoretically make these crystals superior to other infrared detector materials. By varying the amount of the components of this alloy, its electrical and optical properties can be modified to satisfy the needs of a range of applications. However, the growth of large, single crystals that contain a predetermined fraction of each chemical component is hampered by the complexity of the chemistry involved and the effects of gravity. Experiments in microgravity should clarify the role that gravity plays in incorporating the different chemical components into the growing crystal. The composition being grown on this mission has potential applications in infrared detection and imaging systems that can be used in locating and managing petroleum on Earth and the study of distant galaxies and stars.

It is nearly impossible to grow homogeneous, high-quality bulk crystals of HgZnTe on Earth because of gravity-induced fluid flows and compositional segregation. It is expected that more even mixing of the components of the crystal can be obtained in microgravity processing.

The directional solidification method will be used to process samples of HgZnTe in the CGF. After melting the sample in the 800°C hot zone, the furnace will move very slowly over the sample (3.5 mm per day) to resolidify the material. This slow rate is necessary to prevent constitutional supercooling ahead of the solidification interface.

Dr. Sandor L. Lehoczky of the Marshall Space Flight Center is the principal investigator for this experiment.

The Study of Dopant Segregation Behavior During the Growth of GaAs in Microgravity. This experiment investigates ways of obtaining complete uniformity of selenium dopant in gallium arsenide (GaAs) crystals.

GaAs has electronic properties that make it almost as popular as silicon as a material for semiconductors. However, the distribution of the impurities, or dopants, added to GaAs in minute amounts (10 parts per million) to determine its material properties cannot be precisely controlled during the formation of the crystals on Earth because of the effects of gravity.

To produce high-quality GaAs crystals, scientists need to understand the process whereby chemical impurities, whether intentionally or unintentionally introduced, are distributed during crystal growth. Doping elements are impurities deliberately added during processing to improve or precisely control the electronic characteristics of a semiconductor crystal. A better understanding of how the dopant selemium is incorporated during crystallization will help scientists definitively confirm or deny the theories and model used to control crystal growth on Earth.

The principal investigator is D.H. Matthiesen of Case Western Reserve University.

Vapor Transport Crystal Growth of Mercury Cadmium Telluride in Microgravity. This experiment focuses on the initial phase of the process of vapor crystal growth of complex alloy semiconductors. A crystalline layer of HgCdTe will be grown on a substrate of CdTe by the vapor transport method. The resulting crystal will be examined to determine the effects of microgravity on the growth rate, chemical composition, structural characteristics, and other properties of the crystalline layer.

The performance of infrared detectors made of this material will be greatly improved when scientists are able to grow crystals that are free of structural defects and have a more uniform distribution of the chemical components. The vapor transport method will cause layers, or thin films, of HgCdTe to grow on the substrate in a process called epitaxial layer growth. Better understanding of this crystal growth method will enhance the ground-based production of similar semiconductor materials and lead to further improvement of techniques for producing crystals.

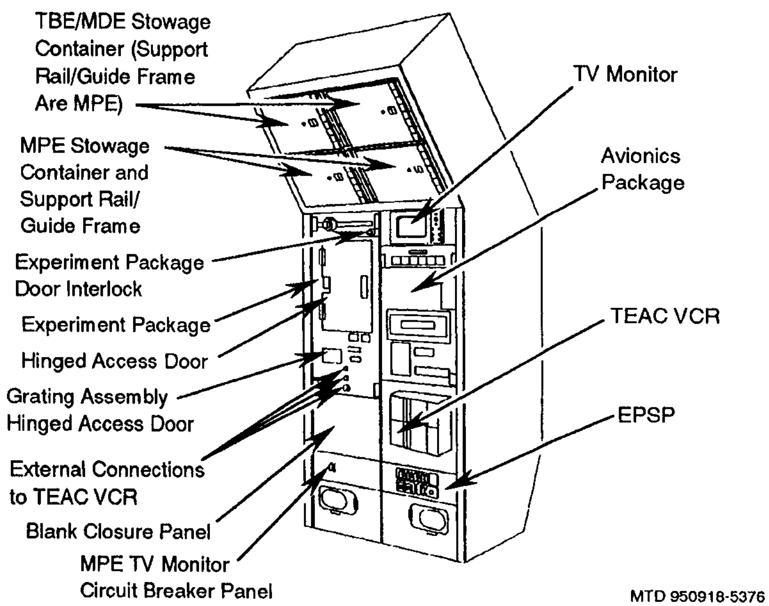
The quality of the HgCdTe crystal grown on USML-1 was considerably better than that of crystals grown on Earth. During their follow-up analysis, investigators found new information about the effects of microgravity on the formation of the initial layer deposited on the substrate. That is why the the USML-2 experiment zeros in on that stage of growth, which determines the atomic arrangement of the entire crystal.

Dr. Herbert Wiedemeier of the Rensselaer Polytechnic Institute is the principal investigator.

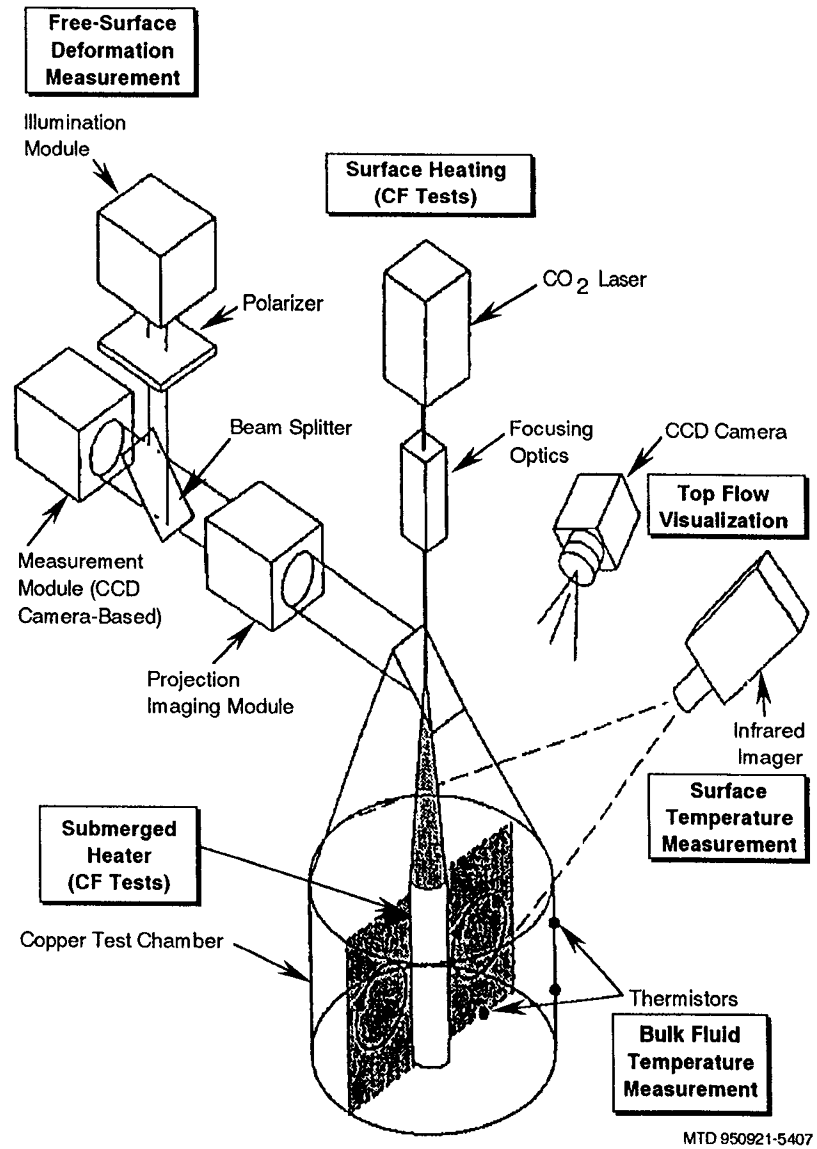
Surface-Tension-Driven Convection Experiment (STDCE)

This experiment studies the basic fluid mechanics and heat transfer of thermocapillary flows in microgravity. Thermocapillary flow is the motion of fluids created by variations in temperature along the free surfaces of liquids. Thermocapillary flow and other types of unwanted flows, such as buoyancy-driven flows, that occur during processing cause defects in crystals, metals, and alloys produced from gases and liquids. Buoyancy-driven flows and convection are overcome by processing materials in microgravity, but thermocapillary flows remain a problem. Free from the effects of gravity, thermocapillary flows are much easier to study in space, and scientists can examine how these flows are influenced by different imposed surface temperature distributions (thermal signatures), interface shapes, and other controllable factors.

Defects in high-tech crystals, metals, alloys, and ceramics can prevent them from performing as predicted or designed. Advanced products, such as crystals used to make computer chips and infrared detectors and the alloys used to make turbine engine blades, require materials that are as free from defects as possible.



STDCE-2 Rack Mounting



STDCE Hardware

In the process of this investigation, scientists will evaluate fluid flow models and theories of how these flows transition from steady (two-dimensional) to oscillatory (three-dimensional) states. They will determine how and when oscillatory thermocapillary flows are created; how flows are affected by different heat sources and surface shapes; how flows affect surface shape; and what relationships exist among free-surface deformation, surface temperature distribution, and fluid flow velocity.

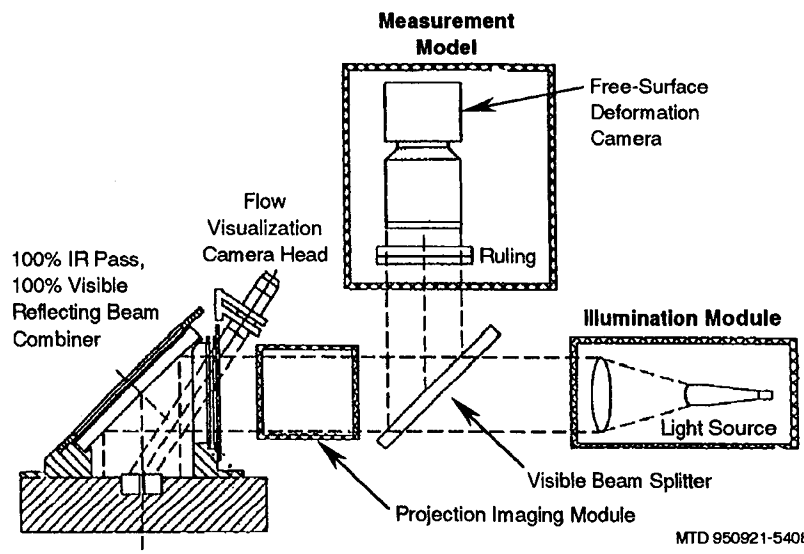
It is important to understand the behavior of thermocapillary flows and their effects because they influence bubble and droplet migration, fuel management and storage, life support systems, and material processing methods, such as crystal growth from liquids, containerless processing, and welding. In the era of longer space flights and space station operations, understanding and controlling the effects of thermocapillary flows will become even more important.

The STDCE apparatus consists of the experiment package and an electronics package in a double Spacelab rack. The chamber modules can be installed on orbit. The modules include a test chamber made of copper to assure good thermal conductivity along the walls and a silicone oil system. Low-viscosity silicone oil is used because it is not susceptible to surface contamination, which can ruin surface tension experiments.

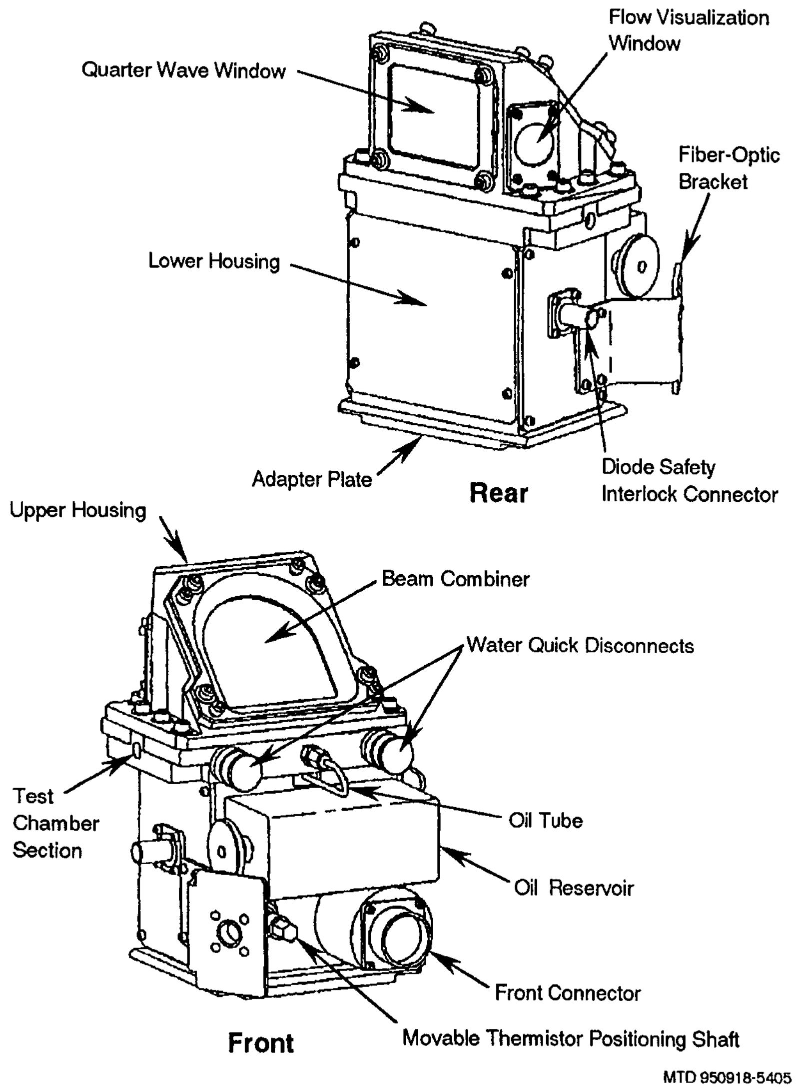
Six modules will be used to study three different test chamber diameters (1.2, 2, and 3 centimeters) and two different heating systems. A submerged heater system will be used for the study of thermocapillary flows over a range of imposed temperature differences, and a surface heating system will be used for the investigation of fluid flows generated by various heat fluxes distributed across the surface of the liquid. The surface heating system consists of a carbon dioxide laser and various optical elements that direct the laser beam to the test chamber and vary the imposed heat flux and its distribution. By analyzing the flows resulting from the diverse imposed thermal signatures, researchers will be able to properly tailor the fluxes.

Temperature and flow field measurements will be taken by a sophisticated data acquisition system connected to the experiment container. Fluid flows can be observed by illuminating aluminum oxide particles suspended in the oil with a laser and recording particle motion with a video camera attached to a view port below the experiment container. Surface temperatures of the oil, which determine the driving force of the flow, will be measured by an infrared imager. A third camera will monitor oil surface deformations and motions associated with oscillatory thermocapillary flows.

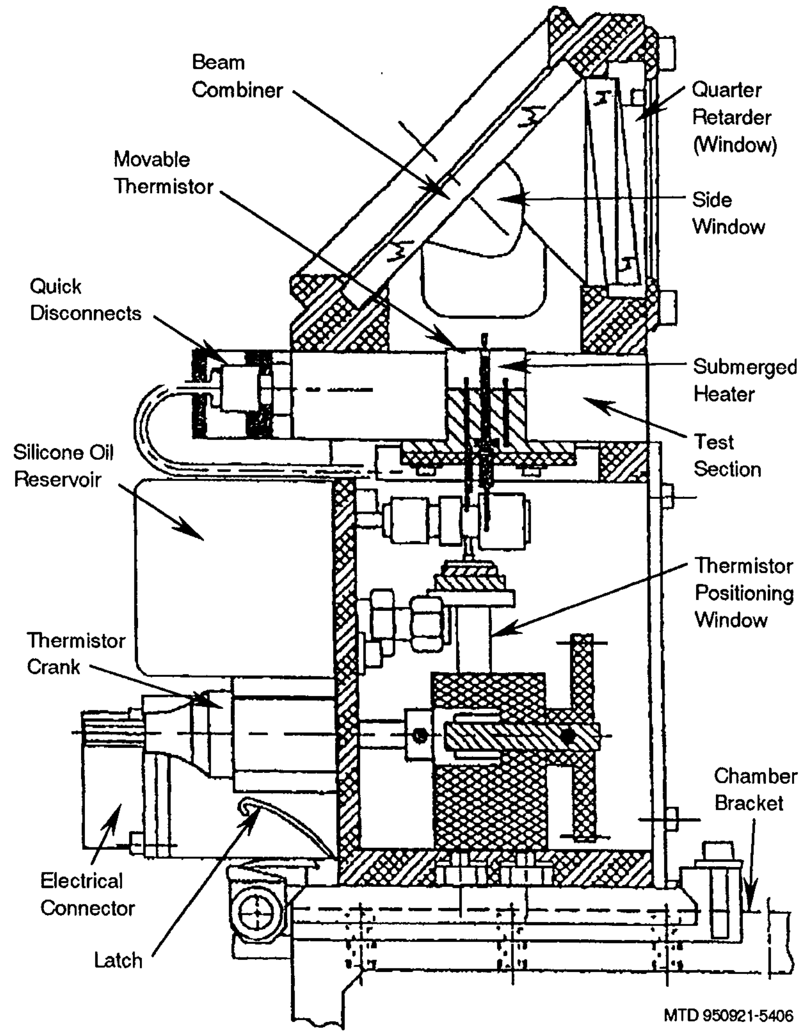
Data from the first series of experiments will be transmitted to researchers in the Spacelab Mission Operations control Center at the Marshall Space Flight Center and the User Operations Facility at the Lewis Research Center. After analyzing the data, they will send new



Flow Visualization and Free-Surface Deformation Optics



Test Chamber Module



Test Chamber Module Cross Section

test parameters for the next series of tests to the experiment computer in Spacelab. The data they obtain will allow scientists to develop mathematical models of oscillatory thermocapillary flows.

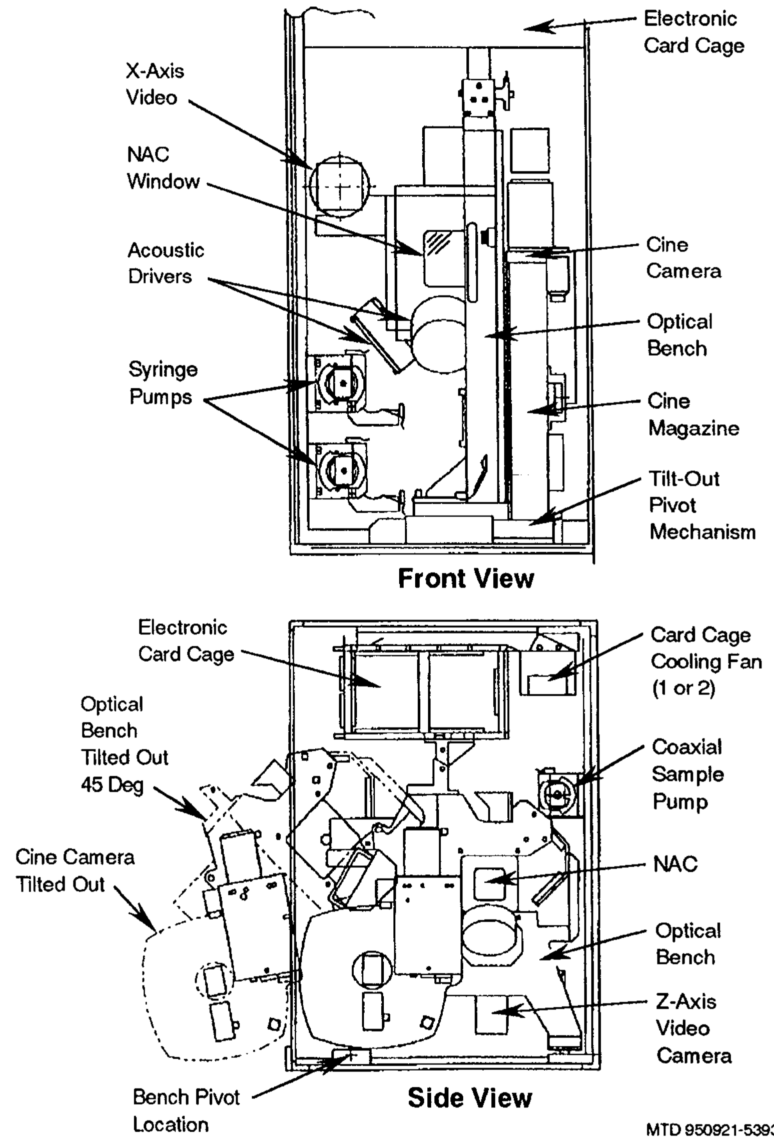
On USML-1, the STDCE experimenters concentrated on steady-state fluid flows, and their results confirmed many of their theoretical predictions. However, they observed no oscillations. On USML-2, they are using three sizes of experiment containers and several viscosities of oil to create conditions favorable for oscillations, and the STDCE imaging system has been improved to make oscillations easier to observe.

Dr. Simon Ostrach of Case Western Reserve University is the principal investigator for this experiment.

Drop Physics Module (DPM)

The DPM, in which drops of material are suspended by relatively weak sound waves, enables scientists to test basic theories of fluid physics that cannot be proved on Earth because of gravity. The DPM used on the USML missions is an advanced version of the module that was flown on Spacelab 3 in 1985.

The DPM allows scientists to study several fluid physics phenomena: a simple surface like the sphere formed by a liquid drop in the absence of gravity, how a drop reacts to different forces (drop dynamics), and how surfaces and compound drops—a drop of one liquid surrounding a drop of a different liquid—interact. Scientists will be able to observe how flows inside a drop and the surface forces interact to produce a variety of dynamic events, including symmetric oscillations that become wild (causing drops to gyrate), dynamic splitting events where a drop breaks into two drops (fission), and the centering of one drop within a second drop. The data collected will allow them to challenge and expand current fluid physics theories models. This could benefit many industries on Earth, from pharmacology to industrial chemistry.



Drop Physics Module Optical Bench Layout

A crew member will conduct all experiments in the module by directly selecting commands from menus on the two video displays or by selecting a sequence of preprogrammed commands. The crew member will monitor the response of the drop on a video display.

Besides being used to study the dynamics of drops in detail, the DPM also demonstrates containerless processing, a technique that may prove valuable in the future because of the way the module, in conjunction with microgravity, isolates the sample being studied from the container and its potentially harmful effects. In the future, scientists plan to melt solids in the DPM, study the fluid, and resolidify the material, all without touching the sample.

Film and video cameras record the behavior of drops positioned in the DPM by sound waves. Crew members can view the drop's response on a video display and manipulate the drop by modulating the sound waves. Small particles, mixed before the flight with most of the fluids, make the fluid motion inside the drop visible. The crew member operating the experiment can manipulate the sound waves to rotate, oscillate, or move the samples.

When real-time video is available, scientists on the ground can observe the experiment, discuss it with the astronaut operator, analyze the video images, and suggest things the operator could do to increase the experiment's scientific return.

Arvid Croonquist of the Jet Propulsion Laboratory is the project scientist on the DPM.

Drop Dynamics Experiment. The experiment will gather high-quality data on the dynamics of drops in low gravity for comparison with theoretical predictions and ground-based studies of very small drops. It will also provide information for use in the development of new fields, such as containerless processing of materials and polymer encapsulation of living cells.

Drop dynamics research is the basis for understanding scientific and technological areas in which liquid drops have a role, ranging from rain formation and weather patterns to chemical processing.

On USML-1, the Drop Physics Module confirmed a 100-year-old theory. The module spun single drops of various fluids until they formed a dog-bone shape. All the drops changed into the same shape at the same point and at exactly the point that had been predicted a century ago by fluid dynamics pioneer Lord Raleigh.

On USML-2, the researchers will examine two new aspects of drop phenomena. They will test a set of theories that describe the fissioning, or breaking apart, of distorted drops as the viscosity (or thickness) of a fluid varies by observing and analyzing the conditions at which various sizes and viscosities of drops split.

In a second thrust, the scientists will attempt to prepare for encapsulating living cells that could be used to treat hormonal disorders by studying the centering of shells (air bubbles within liquid drops) and compound drops (a drop of one liquid encased within a drop of a different liquid). This investigation could demonstrate a method for achieving uniform encapsulation, which would help scientists use polymer systems to encapsulate living cells.

The oscillating and rotating drops will be recorded by video and film cameras. These records will be used to analyze the drop shapes, obtain the oscillation frequencies, and compare the data with theoretical predictions.

The principal investigator for this experiment is Dr. Taylor Wang of Vanderbilt University.

Science and Technology of Surface-Controlled Phenomena. This experiment determines the surface properties of drops coated with surfactants (materials that migrate toward free surfaces or the interface between two liquids) and examines the coalescence of surfactant-coated drops.

The results of the two sets of experiments planned should help scientists to better understand what is going on in the surface layer of a drop of water and provide better information for the application of surfactants in industry. Processes that rely heavily on surfactants range from dishwashing (the classic example of surfactant-liquid interaction), the manufacture of cosmetics, the dissolution of proteins in synthetic drugs, the recovery of oil, and environmental cleanup.

In one set of experiments, water drops that contain a variety of surfactants in different concentrations will be oscillated in the DPM by being "squeezed" acoustically and released. Researchers will relate the measured frequencies and damping of the oscillations to surface properties, such as shear and dilatational viscosities, with the help of theoretical expressions.

In the second set of experiments, two drops of water with varying concentrations of surfactants will be positioned in the DPM and forced toward each other until they coalesce. The drops containing heavier concentrations of surfactants should not coalesce spontaneously; they will be forced to combine. Researchers will try to characterize the critical parameters that cause the drops to rupture and coalesce.

Both sets of experiments will create novel situations that are not possible on Earth, and information gained from the space experiments will enable ground-based scientists to accurately and conveniently measure materials properties during similar tests on Earth.

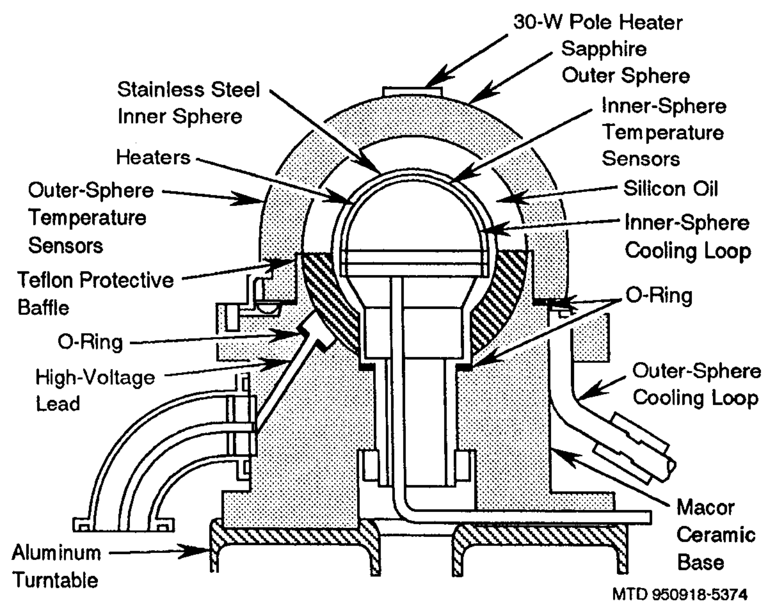
The results of the investigation conducted during USML-1 were used to confirm and adjust theoretical models. The USML-2 experiments will be used to refine these theories further.

Dr. Robert E. Apfel of Yale University is the principal investigator.

Geophysical Fluid Flow Cell

The purpose of the GFFC is to study how fluids move in microgravity as a means of understanding fluid flow in oceans, atmospheres, planets, and stars.

Large-scale motions of the atmospheres of planets and in the convection zones of rotating stars are strongly constrained by rotation and gravity, which create the buoyancy forces that cause thermal circulations. The structures of these large-scale flows are often surprising and baffle scientists seeking fundamental understanding of such phenomena as the zonal bands of Jupiter; the origin of extremely high winds in the tropics and subtropics of Jupiter, Saturn, and Neptune; the persistent differential rotation of the sun; the complex patterns of convection in the slowly rotating mantle of Earth;

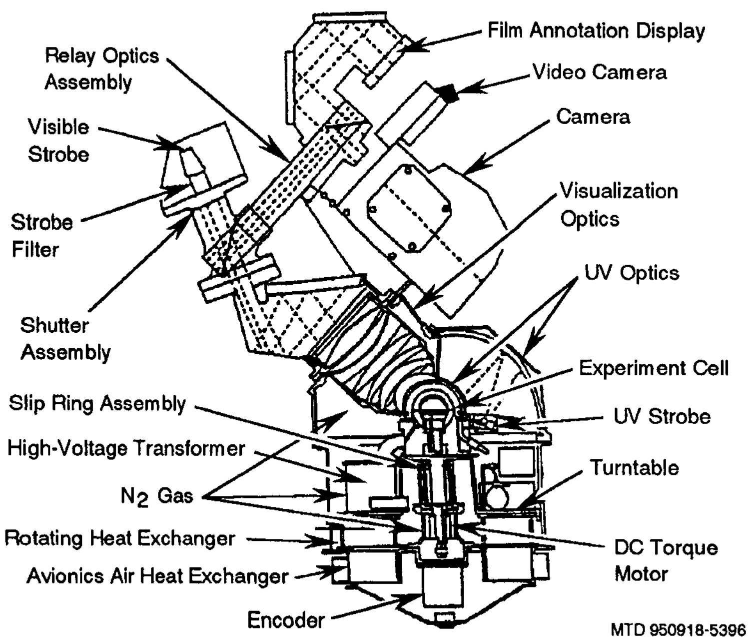


The Geophysical Fluid Flow Cell

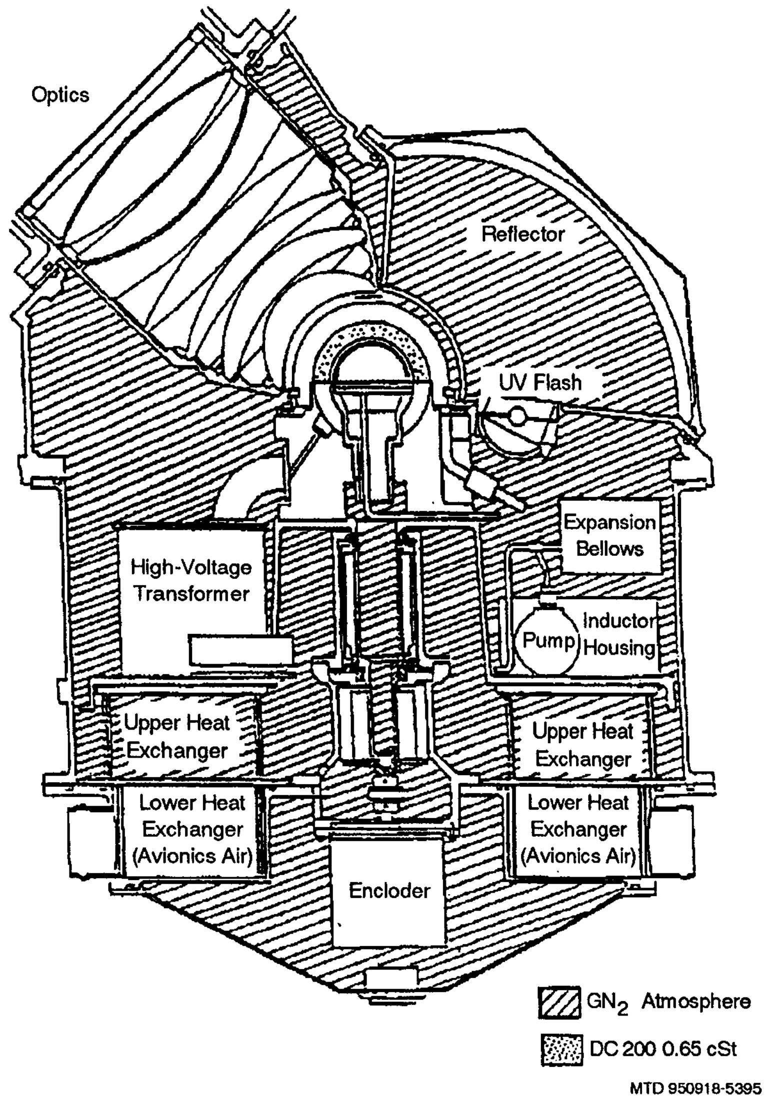
and the rapidly rotating flows in the Earth's core that are thought to generate our magnetic field.

This type of fluid mechanics can be studied only in a microgravity laboratory where the fluids are free from gravitational forces that dominate their behavior on Earth. Although laboratory studies on Earth have been limited to rotating layers between parallel plates oriented perpendicularly to gravity, they have yielded some data on geophysical fluid dynamics. But, because gravity and rotation are parallel in these experiments, the results are only relevant to the polar regions of the atmosphere.

The GFFC lets scientists study rotating fluid shells in an environment unhindered by gravity. Photographs of the experiment will contain data on temperature and velocity fields, revealing the funda-



The Geophysical Fluid Flow Cell



GFFC Gaseous Nitrogen Blanket

mental fluid mechanics processes that govern Earth's atmosphere and oceans, atmospheres of other planets, and the sun and other stars. The atmosphere of Jupiter is of particular interest since it radiates more heat than it receives from the sun, indicating that there may be an internal heat source. Perhaps by experimenting with temperature differences in the GFFC, scientists can better understand what causes the distinctive cloud patterns on Jupiter.

The GFFC previously flew on Spacelab 3 in 1985, operating for more than 100 hours and generating 50,000 frames of photographic data containing images of convection structures, instabilities, and turbulence under varying conditions of differential heating and rotation. Several new types of convection were observed, but some could not be investigated sufficiently because of time limitations and a lack of real-time data. Increased interaction among scientists, the crew, and experiment operations on the USML-2 will allow investigation of a variety of phenomena. This time, the focus is convectional stability and stratified atmospheric flows similar to the layers of Earth's atmosphere, climatic evolution, and temperature distributions not studied on Spacelab 3.

One experiment, with four distinct parts, is planned, during which scientists hope to obtain more than 100 hours of observations. The instrument, located in the Spacelab module, consists of a stainless-steel hemisphere the size of a baseball, surrounded by a sapphire hemisphere, with silicone oil in between. Sapphire is used because it is a good conductor of heat and a transparent material that allows precise temperature control and observations of the silicone oil as it flows between the hemispheres.

Rotation of the hemispheres, which are rigidly mounted on a turntable, is controlled by means of a frequency synthesizer and a phase-locked servo system. High voltage levels (up to 10,000 V root mean square) are applied across the hemispherical capacitor by a variable voltage power supply. Both of these units are under the control of a microcomputer. Different combinations of temperature, rotation speed, and voltage establish various levels of spherical convection within the cell. The resulting convective flow rates and thermal gradients are monitored by an optical visualization system.

GFFC operation is controlled by a microcomputer that stores up to 97 fixed experiment scenarios, each comprising a number of experiment test conditions. Upon initiation by the operator, the computer provides appropriate commands and controls to execute the scenarios, each of which may last as long as 6 hours. These scenario instructions also activate the camera, display pertinent information, and automatically shut down the experiment in the event of a malfunction or hazard.

The inner hemisphere of the experiment cell contains eight heaters and nine temperature sensors. A vacuum-deposited aluminum coating provides a high visual reflectivity surface that serves as a retroreflecting mirror for the visualization optics. The outer sapphire hemisphere, which has a heater at its north pole, is mechanically clamped to a ceramic mounting base.

The optical system of the GFFC is designed for visualization of fluid flow within the experiment cell and for data annotation on photographic film. The major optical system is an array of eight lenses that focus nearly parallel light on the reflective surface of the inner sphere. A system of lenses relays the image to a second plane just ahead of the camera lens. The combination of the visualization lens, relay lens, and camera lens produces an image of a 90-degree sector of the inner sphere on film.

An electric charge is applied to the fluid to create a buoyancy force identical to those on Earth and in other atmospheres being modeled. The silicone oil contains a chemical that forms blue dye lines when subjected to ultraviolet light. Studying the movement of the lines allows investigators to measure the fluid movement and velocity. Temperature measurements are made by studying the variations in the density of the fluid. Varying the rotation rate, temperature, and voltage in the facility creates flow corresponding to the oceans, planetary atmospheres, and stars.

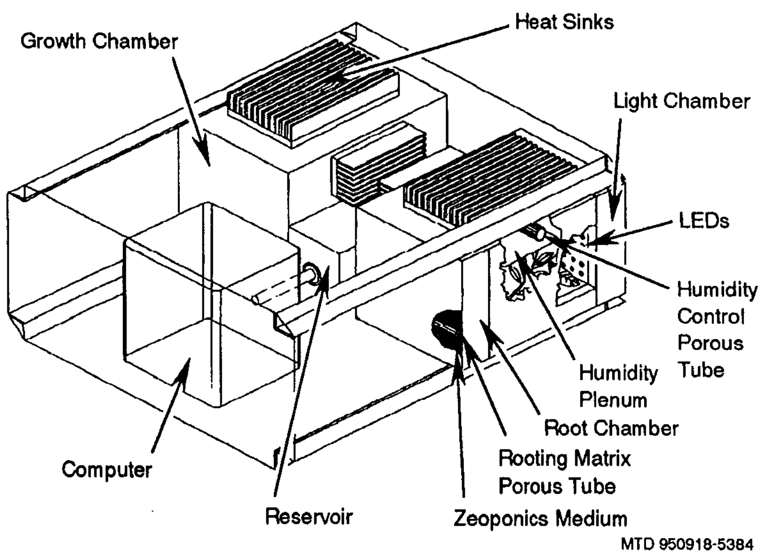
The GFFC principal investigator is Dr. John Hart of the University of Colorado at Boulder.

Astroculture

This experiment will evaluate the performance of the Astroculture plant watering system in microgravity and determine how the accumulation of starch in plants is affected by microgravity. The Astroculture unit is designed to support the growth of plants in microgravity through precise watering and delivery of nutrients.

Astronauts will have to grow plants during lengthy space missions to reduce the costs of providing food, oxygen, and purse water and removing carbon dioxide from the air supply.

A plant growth system must deliver nutrients to plants without allowing the solution to escape into crew quarters. It must also control the amount of moisture in the air to prevent excessive humidity,



ASC Internal Configuration

which could damage experiments and equipment, and maintain a sufficient amount of moisture for healthy plants. Moisture in the air also could be recycled for use in cooking, drinking, or watering plants. Because electrical power is a valuable resource on orbiting spacecraft, the plant growth system must be also able to provide light as efficiently as possible.

The Astroculture unit addresses these issues and provides superior environmental control for plant growth in an inexpensive and reliable package.

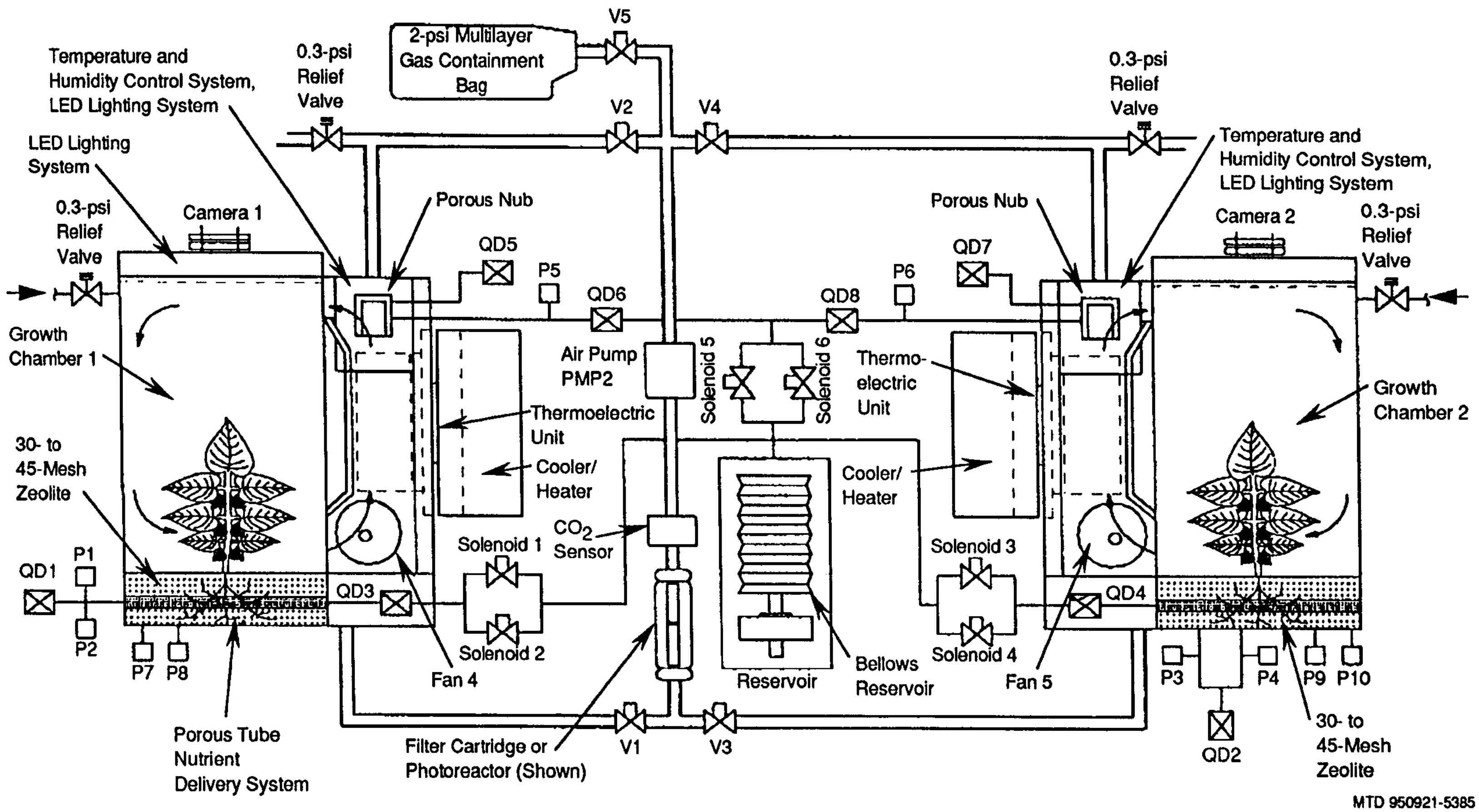
The Astroculture water and nutrient delivery system consists of pumps, porous stainless steel tubes for delivering and recovering a nutrient solution, and a rooting matrix. The delivery tube carries nutrients under negative pressure to the rooting matrix of baked montmorillinitic clay. The recovery tube, operating at a grater negative pressure than the delivery tube, removes water from the rooting matrix, simulating the action of plant roots.

This system has already been proven effective on long-duration space flights.

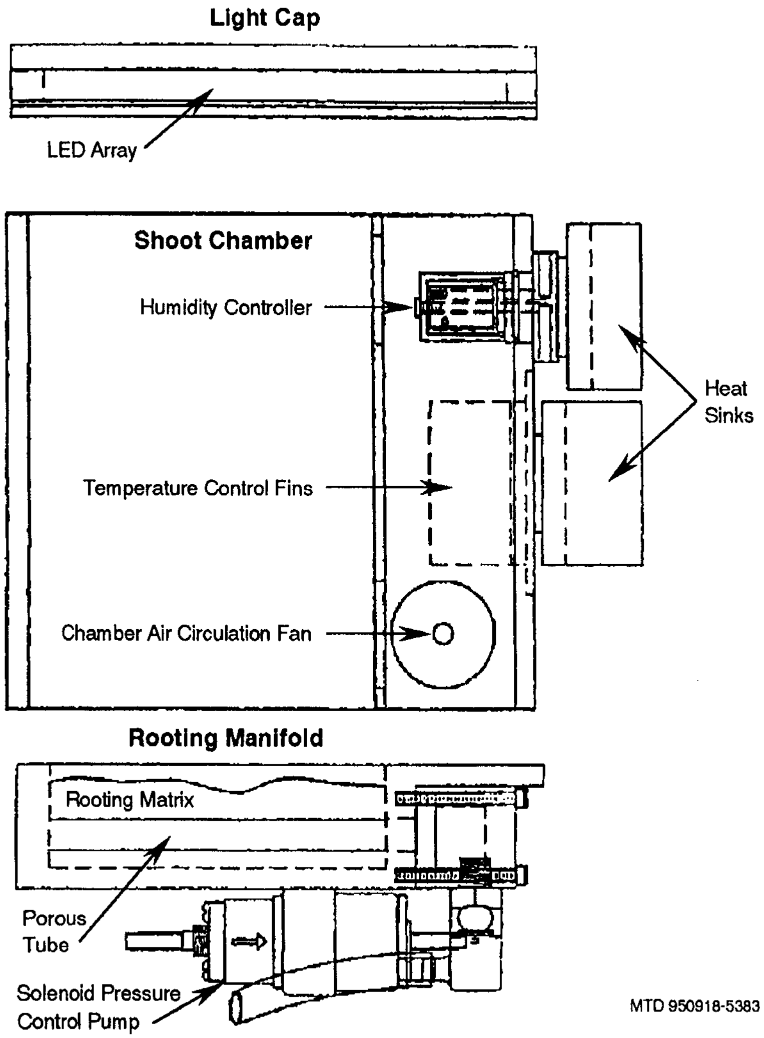
Astroculture's efficient system for controlling moisture in the growth chamber humidifies and dehumidifies the air without a gas/liquid separator, which is required by all other systems, to recover condensed water. The unit's lighting system uses light-emitting diodes to provide high levels of light within the limits of the electrical power available on orbit and with greater safety than any other light sources in use on space-based plant growing facilities.

The sealed experiment package is cooled by an experiment heat exchanger, and carbon dioxide (necessary for photosynthesis) is supplied from a storage tank.

Potato plants will be grown in the Astroculture facility as part of a cooperative experiment with the Secondary Payload Programs of NASA's Life and Biomedical Sciences and Applications Division to determine whether the accumulation of starch, which is an important



ASC Systems Schematic



Astroculture Growth Chamber Assembly

energy storage compound in plants, is restricted in microgravity. Tubers filled with starch can be produced from leaf cuttings in ten to 15 days.

Researchers will evaluate the rates of photosynthesis, movement of photosynthesis products from leaves to tubers, conversion of sugars to starch in storage organs, and enzyme activities involved in the formation and degradation of starch. They will also study the number, size, shape, and distribution of starch grains and the structures that form starch.

This is the last of a series of tests evaluating each of the critical Astroculture systems needed to build a reliable plant growth unit. Astroculture flew on the USML-1 and the SPACEHAB-1 and 2 missions, which validated the lighting, humidity, pH, nutrient supply and composition, and carbon dioxide and atmospheric contaminant systems. After the experiment is qualified for flight on this mission, a plant growth unit will be available for sale or lease to commercial enterprises.

Several commercial products have been developed for use on Earth from the Astroculture technologies. The lighting system has been used as the basis for the development of a unique lighting system for photosynthesis research. The lighting technology is also being used in some novel medical applications, such as measuring blood sugar levels in treating cancer patients. Other applications of the Astroculture technology are improved dehumidification/humidification units, water-efficient irrigation systems, and energy-efficient lighting systems for large commercial nurseries.

The principal investigator for this experiment is Dr. Raymond J. Bula of the Wisconsin Center for Space Automation and Robotics at the University of Wisconsin.

Commercial Generic Bioprocessing Apparatus

The Commercial Generic Bioprocessing Apparatus (CGBA) is a generic research tool that supports life sciences research in biophysics, cellular biology, developmental biology, and physiology. It is sponsored by NASA's Office of Advanced Concepts and Technology and developed by BioServe Space Technologies, a NASA Center for the Commercial Development of Space (CCDS) at the University of Colorado.

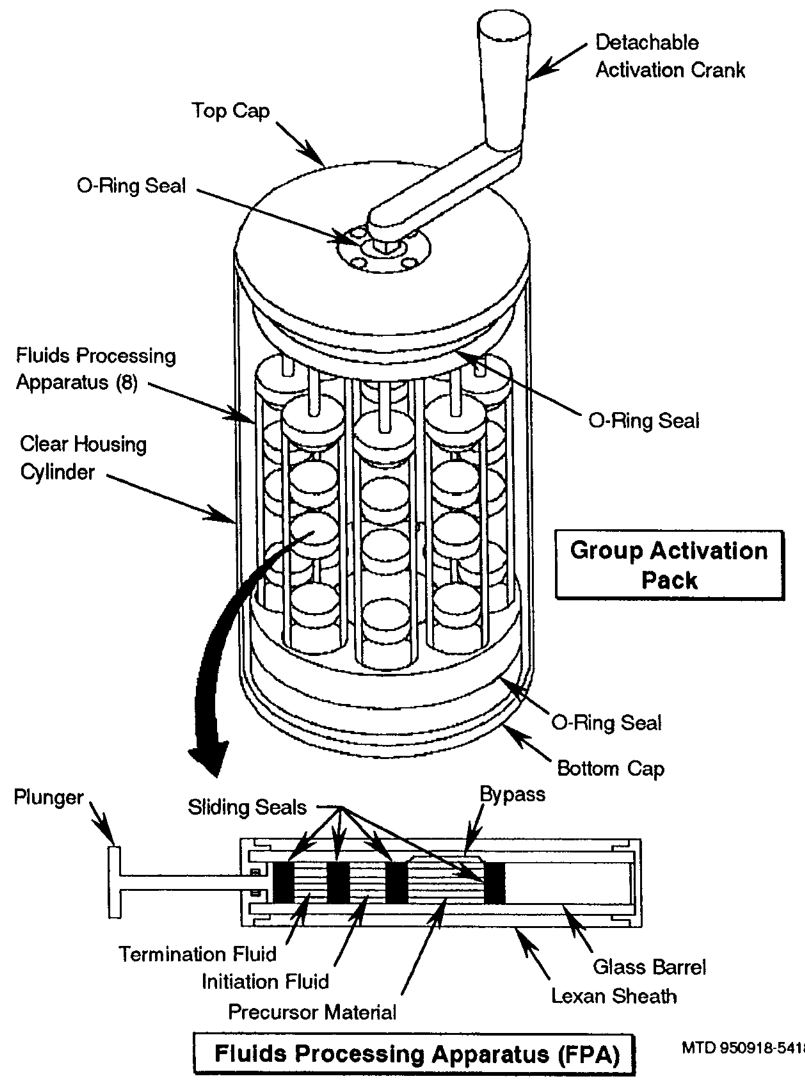
The CGBA serves as the housing, incubator, and data collection point for BioServe's fluids processing apparatuses (FPAs), multi-chambered devices that permit fluids to be mixed in space. One of the strengths of the CGBA payload is that it can meet a wide variety of experimenters' needs. It has also been exceptionally reliable: quality sample and data return rates on previous flights have exceeded 99%.

On USML-1, CGBA investigations included how the human body fights disease, how infectious organisms like bacteria can be controlled, and how cells and molecules develop and grow in reduced gravity. Other experiments focused on seed germination and the effects of microgravity on plant and animal development.

Ecological experiments studied efficient use of bacteria to treat waste and recover water for long-term space flight. Biomaterial experiments tested new methods for producing protein crystals and industrial crystallizers and the growing biomolecular gels of bacteriohodopsin, a protein whose ability to harvest light energy has vast potential for electronic memory storage.

Experiments. The experiments conducted on USML-2 will continue these investigations.

Biomedical Testing and Drug Development: Information from these experiments may lead to better understanding of how microgravity affects bone metabolism, the immune system, and the neuromuscular system. This data could help scientists develop and test new drugs and treatments for diseases and disorders like cancer, osteoporosis, and AIDS.



FPA and Group Activation Pack (GAP)

Ecological Test Systems: This investigation focuses on controlled agricultural applications, waste management processes, and methods of controlling microbes. Experiments are designed to evaluate the effects of microgravity on seeding, seed germination, plant development, and bacterial products and processes. Understanding the development of plants and the relationships between bacteria and plants is crucial to extended stays in space, where plants will be used as both a food source and a means of purifying air.

Biomaterials Products and Processes: Through these experiments, scientists hope to learn more about how bacteria grow in the absence of gravity-driven fluid flows, grow structures that can deliver drugs directly to cells, and model potential synthetic replacements such as skin, tendons, blood vessels, and corneas.

The principal investigator is Dr. Louis Stodieck of the Center for BioServe Space Technologies at the University of Colorado at Boulder.

Flight Hardware. The payload hardware has three major elements: GBA II, a commercial refrigerator/incubator module (CRIM), and a stowage locker. GBA II is stowed in a single middeck locker space and requires 28 volts direct current (Vdc). Stowage is mission specific. For temperature-controlled stowage, the CRIM and a middeck locker supplying 28 Vdc are used. For ambient stowage, a middeck locker is used.

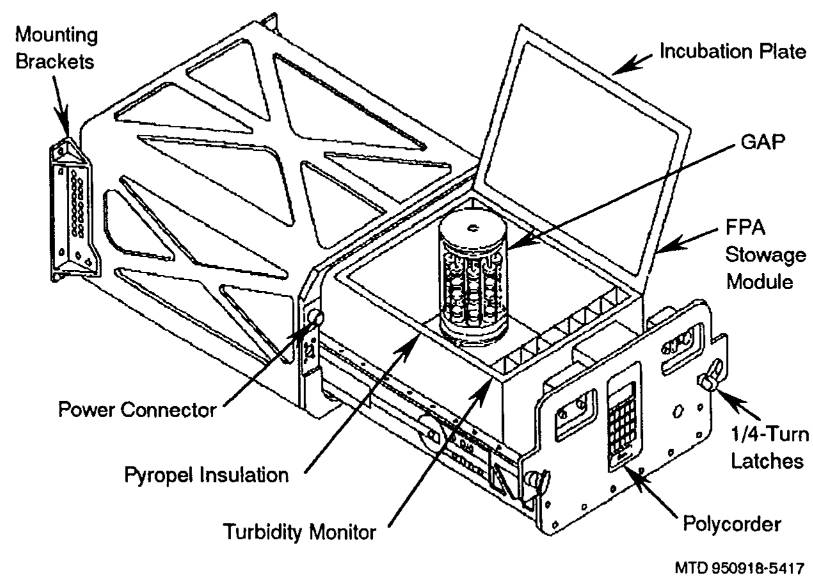
The CGBA can have three different hardware combinations. Configuration A consists of the GBA II module plus the CRIM and the middeck stowage locker, configuration B consists of the GBA II module and the CRIM, and configuration C consists of the GBA II module and the middeck stowage locker. Biological samples are stowed in the CRIM and/or lockers both before and after processing in the GBA II.

The GBA II is a self-contained mixing and heating module in which biological fluid samples are processed in microgravity. Up to 120 fluid samples contained in glass syringes with Lexan sheaths are stored in either the CRIM or a middeck locker. These fluids are manually mixed in the syringes and transferred to a sample containment vial that is then heated and incubated. At the end of the incubation period, the fluid vials are returned to the CRIM or the stowage locker.

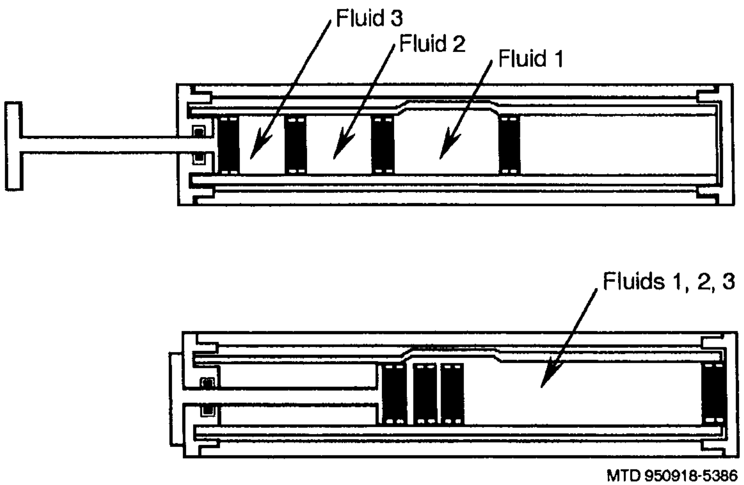
Crew activities consist of mixing samples, incubating samples in the GBA II, transferring data to the payload and general-support computer, and photographing fluid samples.

The CGBA consists of 152 FPAs packaged in 19 group activation packs (GAPs). FPAs are multipurpose fluid mixing devices in which individual experiments are conducted. Each GAP houses a suite of eight FPAs that can be operated simultaneously. Nine of the GAPs are operated manually, and ten are automated, motor-driven types. The FPAs contain biological sample materials that are mixed in orbit to begin and end an experiment.

In the FPA, sample materials are contained inside a glass barrel that has rubber stoppers to separate three chambers. For each investigation, the chambers will contain precursor, initiation, and ter-



GBA-II



Activation of Fluid Processing

mination fluids. The loaded glass barrel is covered with a plastic sheath that protects the glass from breakage and serves as a second level of sample fluid containment.

The FPAs are operated by a plunger mechanism that is depressed in orbit, causing the chambers of precursor fluid and the stoppers to move forward inside the glass barrel. When a stopper reaches an indentation in the glass barrel, initiation fluid from the second chamber is injected into the first chamber, activating the biological process.

Once processing is complete, the plunger is again depressed until the termination fluid in the third chamber is injected across the bypass in the glass barrel into the first chamber. This preserves the sample materials for return to Earth and detailed analysis.

The GAP consists of a 4-inch-diameter plastic cylinder and two aluminum endcaps. Eight FPAs are located around the inside circumference of the GAP cylinder. A crank extends into one end of the GAP and attaches to a metal pressure plate. Rotating the crank advances the plate and depresses the eight FPA plungers simultaneously.

On-Orbit Operations. Upon reaching orbit, the crew initiates the various investigations by attaching a crank handle to each GAP. Turning the crank causes an internal plate to advance and push the plungers on the contained FPAs. This action causes the fluids in the forward chambers of each FPA to mix.

The crew terminates the investigations in a similar manner. Attaching and turning the GAP crank further depresses the FPA plungers, causing the fluid in the rear chamber to mix with the processed biological materials. This fluid typically stops the process or "fixes" the samples for return to Earth in a preserved state. Each GAP is terminated at a different time during the mission. In this manner, sample materials can be processed for as little as one hour to nearly the entire duration of the mission.

Automated versions of the GAPs can be used if no crew monitoring is required.

For most of the investigations, simultaneous ground controls are run. Using identical hardware and sample fluids and materials, ground personnel can activate and terminate FPAs in parallel with the flight crew. Synchronization is based on indications from the crew that specific GAPs are being operated.

Protein Crystal Growth

Scientists want to know what specific proteins do and how their structures determine their function. But the protein crystals grown on Earth that are large enough to study are too flawed to be useful. The Protein Crystal Growth experiment, a veteran of previous shuttle missions, takes advantage of microgravity to produce larger, more uniformly structured crystals that are much better suited to X-ray diffraction analysis, one of the methods used to determine the three-dimensional molecular structure of the crystals.

Investigators also want to assess the growth rates of proteins under various conditions to find the optimum process for space-grown crystals so that they can further their protein studies and produce some of the more difficult-to-grow specimens.

The USML-1 protein crystal growth experiments were very successful. More than 30 protein crystals were flown, and nearly half produced crystals that were large enough for X-ray diffraction analysis.

Some of the largest crystals of the plant protein canavalin ever grown (more than 2 millimeters long) were formed. Crystals of human proline isomerase, a protein associated with transplant rejection and a target of drug designers, yielded the highest-quality data ever collected on the protein.

Large, well-formed crystals of proteins important to immune disorder studies also were grown. These included HIV reverse transcriptase complex, a protein important in the design of drugs to fight AIDS. The three-dimensional structure of Factor D, a protein that plays a role in complications such as inflammation after open-heart surgery, was obtained from the high-quality crystals grown on USML-1.

Single-Locker Protein Crystal Growth. More than 800 protein samples will be processed in a facility designed to produce crystals that have an enhanced internal order. The protein crystallization apparatus for microgravity (PCAM) holds more than six times the samples normally accommodated in the same amount of space.

The PCAM uses the vapor diffusion method to grow crystals. This method has been highly effective in previous experiments. In vapor diffusion, liquid evaporating from a protein solution is absorbed by a reservoir solution. As the protein concentrations rise, crystals form.

Twelve PCAM cylinders—each holding 63 samples—will be housed in two temperature-controlled enclosures called single-locker thermal enclosure systems. Each STES occupies a single shuttle middeck locker. The enclosures maintain temperatures at 72 degrees Fahrenheit.

Eight short PCAMs containing precipitation ("salt") solutions will be kept in an ambient-temperature stowage locker. The solutions will be analyzed to determine the rate at which the vapor diffusion process proceeds in the diffusion-limited environment of microgravity.

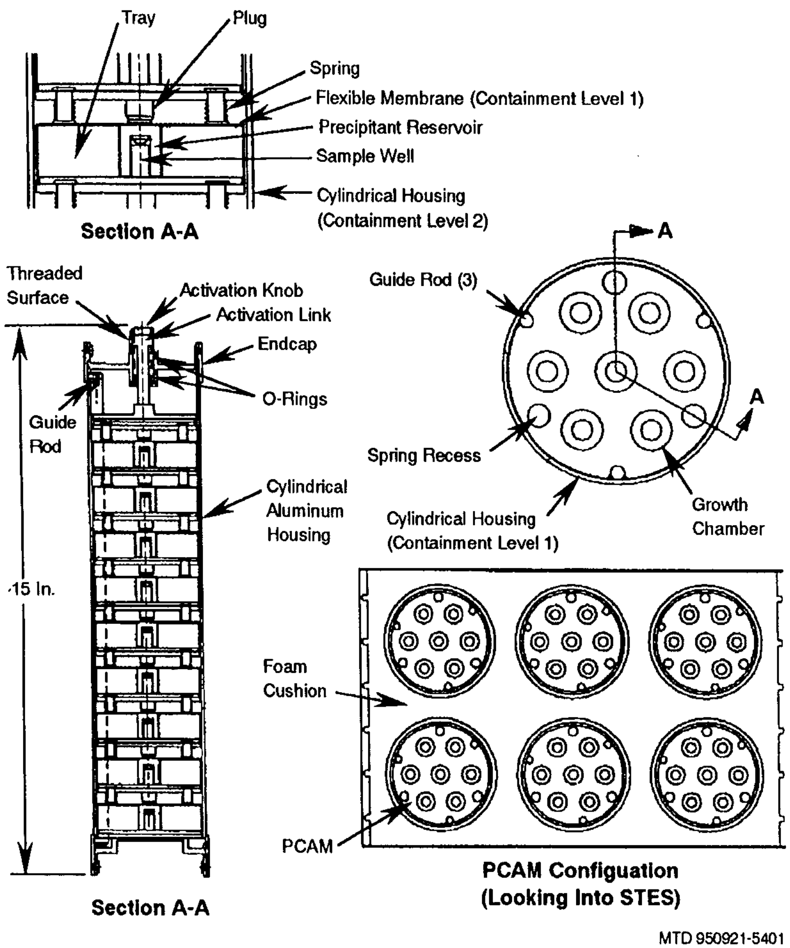
To start the PCAM experiments, a crew member will open the front of the enclosure and rotate a shaft on the end of the cylinder. Diffusion and protein crystal growth will begin. Near the end of the mission, a crew member will rotate the shaft in the opposite direction to stop the process.

A new experiment chamber called the diffusion-controlled crystallization apparatus for microgravity (DCAM) also will be tested. Eighty-one protein-containing DCAMs will be housed in an STES in the Spacelab module. A combination of the liquid-liquid diffusion and the dialysis methods will be used to grow model proteins. NASA scientists developed this method to passively control the crystallization process over extended periods of time. The space-grown proteins will be compared with those grown by the same method on the ground.

The experiment is a precursor to long-duration crystallization experiments on the International Space Station and the Russian Mir station, which would benefit greatly from the ability to control crystal growth times of up to approximately six months.

The principal investigator is Dr. Daniel Carter of the Marshall Space Flight Center.

Crystal Growth by Liquid-Liquid Diffusion. Protein crystals will be grown in four handheld diffusion test cell units, each contain-



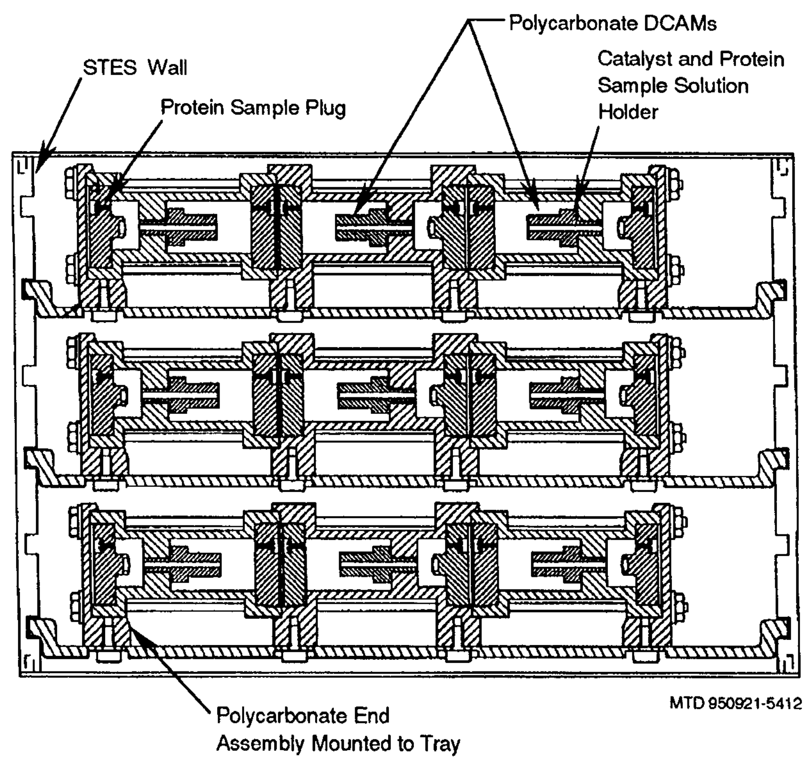
Protein Crystallization Apparatus for Microgravity

ing four test cells, by diffusing one liquid into another. In liquid-liquid diffusion, different fluids are brought into contact but not mixed. Eventually, the fluids diffuse into each other through the random motion of molecules. The gradual increase in the concentration of the precipitant in the protein solution causes the proteins to crystallize.

Liquid-liquid diffusion is difficult on Earth because of thermal convection. The greater density of the crystals also allows them to settle into inappropriate parts of the cell.

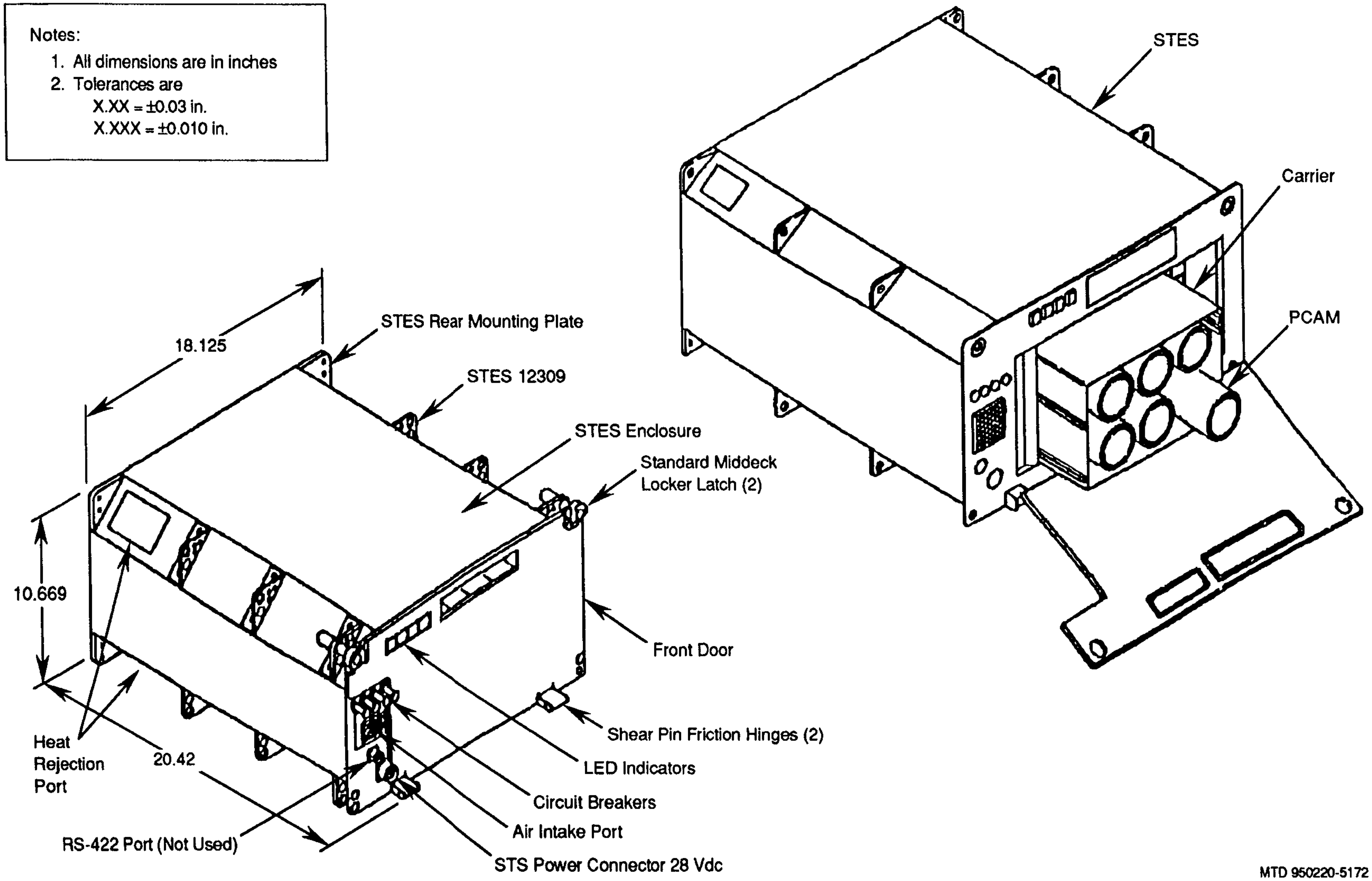
The ends of the HHDTCs, where the crystals will grow, and the containment housing are made of clear plastic so crew members can photograph the growing crystals periodically during the mission.

Each test cell has three chambers: one for the protein solution, one for the buffer solution, and a third for the precipitant solution. A crew member will activate the experiment by rotating the valve that isolates the fluids 90 degrees so the buffer contacts the protein and precipitant and the three form a single volume. When the three liq-



DCAM Unit (STES Door Removed for Clarity)

Notes:
1. All dimensions are in inches
2. Tolerances are
X.XX = ±0.03 in.
X.XXX = ±0.010 in.



Protein Crystal Growth Single-Locker Thermal Encloure System Block II Configuration uids are in contact, they will slowly diffuse into each other. The crew will close the valves before the return to Earth.

Dr. Alexander McPherson, Jr. of UC Riverside is the principal investigator.

Commercial Protein Crystal Growth. This experiment will use the batch process method to grow large quantities of crystals of various proteins.

Crystallization will take place in a protein crystallization facility housed in a commercial refrigerator/incubation module in the orbiter middeck. The PCF contains four cylindrical crystallization chambers which will be kept at 104 degrees Fahrenheit until the shuttle reaches orbit. Then they will be gradually cooled to 72 degrees Fahrenheit over a 24-hour period. The change in temperature will cause crystal growth to begin. Crystals form as the chamber cools.

More crystals will be grown in a vapor diffusion apparatus as part of this experiment.

Dr. Larry DeLucas of the Center for Macromolecular Crystallography in Birmingham, Ala., is the principal investigator.

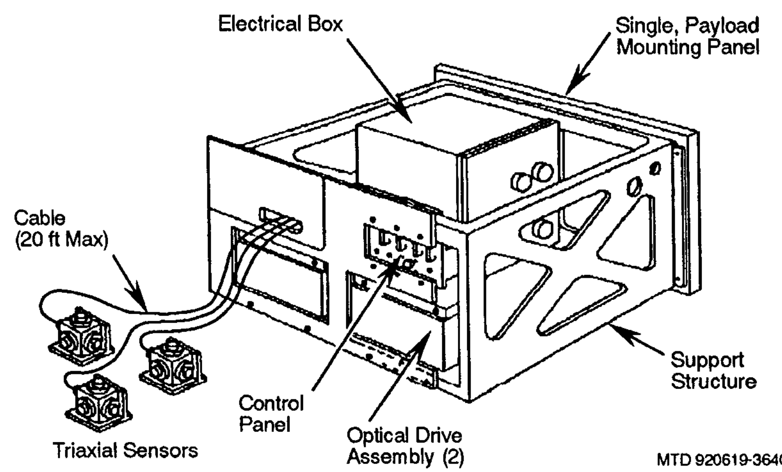
Measuring Microgravity

Experiments conducted on the shuttle need a very stable microgravity environment that will not disturb their delicate operations. However, astronauts living and working on the shuttle orbiter maneuvers, and antenna motions produce accelerations that make absolute stability impossible to achieve. Investigators need to know the precise strength of gravitational influences and vibrations affecting their experiments in order to interpret their results correctly and understand the effects caused by these forces. USML-2 includes three facilities to measure different types of accelerations and will test a device that could be used to isolate sensitive experiments from disturbances.

Space Acceleration Measurement System. Microgravity, which allows unique experiments in the Spacelab environment, is not the total absence of gravity. Investigators need to know to what extent the momentary vibrations of crew movement, equipment operation, and spacecraft maneuvers act like gravitational forces on their experiments. They also want to measure the quasi-steady accelerations caused by the constant drag and rotation of the orbiting shuttle.

This measurement system will record vibrations in three crucial Spacelab areas: the Surface-Tension-Driven Convection Experiment, the Crystal Growth Furnace, and the Glovebox. Its three triaxial sensor heads, placed at the three experiment locations, measure accelerations along three orthogonal axes.

Investigators will use SAMS data to determine how crew movements, equipment operations, and shuttle maneuvers affect their

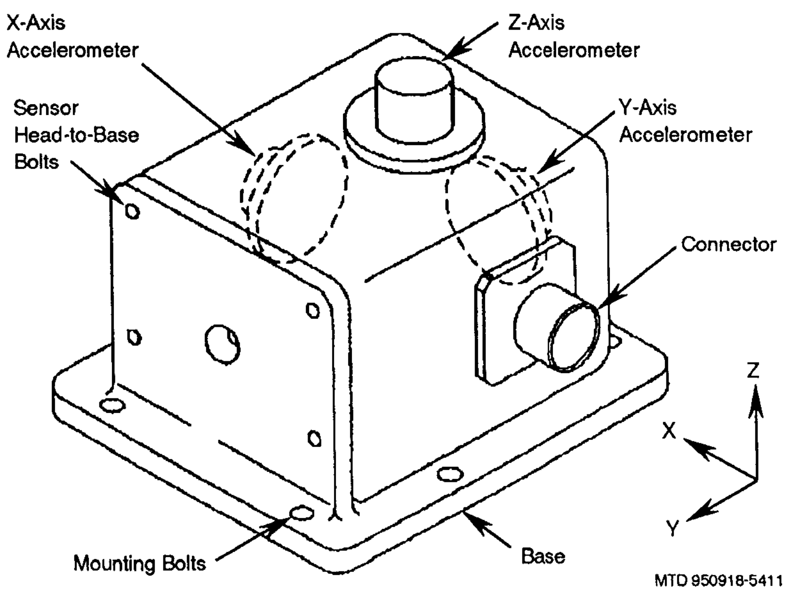


SAMS Hardware

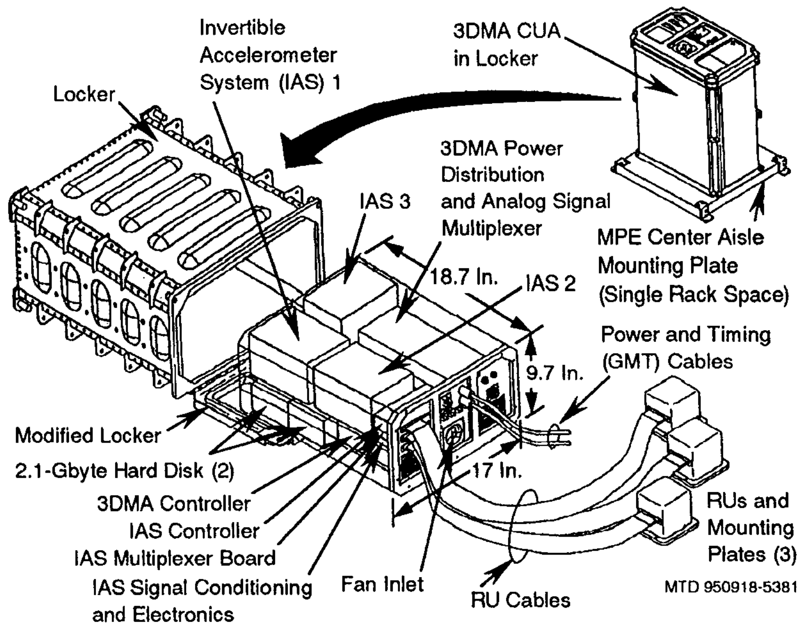
experiments on USML-2. Scientists will analyze the data after the flight to determine that a disturbance took place at a particular time. They can make allowances for the disturbance as they analyze their experiment data.

Ron Sicker of NASA's Lewis Research Center is the project manager.

Three-Dimensional Microgravity Accelerometer. Three instruments will measure deviations from zero gravity in three dimensions inside the Spacelab module at different locations so that researchers can determine their effect on experiments. Measurements of disturbances caused by the operation of the experiments, the orbiter's rotational motions, and vehicle drag will be used to calculate microgravity levels in the Spacelab.



Typical Triaxial Sensor

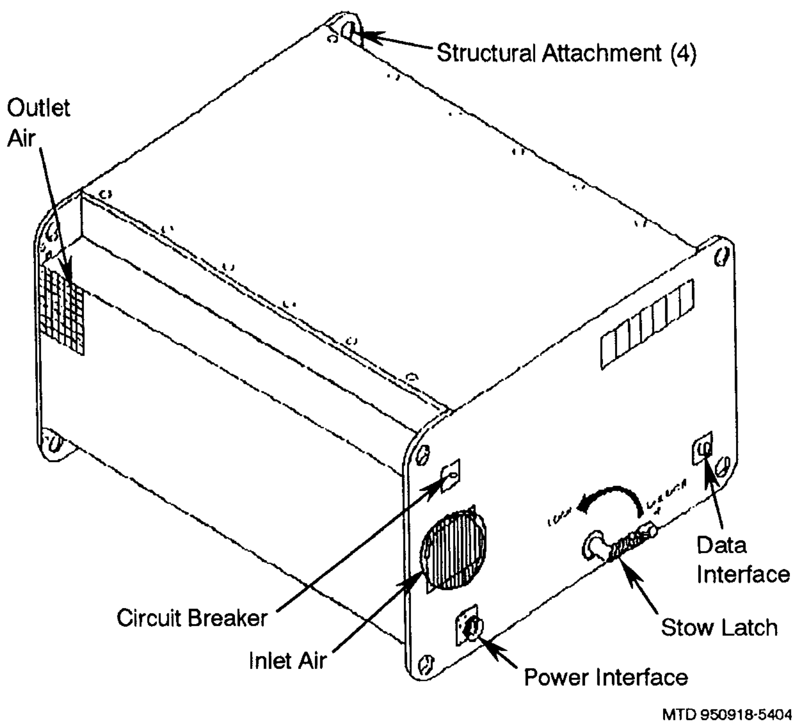


3DMA Flight Hardware

The Consortium for Materials Development in Space, a NASA CCDS based at the University of Alabama in Huntsville, is the sponsor of this payload. Jan Bijvoet of the University of Alabama is the principal investigator.

Suppression of Transient Accelerations by Levitation Evaluation (STABLE). The STABLE experiment will demonstrate the capability to reduce on-orbit accelerations to levels required for microgravity experiments. A fluid experiment integrated on the STABLE isolation platform will demonstrate the science potential.

The STABLE experiment hardware consists of three position sensors, each with a small diode laser mounted on the base. The three position sensors measure the relative motion of the platform with respect to the base. The lasers are mounted so that none of the beams is ever directed toward the front panel. The hardware occu-

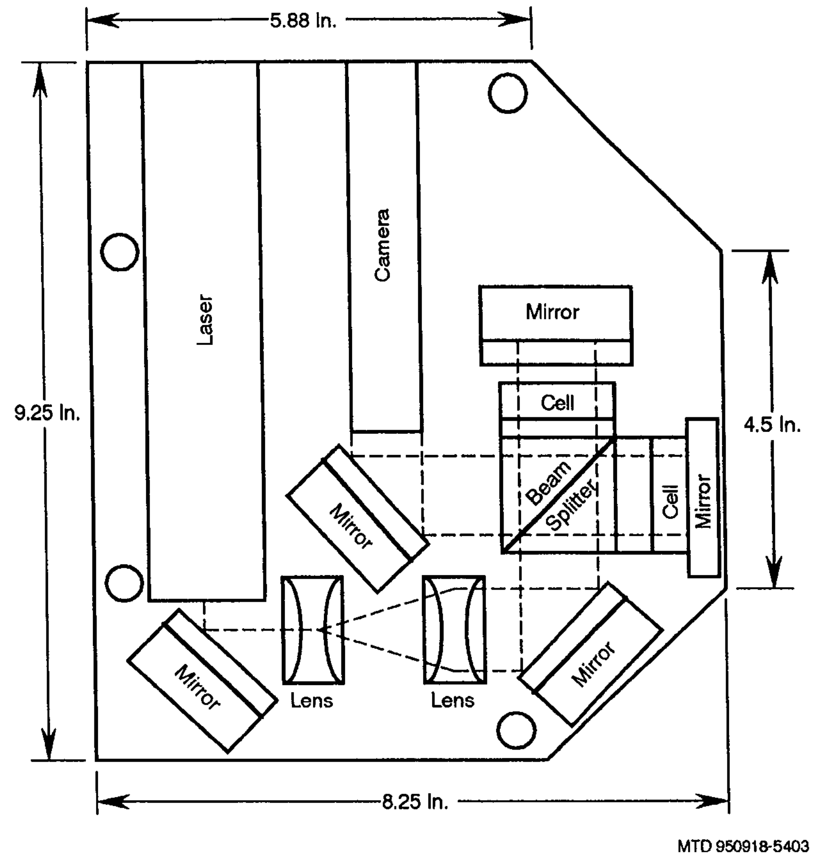


STABLE Assembly

pies a single locker in the SMIDEX rack. The enclosure houses the electronics, isolation platform, actuators, accelerometers, position sensors, and the CHUCK fluid experiment.

The CHUCK experiment is designed to detect and measure the density variations produced by microgravity accelerations. The experiment users a medium-power diode laser to illuminate two separate cells containing halocarbon oil. The images are combined and recorded by a video camera.

STABLE has been designed to require minimal crew involvement during its 72 hours of scheduled operation. Initially, two cables must be connected by a crew member, one for storing data on the



CHUCK Investigation

Spacelab PGSC and the other for sending video to the Spacelab videotape recorder for the CHUCK experiment.

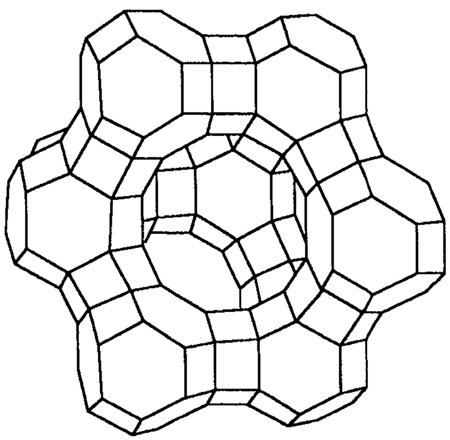
Zeolite Crystal Growth

Zeolite is used in chemical processes as a catalyst and filter because of its three-dimensional crystal structure. If investigators can grow crystals in space that are 500 to 1,000 times larger than those grown on Earth, they can learn much more about the zeolite crystalline structure and the chemical process industry can reap the benefits of a nearly perfect separation membrane.

Zeolites are complex arrangements of silica and alumina whose three-dimensional crystalline structure can be used to absorb elements or compounds selectively. This quality makes them ideal catalysts, molecular sieves, absorbents, and ion exchange materials. If superior space-grown crystals can be produced in mass quantities, they could drastically reduce the time required for dialysis, remove impurities from blood supplies, increase gasoline yield from crude oil processing, and make industrial processes more efficient.

The Zeolite Crystal Growth Furnace flew on USML-1 and in SPACEHAB-1. Companion experiments in the Glovebox maximized the science return and led to new strategies and methodologies for improving the growing of zeolite crystals in orbit.

After USML-1, researchers found that in most of the samples where nucleation was controlled, crystal growth was enhanced and the crystals reached a degree of perfection as high or higher than that of any crystal produced on Earth. Several crystals of zeolite A



MTD 920610-3601

Drawing of a Typical Zeolite Crystal

appeared to be approaching the theoretically perfect silicon/aluminum ratio—the first time this had been achieved. Increases of 96% in the crystals' area and 175% in their volume beyond the Earth-grown control samples were observed in zeolite A. The area and volume of crystals of zeolite X increased 50% and 83%, respectively, compared to the best laboratory samples produced by the principal investigator.

Before the shuttle is launched, 38 separate cylindrical autoclaves will be loaded with solution. During the mission, a crew member will mix the two elements of the solution by turning a nut on the autoclaves back and forth and then place them in a furnace assembly that takes up two middeck lockers. When all the autoclaves have been activated and installed, the furnace will automatically process the samples in three independently controlled temperature zones.

A crew member will check the furnace very two hours to make sure the experiment is operating properly. When the time is up, the autoclaves will be removed and stored for postmission analysis.

The principal investigator is scientist-astronaut Dr. Albert Sacco, Jr., of Worcester Polytechnic Institute.

Advanced Protein Crystallization Facility

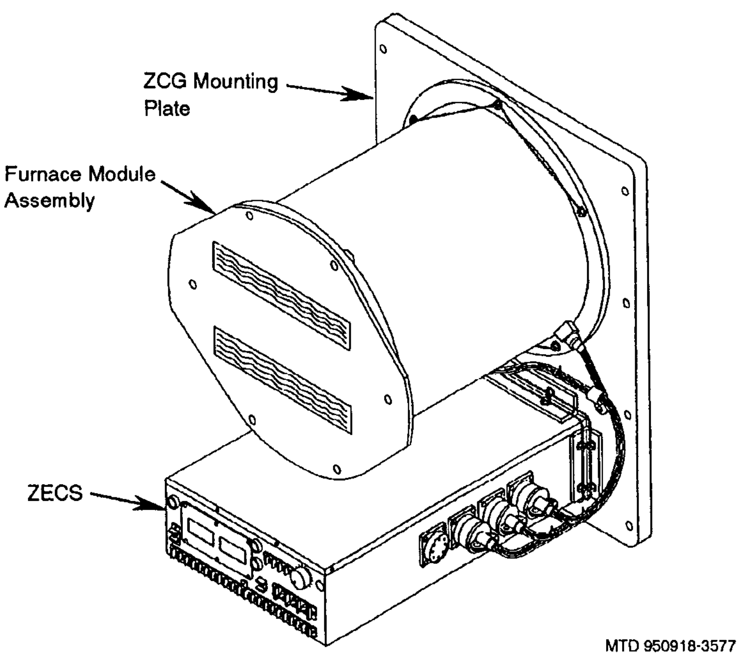
The purpose of research conducted with the Advanced Protein Crystallization Facility is to produce biologically important protein crystals that are difficult to grow and to figure out the mechanisms of their growth.

Scientists are trying to discover the structure and function of proteins in order to increase their understanding of living systems and to help them develop new drugs. Protein crystals grown in space are larger and of better quality than Earth-grown crystals and yield better information about their structure.

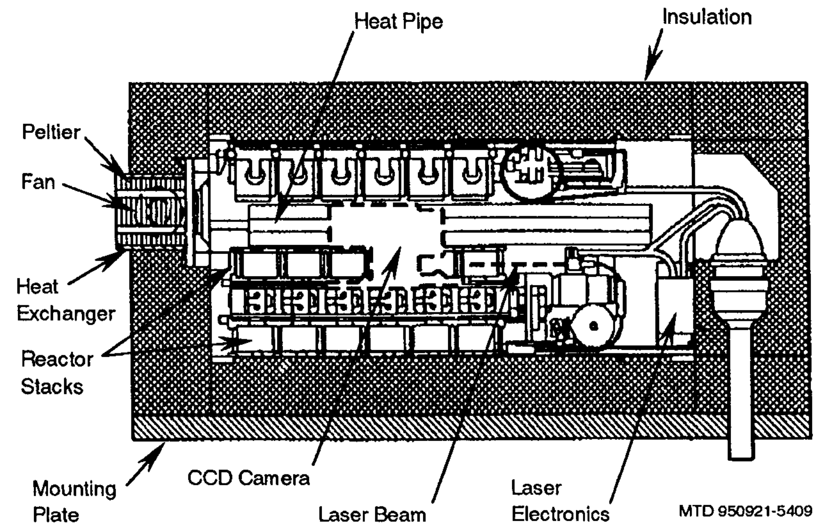
The APCF consists of one unit mounted in a locker in Columbia's middeck area. The unit has 24 growth chambers, or reactors, and 12 of the chambers can be monitored by a movable video camera. A microprocessor controls the temperature and video and tape recording, activates and deactivates the growth chambers, and monitors basic housekeeping parameters.

Three techniques will be used to grow crystals: vapor diffusion, liquid-liquid diffusion, and dialysis.

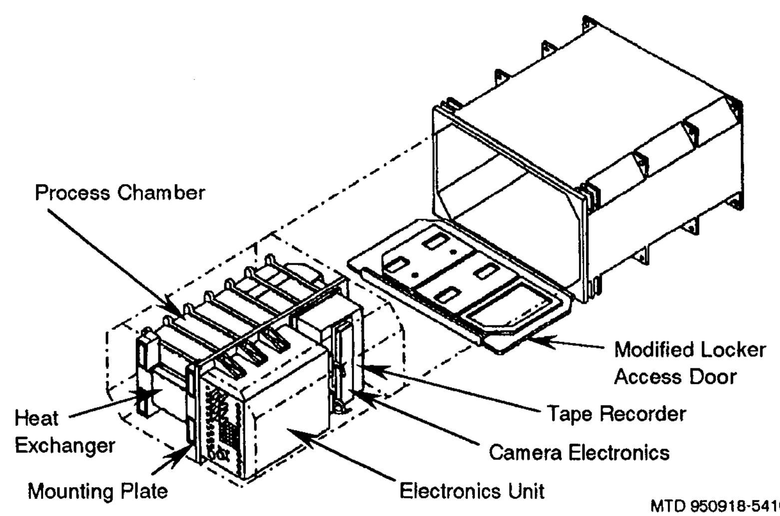
The liquid-liquid diffusion reactor is a quartz glass housing with three chambers: one for a buffer solution, one for a protein solution, and one for a salt solution. The solutions are separated by a plug that is rotated automatically when the experiment is activated in orbit.



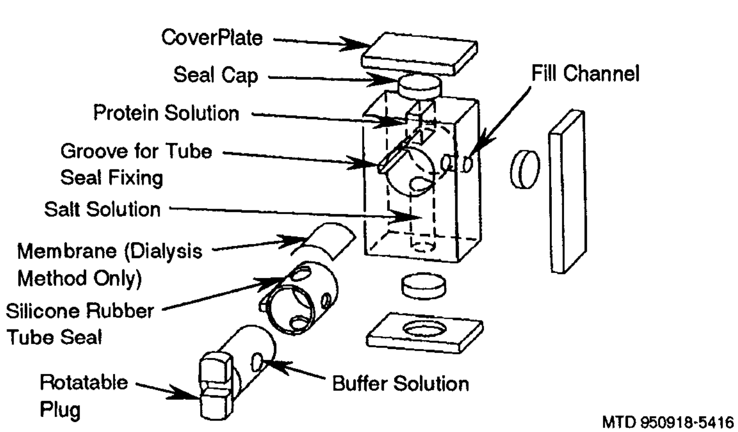
ZCG Flight Configuration



Top View of APCF Process Compartment



APCF Locker Equipment



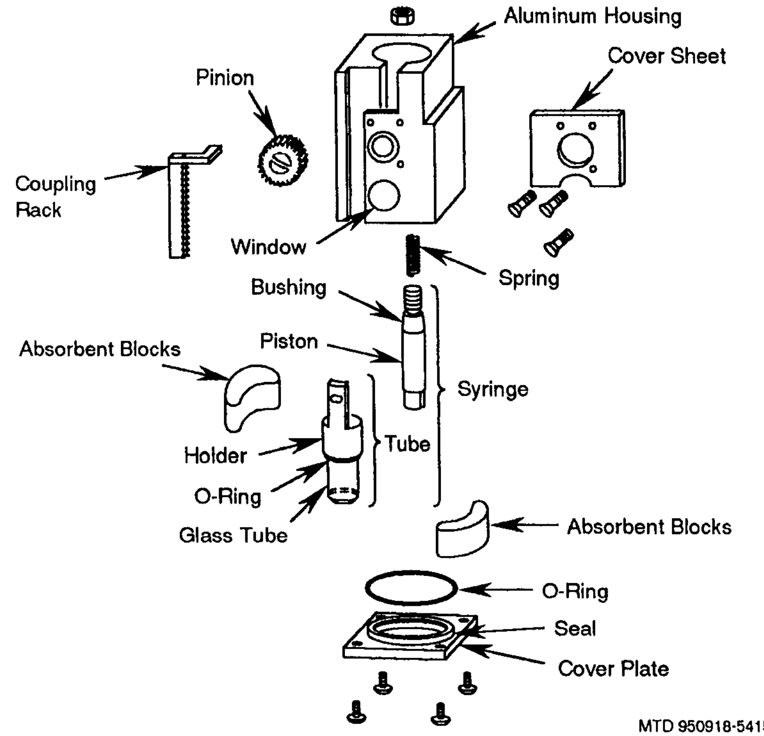
APCF Quartz Glass Experiment Reactors

The dialysis reactor is similar to the liquid-liquid diffusion reactor except that the protein and salt solutions are separated by a membrane.

The hanging drop reactor is a sealed aluminum housing with a glass syringe and a leak-tight piston. Small glass windows on two sides allow video monitoring of the hanging drop. To activate the process, the syringe is raised by a rotating pinion until the piston pushes the liquid out, forming a suspended drop.

After the mission researchers will use the video images of the crystals forming to study the history of crystal development in microgravity. They are particularly interested in learning how and why crystals nucleate to begin the formation process.

Scientists will also subject the crystals grown in space to analysis by X-ray beams, sophisticated detectors, and data processing equipment to determine the internal arrangement of their molecules. A better understanding of molecular biological processes may lead to applications in agriculture and medicine.



Hanging Drop Reactor

Fifteen experiments are planned for this mission. They are described in the table on the following pages.

The European Space Agency developed the APCF. It was previously flown on STS-57 in 1993 and as part of the second International Microgravity Laboratory on STS-65 in July 1994.

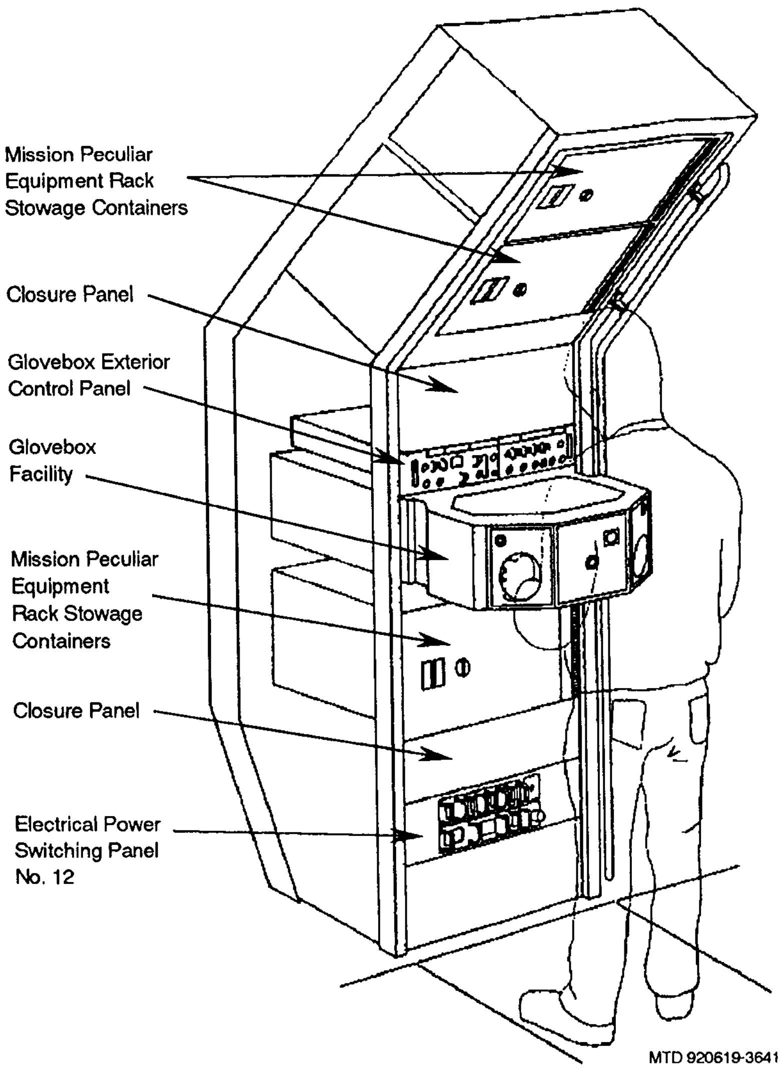
Glovebox Experiments

The Spacelab Glovebox, provided by the European Space Agency, is a versatile, transparent enclosure where experimenters can test and develop procedures and technologies in microgravity. It enables crew members to handle, transfer, and manipulate materials

Experiment	Principal Investigator	Description
Crystallization of Apocrystacyanin C	Dr. Naomi Chayen Imperial College London, England	Apocrystacyanin C is a member of the lipocalin family of proteins, which bind to certain pigments widely distributed in plants and animals. Knowledge of the structure of lipocalins will help scientists alter these proteins to produce carriers that will bind more strongly to the pigment crocetin, which has anticancer properties.
Crystal Structure Analysis of the Bacteriophage Lamda Lysozyme	Dr. Jean-Paul Declercq Catholic University of Louvain Belgium	Lambda lysozyme, a small protein with 158 amino acids, is involved in the dissolution of the cell walls of bacteria. Investigators would like to know how this organism destroys cell walls.
Crystallization of RNA Molecules Under Microgravity Conditions	Dr. Volker Erdmann Free University of Berlin Germany	The diverse biological roles of ribonucleic acid (RNA) molecules include carrying genetic information for protein synthesis in living cells. They may also exhibit behavior characteristic of enzymes. RNA is extremely difficult to synthesize on Earth because of the large mass of its molecules.
Crystallization of the Protein Grb2 and Triclinic Lysozyme	Dr. Arnaud Ducruix Centre National de la Recherche Scientifique Université de Paris Sud, France	Grb2 is an adapter protein involved in the transfer of signals between cells. Space-grown crystals should have better resolution than those grown in Earth-based labs. Lysozyme crystals grown in the APCF during the IML-2 mission had a much higher level of perfection than those grown on earlier missions. USML-2 investigators are extending the study to triclinic lysozyme and expect to reach even better resolution values.
Microgravity Crystallization of Thermophilic Aspartyl-tRNA Synthetase and Thaumatin	Dr. Richard Giegé Centre National de la Recherche Scientifique Strasbourg, France	This is an expansion of the IML-2 crystallization studies on thermophilic aspartyl-tRNA synthetase and will also crystallize the plant-sweetening protein thaumatin. Both proteins are biochemically stable and are purified easily, but their significant structural and behavioral differences make them interesting subjects for comparative crystallography studies.
Crystallization in Space of Octarellins, de Novo Designed (alpha/beta)-Barrell Proteins, and of a Mutated Human TIM Forming a Monomeric (alpha/beta)-Barrell Structure	Dr. Joseph Martial University of Liège Belgium	Before investigators can design a three-dimensional "scaffold" on which to build amino-acid bonds, eventually producing therapeutic agents for the treatment or prevention of disease, they need more knowledge about rules governing protein folding and structure stabilization. Resolving the three-dimensional structure of crystals of the synthetic protein octarellin may provide this information.
Crystallization in a Microgravity Environment of CcdB, a Protein Involved in the Control of Cell Death	Dr. Lode Wyns Free University of Brussels Belgium	Clarifying the structure and mode of action of CcdB may lead to the design of new antibiotics and antitumor drugs.
A Multivariate Analysis of X-ray Diffraction Data Obtained from Glutathione S Transferase	Dr. Lennart Sjölin University of Göteborg Sweden	An extensive comparative analysis of X-ray data from space-grown crystals and ground-based controls will be performed to provide a statistical comparison of the two. Scientists will use this statistically significant data to confirm or refute various hypotheses about the value of a convection-free environment for enhancing the quality of crystals.
Protein Crystal Growth: Light-Driven Charge Translocation Through Bacteriorhodopsin	Dr. Gottfried Wagner University of Geissen Germany	This protein converts light energy to voltages in the membrane of photoenergetic micro-organisms. Crystals grown in the APCF during IML-2 had a much higher level of perfection and for the first time in microgravity showed a precise tendency to form as cubes. Resolution of the three-dimensional structure of bacteriorhodopsin will help scientists understand the mechanisms used to convert light energy to energy for growth.

APCF Experiments (Cont)

Experiment	Principal Investigator	Description
Crystallization of Ribosomes	Dr. Ada Yonath Max-Planck Laboratory for Ribosomal Structure Hamburg, Germany	Ribosomes, which are responsible for the translation of genetic code to proteins, are the only portion of living cells researchers have been able to crystallize, but most Earth-grown crystals are very thin and crack when handled. The APCF growth chambers are almost tailor-made for growing this type of protein, so this experiment could produce crystals with better internal order, shape, size and mechanical properties.
Crystallization of *Sulfolobus Solfataricus* Alcohol Dehydrogenase	Dr. Adriana Zagari University of Naples Italy	The alcohol dehydrogenase (ADH) enzyme occurs in large amounts in the livers of mammals and plays an important role in several physiological functions, including the breakdown of alcohol. Unlike mammalian ADH, which is unstable at high temperatures or in the presence of organic solvents, ADH from the bacterium *Sulfolobus solfataricus* has greater thermal stability and is hardly affected by organic solvents. These properties make the enzyme a good candidate for industrial applications.
Crystallization of Turnip Yellow Mosaic Virus, Tomato Aspermy Virus, Satellite Panicum Mosaic Virus, Canavalin, Beef Liver Catalase, Concanavalin B	Dr. Alexander McPherson University of California Riverside, Calif.	Researchers are studying canavalin, catalase and concanavalin B to determine the effects of microgravity on protein crystal growth by evaluating their size, habit, quality, defects and diffraction properties. They are using three viruses, which are very large proteins, to verify the theory that the effect of altered transport properties in microgravity should be magnified in proportion to the decreased diffusivity of such large molecules.
Crystallization of the Epidermal Growth Factor (EGF) Receptor	Dr. Wolfgang Weber University of Hamburg Germany	The importance of the receptor for epidermal growth factor as a predictor for a series of human malignancies is increasing. Knowledge of its three-dimensional structure may allow drugs to be tailored to treat numerous types of tumors. So far, researchers have solved the crystal structure of only one hormone receptor (growth hormone).
Structure of the Membrane-Embedded Protein Complex Photosystem I	Dr. Wolfram Sänger Free University of Berlin Germany	This protein complex is one of two responsible for the primary conversion of visible light into chemical energy in water-oxidizing photosynthesis. This experiment will try to identify the complete arrangement of the chlorophyll molecules that perform this conversion process in the most efficient way.
Crystallization of Visual Pigment Rhodopsin	Dr. Willem de Grip University of Nijmegen The Netherlands	Rhodopsin and other visual pigments are the primary photoreceptor proteins for vision and other light-regulated processes. Scientists need to study this protein's crystals to unravel the molecular mechanisms responsible for these processes.



Glovebox

in ways that are impractical in the open Spacelab. The facility is also equipped with photographic equipment that keeps a visual record of experiment operations.

The Glovebox cabinet is a clean working space that minimizes contamination risks to both the Spacelab and experiment samples. There are two types of containment for small quantities of materials: physical isolation and enclosure air pressure that is lower than that of the Spacelab module. An air-filtering system also protects the crew from harmful experiment products. When an air-tight seal is required, crew members insert their hands in rugged gloves attached to the cabinet doors. If an experiment requires more sensitive handling, the crew can don surgical gloves and insert their arms through a set of adjustable sleeves.

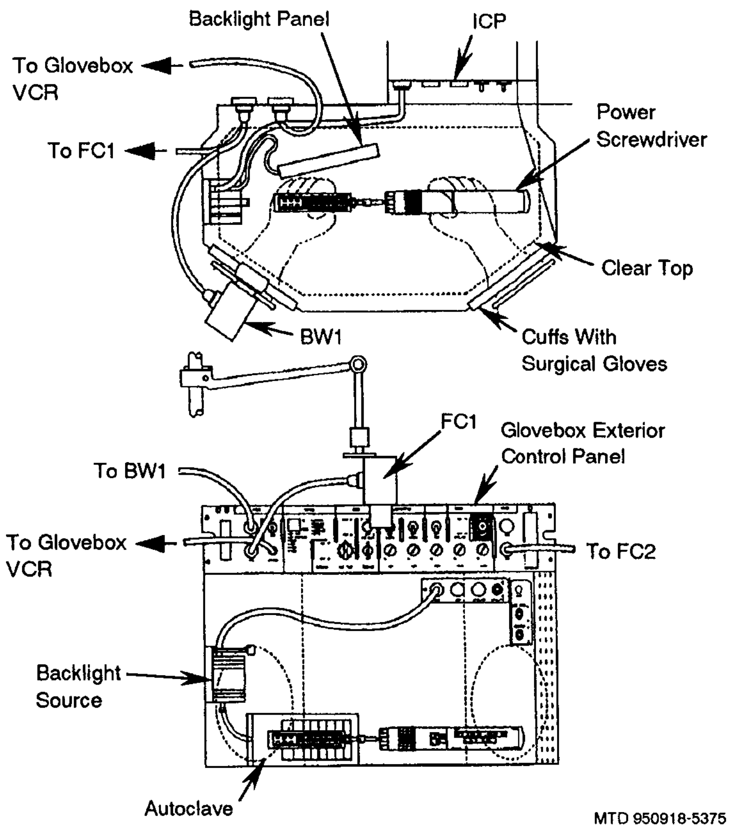
The Glovebox facility first flew on USML-1. Its working area has been increased for this mission, and lighting has been improved. On USML-2, seven investigations will use the facility.

Interface Configuration Experiment. This follow-up to a USML-1 investigation studies the shapes that fluid surfaces in microgravity assume within specific containers. It will observe how colored liquid settles to equilibrium within clear plastic containers of two different shapes. Currently, the microgravity behavior of free-liquid/vapor interfaces, such as the movement of liquid propellant inside spacecraft fuel tanks, cannot be predicted satisfactorily. Since many on-orbit operations involve fluids and depend on their behaviors, it is important to test and refine models to determine how container shape affects the location and shape of fluid surfaces.

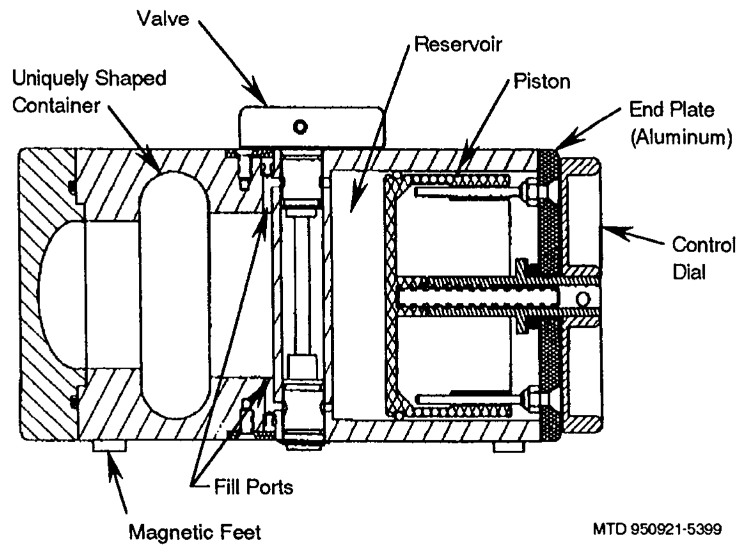
The principal investigator is Dr. Paul Concus of the University of California, Berkeley.

Oscillatory Thermocapillary Flow Experiment. This investigation, also a USML-1 follow-up, complements the Surface-Tension-Driven Convection Experiment. It studies conditions for the onset of oscillations, or periodic variations, in surface-temperature-induced fluid flows. Heat will be applied to silicone oil in four vessels of different volumes and depths to determine how container dimensions affect the onset of oscillations.

On Earth, thermocapillary flows (generated by temperature variations along a free liquid surface) begin to oscillate under certain



Glovebox



Interface Configuration Experiment Container

conditions. Both the flows themselves and the oscillations may reduce the purity and uniformity of crystal growth solutions and molten metals. By studying the conditions under which oscillations begin in microgravity and by comparing them to onset conditions on Earth, scientists should be able to determine the cause of the oscillations.

The principal investigator is Dr. Yasuhiro Kamotani of Case Western Reserve University, Cleveland, Ohio.

Fiber-Supported Droplet Combustion. This new Glovebox investigation tests a technique for studying combustion in microgravity. Droplets of different types of fuel will be suspended on a thin fiber and then ignited. Team members will observe the shape of the flame, how the flame grows, and how fast it shrinks as it consumes the fuel.

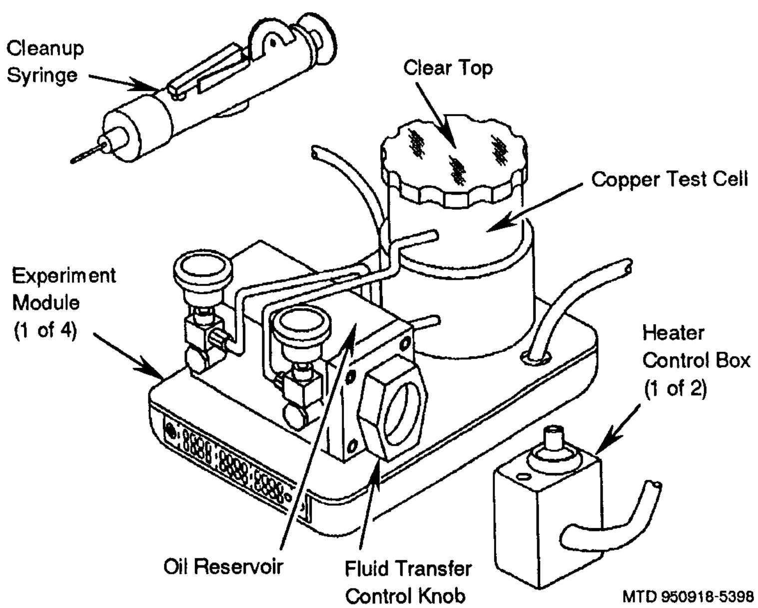
Droplet combustion studies are very difficult to perform on Earth. Drops burn unevenly because gravity causes high-density drops to sink and buoyancy-induced acceleration forces combustion products to rise. In space, the drop is expected to assume a symmetrical sphere shape and thus burn more evenly, making it easier to validate combustion theories. If successful, this new technique for studying droplet combustion could provide insight into fundamental combustion processes, such as how pollutants are formed.

The principal investigator is Dr. Forman A. Williams of the University of California, San Diego.

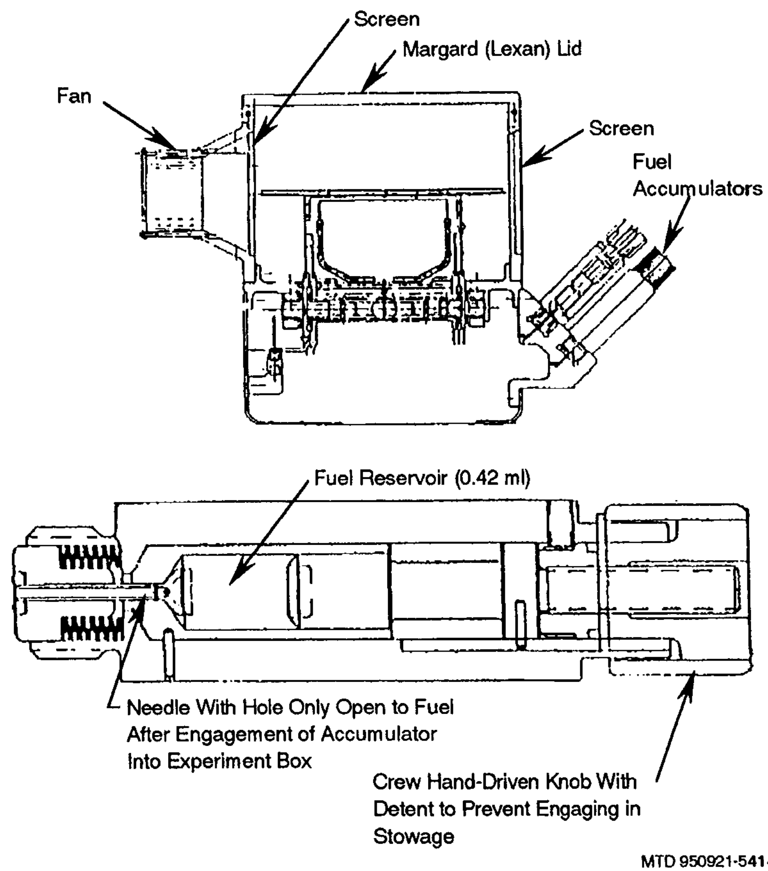
Protein Crystal Growth—Glovebox. This repeat of the highly successful USML-1 protein crystal growth Glovebox experiments will help confirm the advantages of crew interaction in the process of growing protein crystals in microgravity.

Protein crystals, important for analyzing the molecular structure of these "building blocks of life," are very difficult to produce. This experiment allows a crew member to modify protein crystal growth conditions (such as mixing procedures, crystal seeding, crystal mounting, and crystal preservation) based on observations of previous sets of investigations.

On USML-1, these modifications produced several crystals of much higher quality than had ever been grown before. In addition to improving the quality of crystals grown on this mission, USML-2 Glovebox PCG research will be used to improve protein crystal



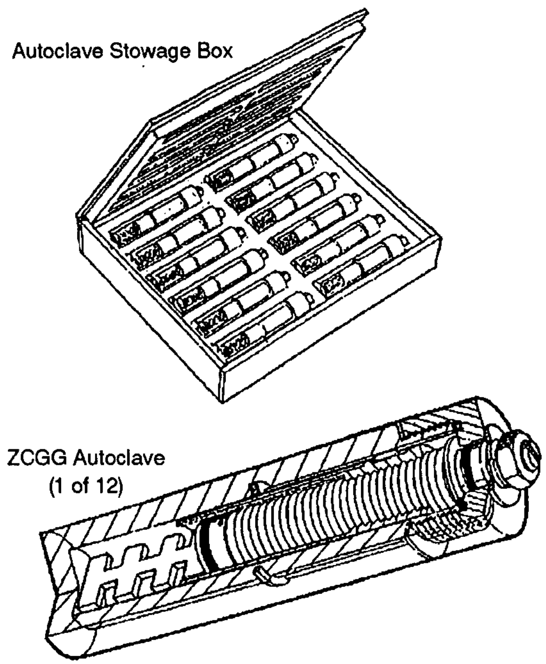
Oscillatory Thermocapillary Flow Experiment



Fiber-Supported Droplet Combustion Box Fuel Accumulator growth procedures on future shuttle missions and on the space station.

The principal investigator is Dr. Larry DeLucas of the Center for Macromolecular Crystallography in Birmingham, Ala.

Zerolite Crystal Growth—Glovebox. This Glovebox investigation extends the USML-1 evaluation of on-orbit mixing procedures for zerolite crystal growth experiments.



Each autoclave is wrapped in a tissue in an individual, sealed Ziplock bag (not shown) during stowage in the box.

MTD 950918-5377

ZCGG Autoclave and Stowage Box

Zerolite crystals are used as catalysts and filters in the chemical processing industry. To produce usable crystals, the growth solutions must be precisely mixed. During USML-1, crew member involvement resulted in more uniform mixing and helped minimize bubble formation. The USML-2 experiment will give additional mixing information to researchers using the Zeolite Crystal Growth Furnace.

The principal investigator is Dr. Albert Sacco, Jr. of Worcester Polytechnic Institute, Mass.

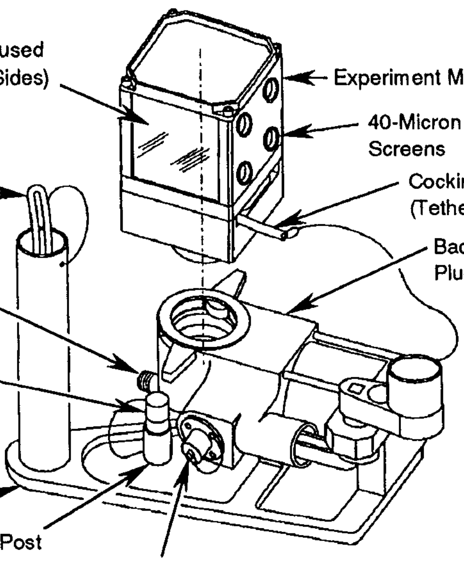
Colloidal Disorder-Order Transitions. This new Glovebox investigation looks at a fundamental question in condensed-matter physics: how the density of a substance finely and uniformly dispersed within another substance of a different phase (a mixture called a colloid) affects its transition from a liquid to an ordered solid phase.

Several containers will hold different concentrations of fine solid spheres suspended in a liquid. The principal investigator will observe which concentration is dense enough that the spheres arrange themselves in an ordered state, rather than remaining randomly distributed within the liquid.

A better understanding of what happens at the boundary between solid and liquid states of a colloid should help researchers improve material processing methods on Earth as well as in microgravity.

The principal investigator is Dr. Paul Chaikin of Princeton University, N.J.

Particle Dispersion Experiment. This follow-up investigation from USML-1 uses the microgravity environment to study how fine natural particles, such as dust, disperse within an atmosphere and then reassemble (or reaggregate) in larger clusters. A short puff of air will disperse sand particles within a small, transparent container,



Particle Dispersion Experiment

and the principal investigator will observe how they cluster in an environment free from the interference of gravity.

The principal investigator is Dr. John Marshall of the NASA Ames Research Center, Moffett Field, Calif.

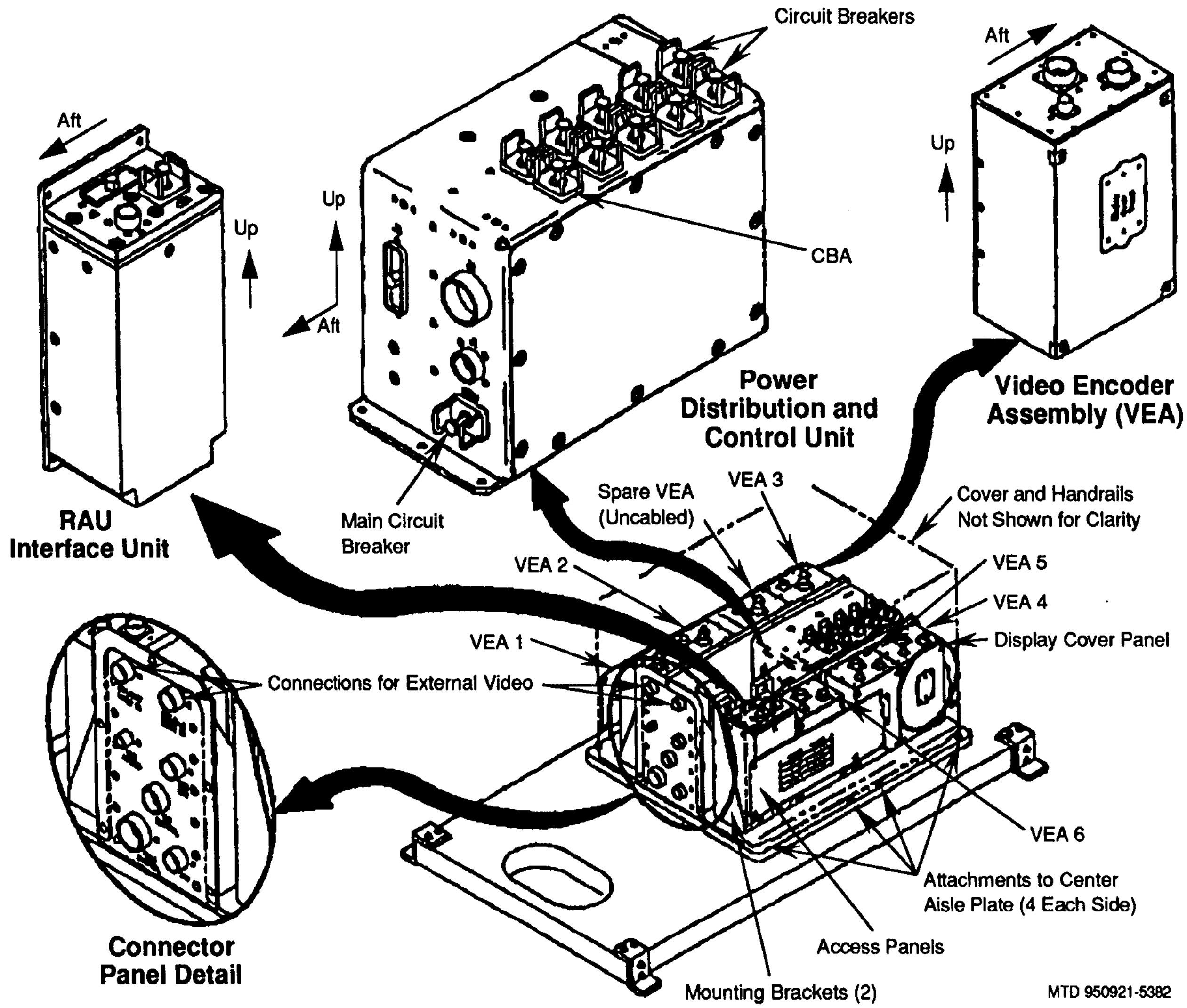
High-Packed Digital Television Demonstration

The purpose of HI-PAC is to digitize up to six video input signals from experiments and Spacelab cameras aboard USML-2 and demonstrate future real-time video downlinking options from space. With this technical demonstration, NASA will extend the "information superhighway" into space, allowing scientists on Earth to view multiple channels of real-time video from the Spacelab module.

Normally, only one video channel can be sent down (downlinked) from the Spacelab, which limits the transmission of video data from experiments and other sources. Designated to operate from the Spacelab, high-packed digital television will provide researchers on the ground with up to six channels of video. The potential benefits include increased science return, ability of scientists to monitor and change experiment parameters, improved the quality and quantity of downlinked data, and simultaneous video downlink from multiple sources. This technology, which will support the remaining Spacelab missions, will extend well into the space station era.

Using Spacelab's high-rate data system, HI-PAC converts standard analog video signals into digital signals, compressing the signal in the process, and downlinks it by the same method used for other digital data. When the Spacelab Mission Operations Control Center at the Marshall Space Flight Center receives the signal, the digital data is converted back into an analog signal and distributed to scientists for viewing on monitors in the Science Operations area.

Once the shuttle reaches orbit, a crew member will switch the closed-circuit television system from the standard analog video to the HI-PAC system. After the system has been checked out, the equipment will operate in the HI-PAC mode unless analog mode is required. The system can be switched easily from one mode to the other when necessary.



HIPAC DTV Flight Hardware Components and Details for USML-2

SPACELAB

Spacelab is a unique laboratory facility carried in the cargo bay of the space shuttle orbiter that converts the shuttle into a versatile on-orbit research center. The reusable laboratory can be used to conduct a wide variety of experiments in such fields as life sciences, plasma physics, astronomy, high-energy astrophysics, solar physics, atmospheric physics, materials sciences, and Earth observations.

Spacelab is developed on a modular basis and can be varied to meet specific mission requirements. Its four principal components are the pressurized module, which contains a laboratory with a shirt-sleeve working environment; one or more open pallets that expose materials and equipment to space; a tunnel to gain access to the module; and an instrument pointing subsystem. Spacelab is not deployed free of the orbiter. The pressurized module will be flown on the STS-73 mission.

The European Space Agency developed Spacelab as an essential part of the United States' Space Transportation System. Eleven European nations are involved: Germany, Belgium, Denmark, Spain, France, United Kingdom, Ireland, Italy, the Netherlands, Switzerland, and, as an observer state, Austria. On Sept. 24, 1973, ESA and NASA signed a memorandum of understanding to design and develop Spacelab with NASA's George C. Marshall Space Flight Center as lead center for ESA.

An industrial consortium headed by ERNO-VFW Fokker (Zentralgesellschoft VFW-Fokker mbh) was named by ESA in June 1974 to build the pressurized modules. Five 10-foot-long, unpressurized, U-shaped pallet segments were built by the British Aerospace Corporation under contract to ERNO-VFW Fokker. The IPS is built by Dornier.

Spacelab is used by scientists from countries around the world. Its use is open to research institutes, scientific laboratories, industrial companies, government agencies, and individuals. While many missions are government sponsored, Spacelab is also intended to provide services to commercial customers.

Each experiment accepted has a principal investigator assigned as the single point of contact for that particular scientific project. The principal investigators for all experiments on a given mission form what is called the Investigators Working Group. This group coordinates scientific activities before and during the flight.

The investigators prepare the equipment for their experiments in accordance with size, weight, power, and other limitations established for the particular mission.

Responsibility for experiment design, development, operational procedures, and crew training rests with the investigator. Only after it is completed and checked out is the equipment shipped to the Kennedy Space Center for installation on Spacelab.

Each mission has a mission scientist, a NASA scientist who, as chairman of the Investigators Working Group, serves as the interface between the science-technology community and NASA's payload management people. Through the mission scientist, the science-technology needs of the mission and the investigators' goals are injected into the decision-making process.

NASA astronauts called mission specialists, as well as non-career astronauts called payload specialists, fly aboard Spacelab to operate experiments. Payload specialists are nominated by the scientists sponsoring the experiments aboard Spacelab. They are accepted, trained, and certified for flight by NASA. Their training includes familiarization with experiments and payloads as well as information and procedures to fly aboard the space shuttle. From one to four payload specialists can be accommodated for a Spacelab flight. These specialists ride into space and return to Earth in the orbiter crew compartment cabin, but they work with Spacelab on orbit. Because Spacelab missions often operate around the clock, the flight crew is usually divided into two teams. The STS-73 crew will work two 12-hour shifts.

PRESSURIZED MODULE

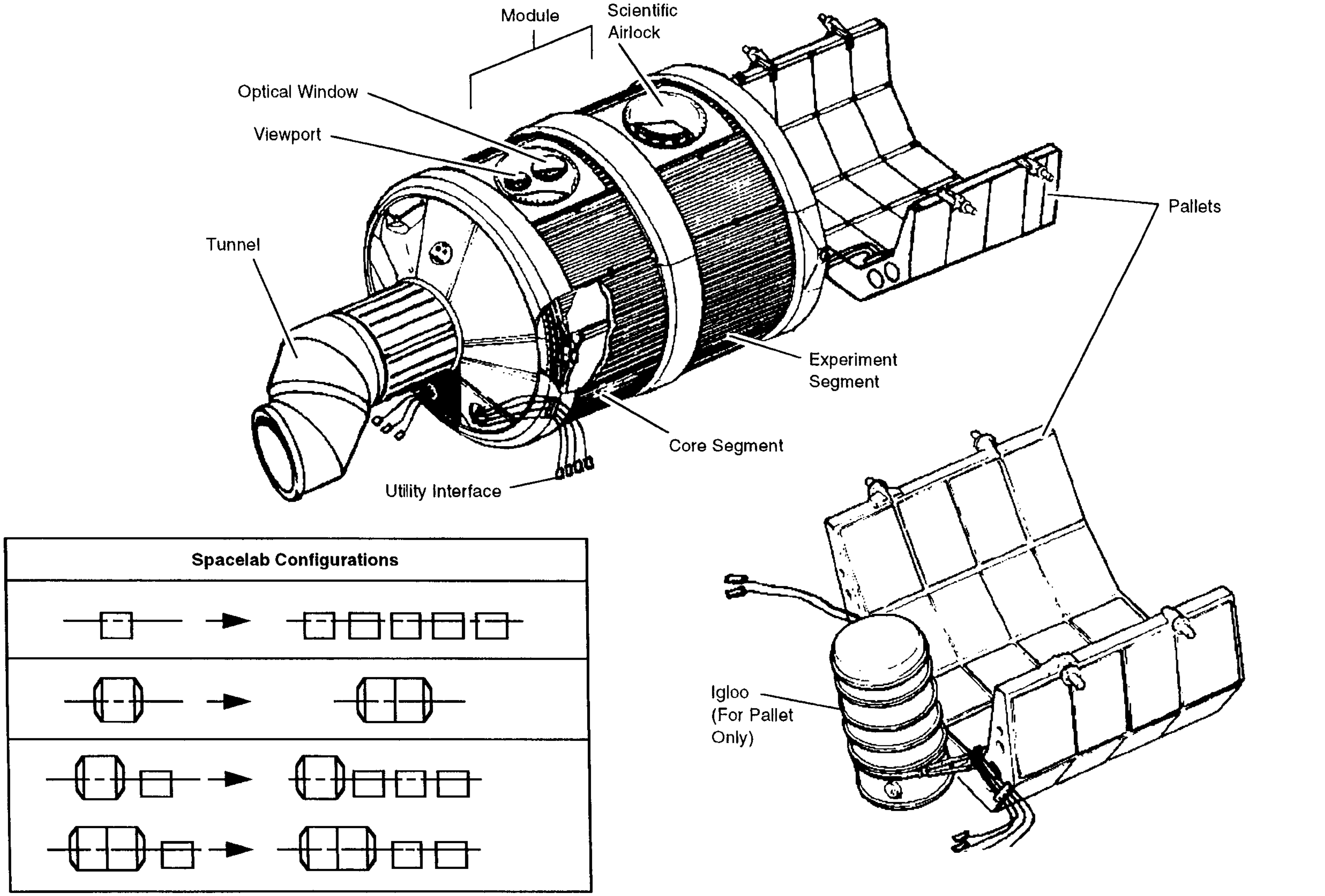
The pressurized module, or laboratory, is available in two segments. One, called the core segment, contains supporting systems, such as data processing equipment and utilities for the pressurized modules and pallets (if pallets are used in conjunction with the pressurized modules). The laboratory has fixtures, such as floor-mounted racks and a workbench. The second, called the experiment segment, provides more working laboratory space and contains only floor-mounted racks. When only one segment is needed, the core segment is used. Each pressurized segment is a cylinder 13.1 feet in outside diameter and 9 feet long. When both segments are assembled with end cones, their maximum outside length is 23 feet.

The pressurized segment or segments are structurally attached to the orbiter payload bay by four attach fittings consisting of three longeron fitting sets (two primary and one stabilizing) and one keel fitting. The segments are covered with passive thermal control insulation.

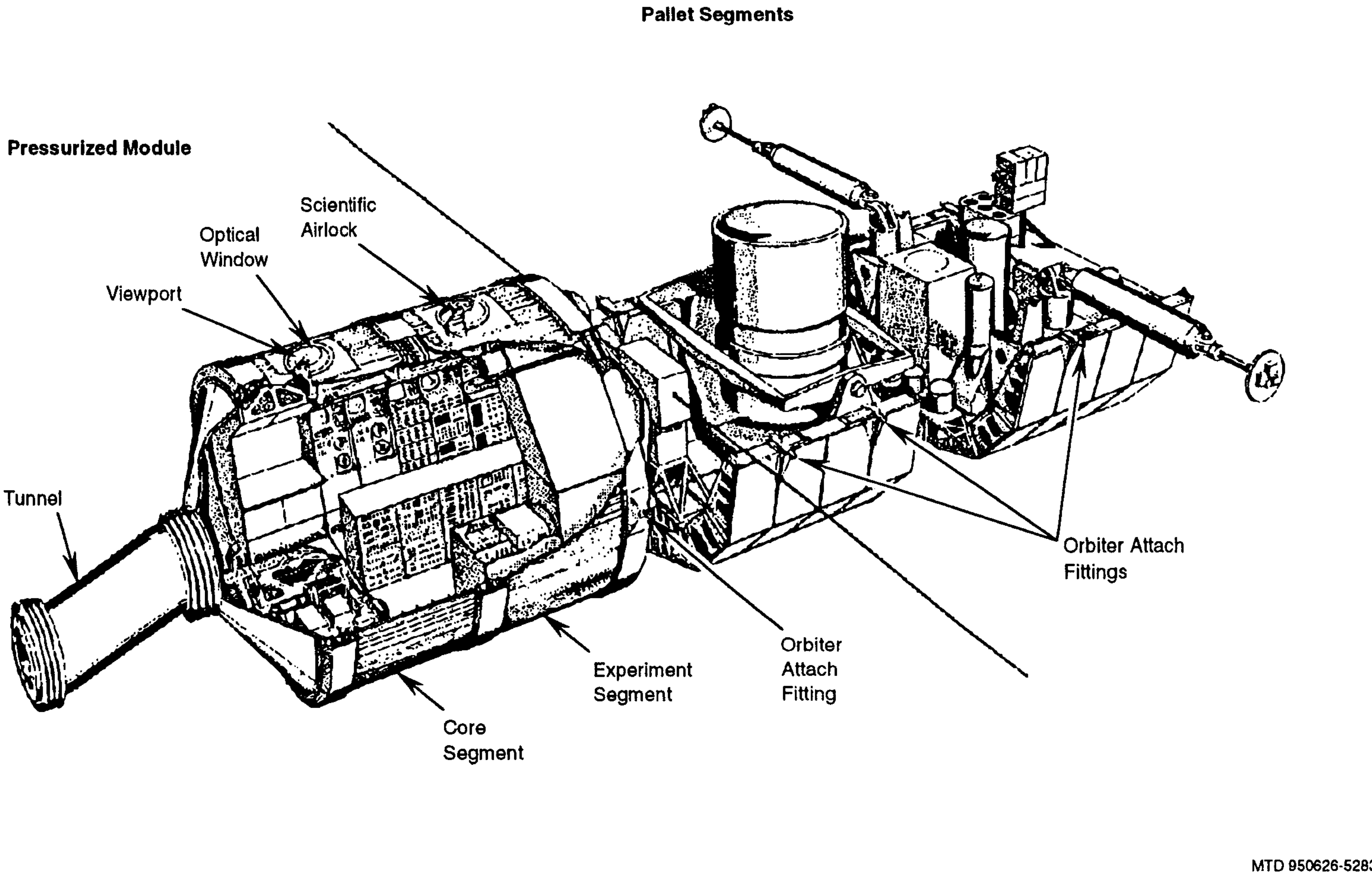
The ceiling skin panel of each segment contains a 51.2-inch-diameter opening for mounting a viewport adapter assembly, a Spacelab window adapter assembly, or scientific airlock; if none of these items are used, the openings are closed with cover plates that are bolted in place. The module shell is made from 2219-T851 aluminum plate panels. Eight rolled integral-machined waffle patterns are butt-welded together to form the shell of each module segment. The shell thickness ranges from 0.6 of an inch to 0.14 of an inch. Rings machined from aluminum-roll ring forgings are butt-welded to the skin panels at the end of each shell. Each ring is 20 inches long and 195.8 inches in diameter at the outer skin line. Forward and aft cones bolted to the cylinder segments consist of six aluminum skin panels machined from 2219-T851 aluminum plate and butt-welded to each other and to the two end rings. The end rings are machined from aluminum-roll ring forgings. The end cones are 30.8-inch-long truncated cones whose large end is 161.9 inches in outside diameter and whose small end is 51.2 inches in outside diameter. Each cone has three 16.4-inch-diameter cutouts: two located at the bottom of the cone and one at the top. Feedthrough plates for routing utility cables and lines can be installed in the lower cutouts of both end cones. The Spacelab viewport assembly can be installed in the upper cutout of the aft end cone, and the upper cutout of the forward end cone is for the pressurized module vent and relief valves. The pressurized modules are designed for a lifetime of 50 missions. Nominal mission duration is seven days.

Racks for experiment equipment that goes into the habitable module are standardized. The 19-inch-wide (48-centimeter) racks are arranged in single and double assemblies. Normally, the racks and floor are put together outside the module, checked out as a unit, and slid into the module where connections are made between the rack-mounted experiment equipment, the subsystems in the core segment, and the primary structure.

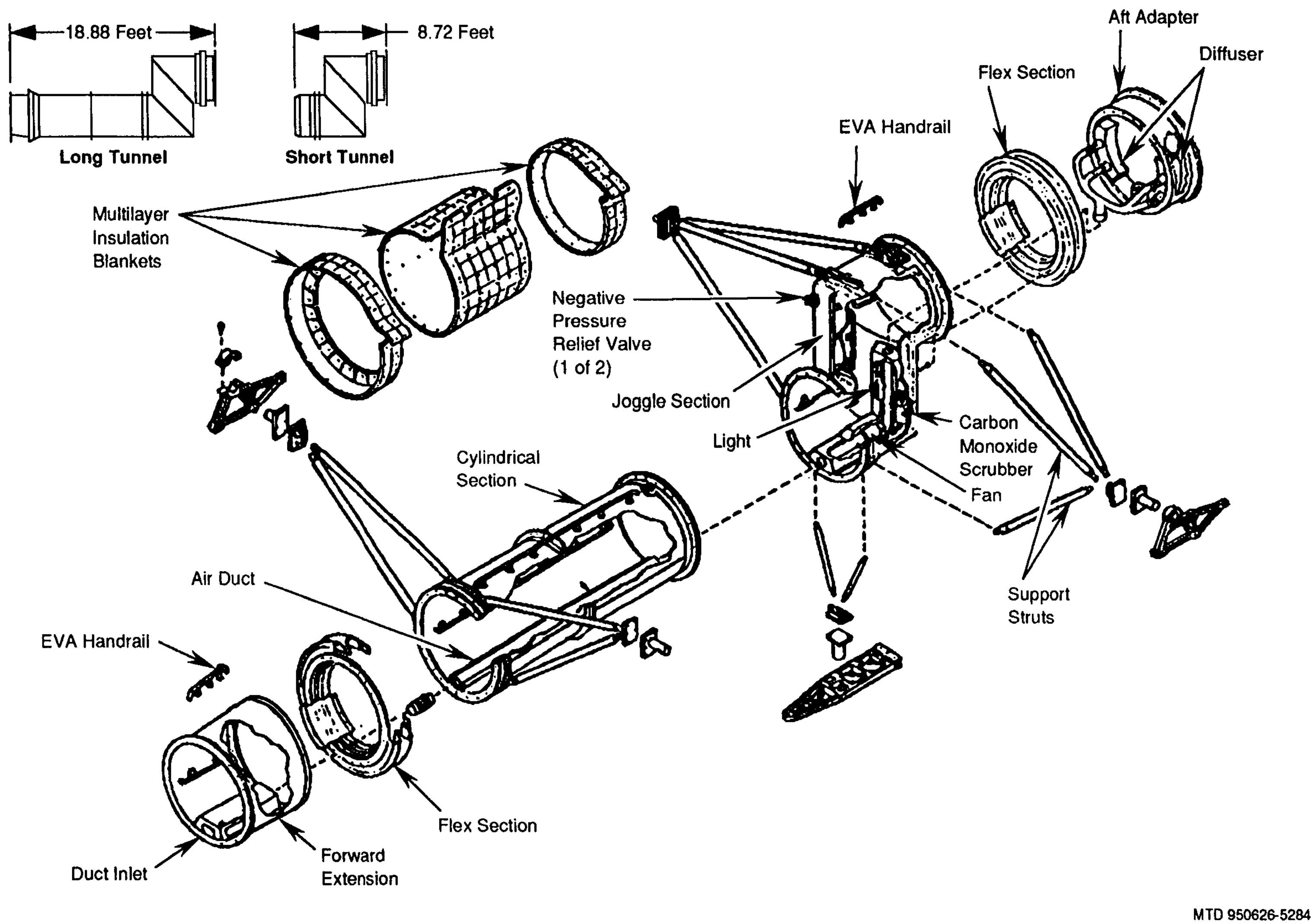
Because of the orbiter's center-of-gravity conditions, the Spacelab pressurized modules cannot be installed at the forward end of the payload bay. Therefore, a pressurized tunnel is provided for equipment and crew transfer between the orbiter's pressurized crew compartment and the Spacelab pressurized modules. The transfer tunnel is a cylindrical structure with an internal unobstructed diameter of 40 inches. The cylinder is assembled in sections to allow length adjustment for different module configurations. Two tunnel lengths can be used—a long tunnel of 18.88 feet and a short tunnel of 8.72 feet. The joggle section of the tunnel compensates for the 42.1-inch vertical offset of the orbiter middeck to the Spacelab pressurized module's centerline. There are flexible sections on each end of the tunnel near the orbiter and Spacelab interfaces. The tunnel is built by McDonnell Douglas Astronautics Company, Huntington Beach, Calif.



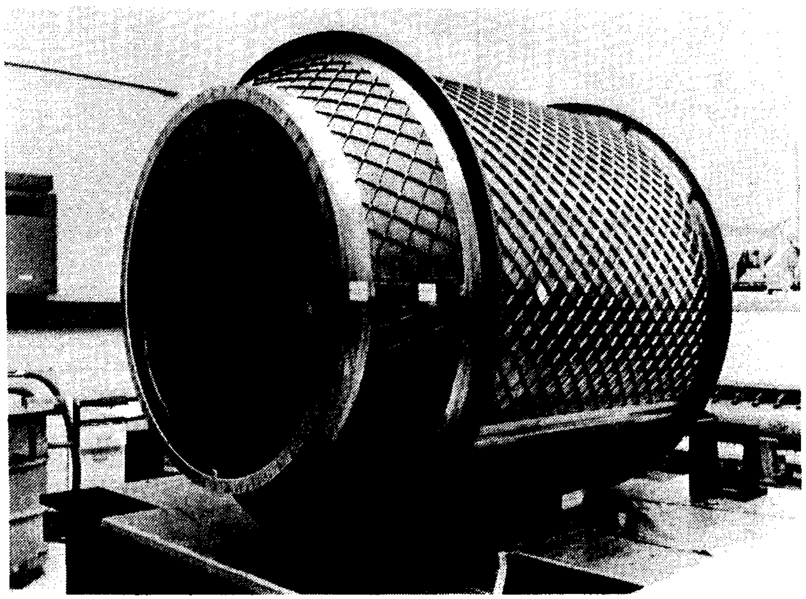
Spacelab External Design Features



European Space Agency's Spacelab



Spacelab Transfer Tunnel



Tunnel Adapter

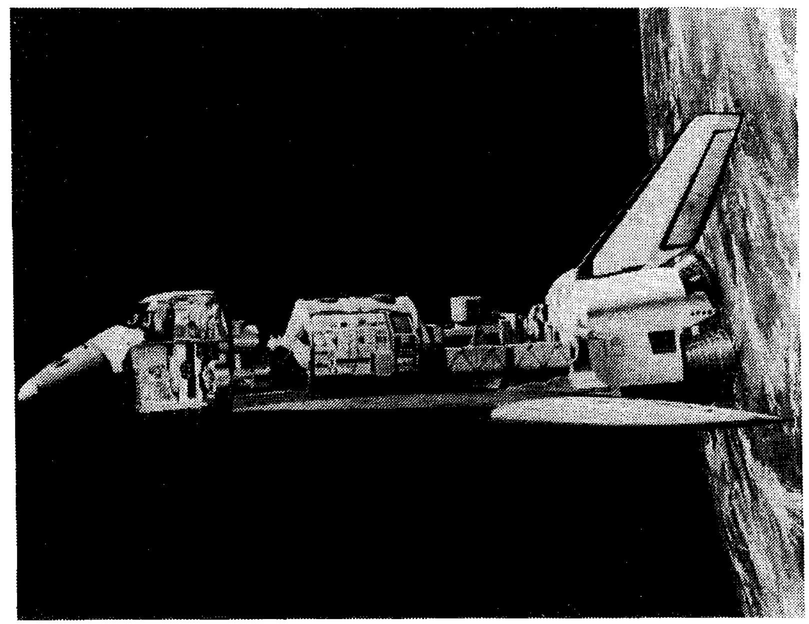
The airlock in the middeck of the orbiter, the tunnel adapter, hatches, the tunnel extension, and the tunnel itself permit the flight crew members to transfer from the orbiter middeck to the Spacelab pressurized module or modules in a pressurized shirt-sleeve environment. The airlock, tunnel adapter, tunnel, and Spacelab pressurized modules are at ambient pressure before launch. In addition, the middeck airlock, tunnel adapter, and hatches permit crew members outfitted for extravehicular activity to transfer from the airlock/tunnel adapter in space suits to the payload bay without depressurizing the orbiter crew compartment and Spacelab modules. If an EVA is required, no flight crew members are permitted in the Spacelab tunnel or module.

INSTRUMENT POINTING SUBSYSTEM

Some research to be accomplished on Spacelab missions requires that instruments be pointed with very high accuracy and stability at stars, the sun, the Earth, or other targets of observation. The IPS provides precision pointing for a wide range of payloads, including large single instruments or a cluster of instruments or a single small-rocket-class instrument. The pointing mechanism can accommodate instruments of diverse sizes and weights (up to 15,432 pounds) and can point them to within 2 arc seconds and hold them on target to within 1.2 arc seconds.

The IPS consists of a three-axis gimbal system mounted on a gimbal support structure connected to the pallet at one end and to the aft end of a payload at the other, a payload clamping system to support the mounted experiment elements during launch and landing, and a control system based on the inertial reference of a three-axis gyro package and operated by a gimbal-mounted minicomputer.

The basic structural hardware is the gimbal system, which includes three bearing/drive units, a payload/gimbal separation mechanism, a replaceable extension column, an emergency jettison-

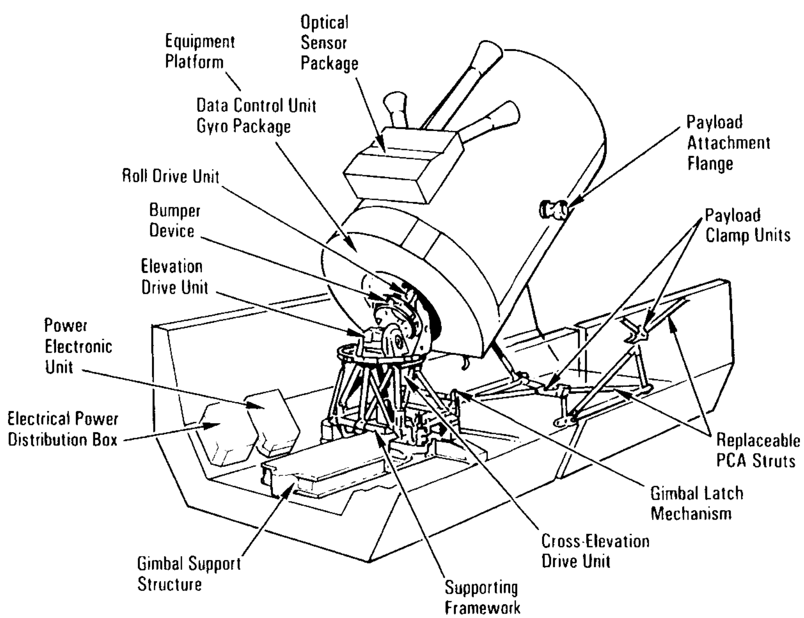


Spacelab

ing device, a support structure and rails, and a thermal control system. The gimbal structure itself is minimal, consisting only of a yoke, an inner gimbal, and an outer gimbal to which the payload is attached by the payload-mounted integration ring.

The three identical drive units are so arranged that their axes intersect at one point. From pallet to payload, the order of the axes is elevation, cross-elevation, and azimuth. Each drive assembly includes three wet-lubricated ball bearings, two brushless dc-torquers, and two single-speed/multispeed resolvers.

The gimbal/payload separation mechanism is located between the outer gimbal and the payload integration ring. This device prevents the payload and the pointing mechanism from exerting excessive loads on each other during launch and landing. For orbital operations, the outer gimbal and integration ring are pulled together and locked.



Instrument Pointing Subsystem

The operating modes of the different scientific investigations vary considerably. Some require manual control capability; others require long periods of pointing at a single object, slow scan mapping, or high angular rates and accelerations. Performance in all these modes requires flexibility, which is achieved by computer software. The IPS is controlled through the Spacelab subsystem computer and a data display unit and keyboard. It can be operated either automatically or by the Spacelab crew from the pressurized module and also from the payload station on the orbiter aft flight deck.

The IPS has two operating modes, which depend on whether the gimbal resolver or gyro is used for feedback control of attitude. An optical sensor package consisting of one boresighted fixed-head star tracker and two skewed fixed-head star trackers is used for attitude correction and also for configuring the IPS for solar, stellar, or Earth viewing.

PALLET ONLY

Each pallet is more than a platform for mounting instrumentation; with an igloo attached, it can also cool equipment, provide electrical power, and furnish connections for commanding and acquiring data from experiments. When only pallets are used, the Spacelab pallet portions of essential systems required for supporting experiments (power, experiment control, data handling, communications, etc.) are protected in a pressurized, temperature-controlled igloo housing.

The pallets are designed for large instruments, experiments requiring direct exposure to space, or systems needing unobstructed or broad fields of view, such as telescopes, antennas, and sensors (e.g., radiometers and radars). The U-shaped pallets are covered with aluminum honeycomb panels. A series of hard points attached to the main pallet structure is provided for mounting heavy payload equipment. Up to five segments can be flown on a single mission.

Each pallet train is held in place in the payload bay by a set of five attach fittings: four longeron sill fittings and one keel fitting. Pallet-to-pallet joints are used to connect the pallets to form a single rigid structure called a pallet train. Twelve joints are used to connect two pallets.

The pallets are uniform. Each is a U-shaped aluminum frame and panel platform 13.1 feet wide and 10 feet long.

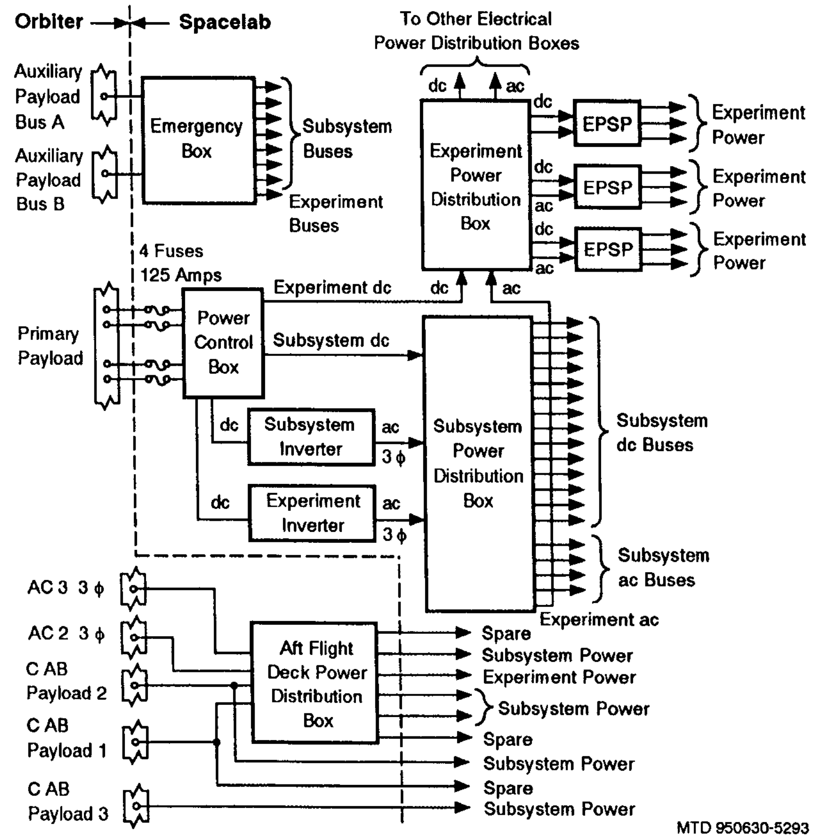
Cable ducts and cable support trays can be bolted to the forward and aft frame of each pallet to support and route electrical cables to and from the experiments and subsystem equipment mounted on the pallet. All ducts mounted on the right side of the pallet are used to route subsystem cables, and all ducts on the left side carry experiment utility cables. The ducts and cable trays are made of aluminum alloy sheet metal. In addition to basic utilities, some special accommodations are available for pallet-mounted experiments.

The igloo is attached vertically to the forward end frame of the first pallet. Its outer dimensions are approximately 7.9 feet in height and 3.6 feet in diameter. The igloo is a closed cylindrical shell made of aluminum alloy. A removable cover allows full access to the interior. The igloo houses subsystems and equipment in a pressurized, dry-air environment at sea-level atmospheric pressure (14.7 psia). Two feedthrough plates accommodate utility lines and a pressure relief valve. The igloo is covered with multilayer insulation.

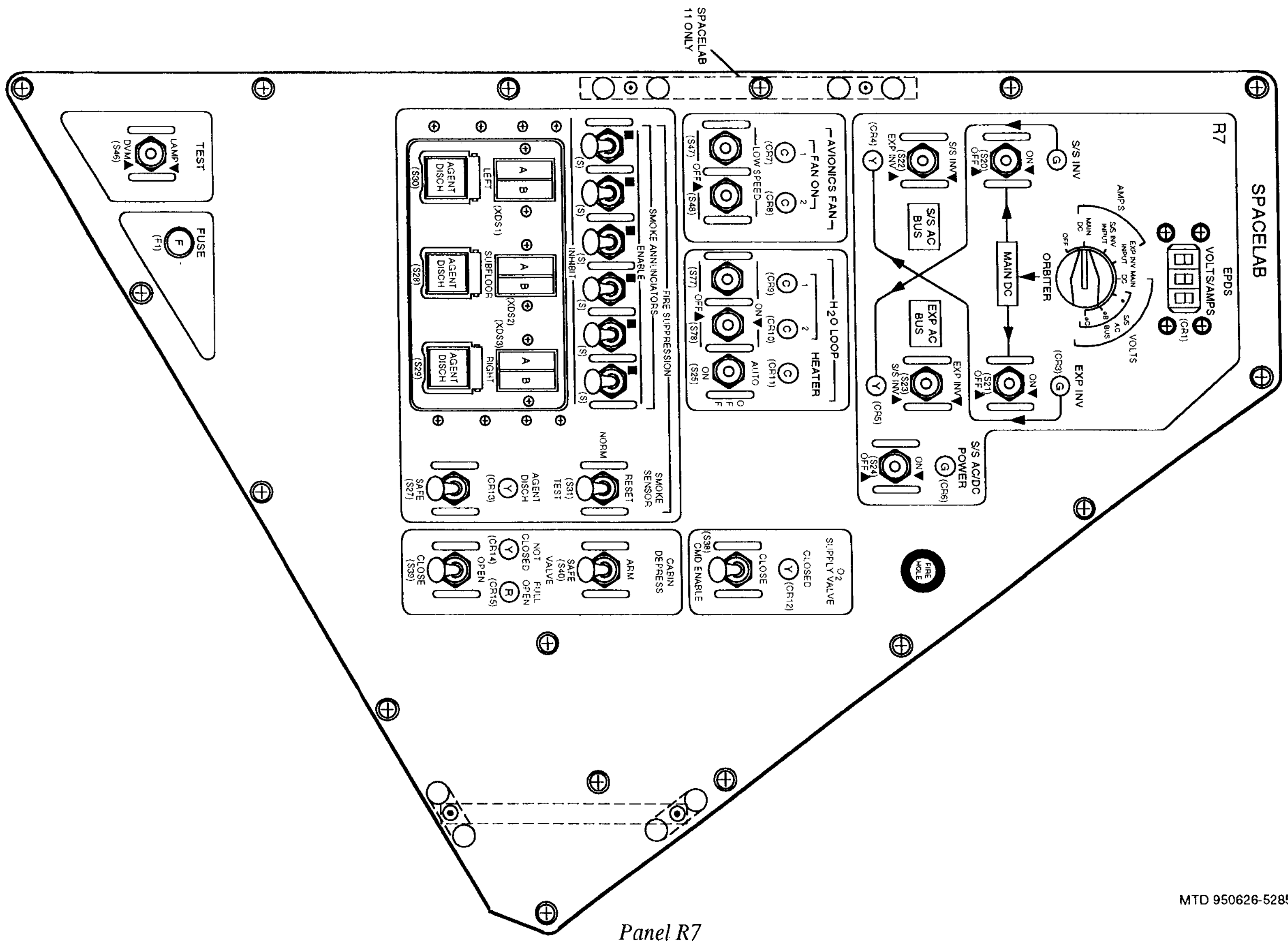
ELECTRICAL POWER

The Spacelab electrical power distribution subsystem controls and distributes main, essential, and emergency dc and ac power to Spacelab subsystems and experiment equipment. Orbiter fuel cell power plants 2 and 3 provide dc power to orbiter main buses B and C, respectively. In addition, through the orbiter main bus tie system (managed and controlled from orbiter display and control panels R1 and F9), dc power is distributed from orbiter main bus C to the orbiter primary payload 1 bus and the Spacelab power control box through four (redundant) main dc power feeders. The orbiter electrical power distribution system is capable of distributing 7 kilowatts maximum continuous (12 kilowatts peak) power to Spacelab subsystems and experiments during on-orbit phases. This is equivalent to supplying 14 average homes with electrical power. If a single fuel cell fails on orbit, the system remains operational with a maximum power level of 5 kilowatts continuous and 8 kilowatts peak.

The primary dc power received in the Spacelab from the orbiter primary payload bus is nominally 28 volts, a maximum of 32 volts, and a worst-case minimum of 23 volts. The four redundant power feeders from the orbiter supply the Spacelab power control box with power through 125-amp fuses. Spacelab main bus voltage and current readings are available on orbiter CRT Spacelab displays. For the



Orbiter Spacelab Electrical Power Distribution



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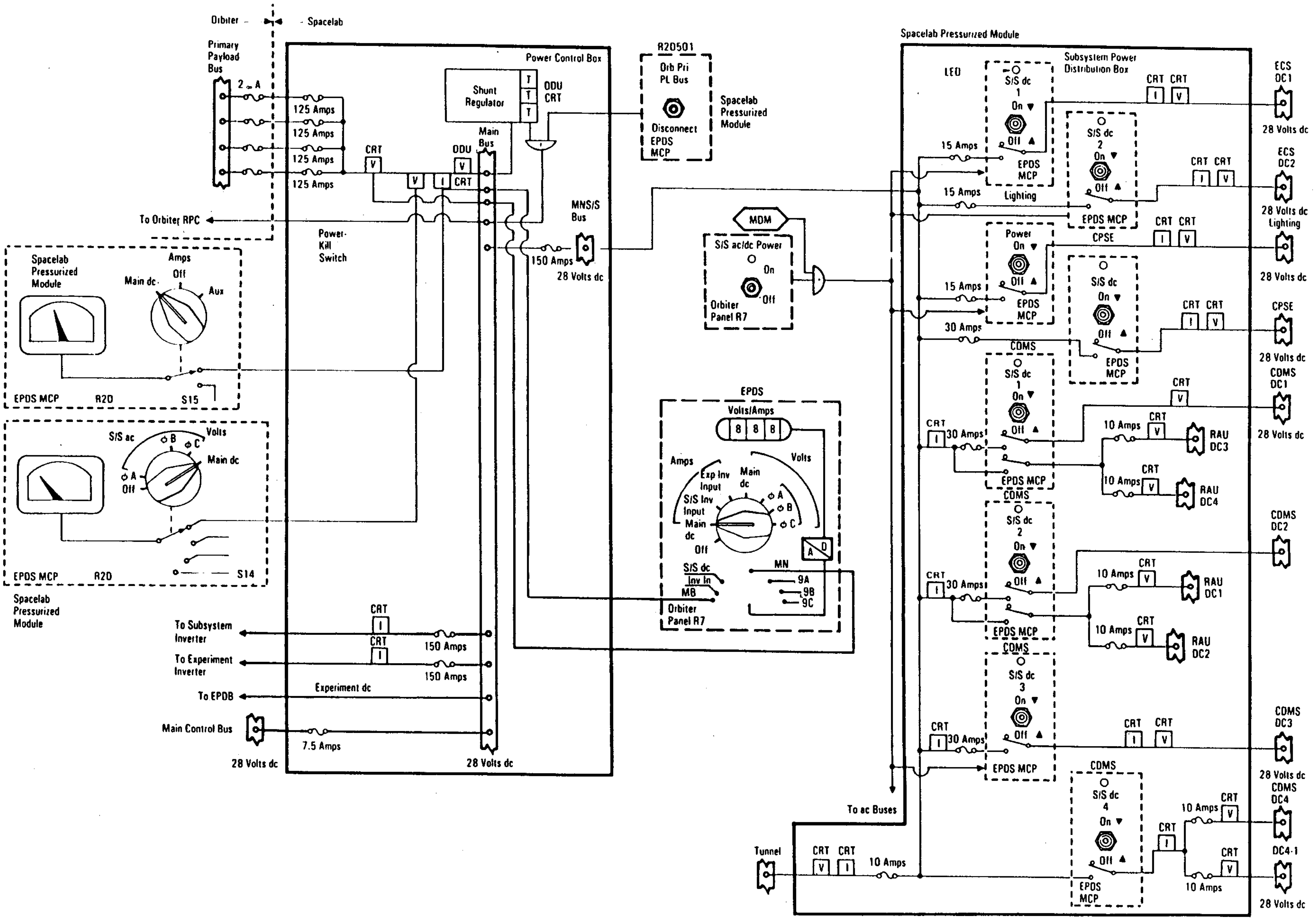
Panel R7



Orbiter-to-Spacelab Electrical Power Distribution—Subsystem dc Power Distribution igloo/pallet configuration, the main bus dc voltage and amperage are also available to the flight crew from the EPDS *volts/amps* digital meter and rotary switch on panel R7 at the orbiter crew compartment aft flight deck mission specialist station. The Spacelab power control box is installed in the subfloor of the Spacelab pressurized core segment and in the igloo of the pallet-only configuration.

In the Spacelab pressurized module configuration, the main dc voltage and amperage are available in the pressurized module on the control center rack EPDS monitoring and control panel. The voltage reading is obtained by setting the *volts* rotary switch on the EPDS MCP to the *main dc* position, and the amperage reading is obtained by setting the amps rotary switch to the *main dc* position. The meters on the EPDS MCP panel have only colored zones to indicate nominal (green) or off-nominal (red) readings. The amp readout for main dc power has an additional color field (yellow) to indicate a peak power loading condition.

In the pressurized module configuration, the EPDS MCP provides a manually operated *orb PRI PL bus* disconnect switch, which acts as a kill-power switch for the main dc power to the module. When this switch is positioned momentarily to the *disconnect* position, all Spacelab subsystem functions supplied by normal dc and ac power cease to operate, and the Spacelab water pump, Freon pump, and avionics delta pressure caution channels are activated.

The Spacelab subsystem power distribution box distributes the subsystem dc bus and ac bus power into subsystem-dedicated feeders. In the pressurized module configuration, all outputs except the tunnel and environmental control subsystem ac and experiment ac outputs are remotely switched by latching relays. Power protection circuits and command activation are controlled by the remote amplification and advisory box. In the subsystem power distribution box, the dc power line feeds several subsystem power buses controlled by switches on the electrical power distribution subsystem monitoring and control panel. In the pallet-only configuration, all outputs are remotely switched by latching relays.

Various Spacelab systems' operations are controlled on orbit from panel R7 in the orbiter crew compartment aft flight station. In either the pallet-only or pressurized module configuration, Spacelab power protection circuits and command activation are controlled from the remote amplification and advisory box. The subsystem power distribution box is controlled by the *S/S ac/dc power on/off* switch on the orbiter aft flight deck panel R7 or by an item command on several orbiter CRT Spacelab displays. The status of this switch on panel R7 is displayed on the orbiter CRT and indicated by a green LED above the manual switch on panel R7. The voltages and currents of the various Spacelab subsystem buses are also available to the flight crew on the orbiter CRT Spacelab subsystem power display.

The dc power in the Spacelab power control box is directed through two parallel 150-amp fuses, one to the Spacelab subsystem dc/ac inverter and the other to a Spacelab experiment dc/ac inverter. Normally, only the subsystem inverter is used to power both subsystem and experiment ac requirements, and the experiment inverter is used as a backup. Each inverter generates three-phase ac power at 117/203 volts, 400 hertz. It is possible to connect the ac experiment bus to the subsystem inverter and, conversely, the subsystem ac bus to the experiment inverter.

In the Spacelab pressurized module configuration, the inverters are mounted on cold plates in the control center rack of the core segment. In the pallet-only configuration, the inverters are mounted on cold plates on the first (forward) pallet in the orbiter payload bay.

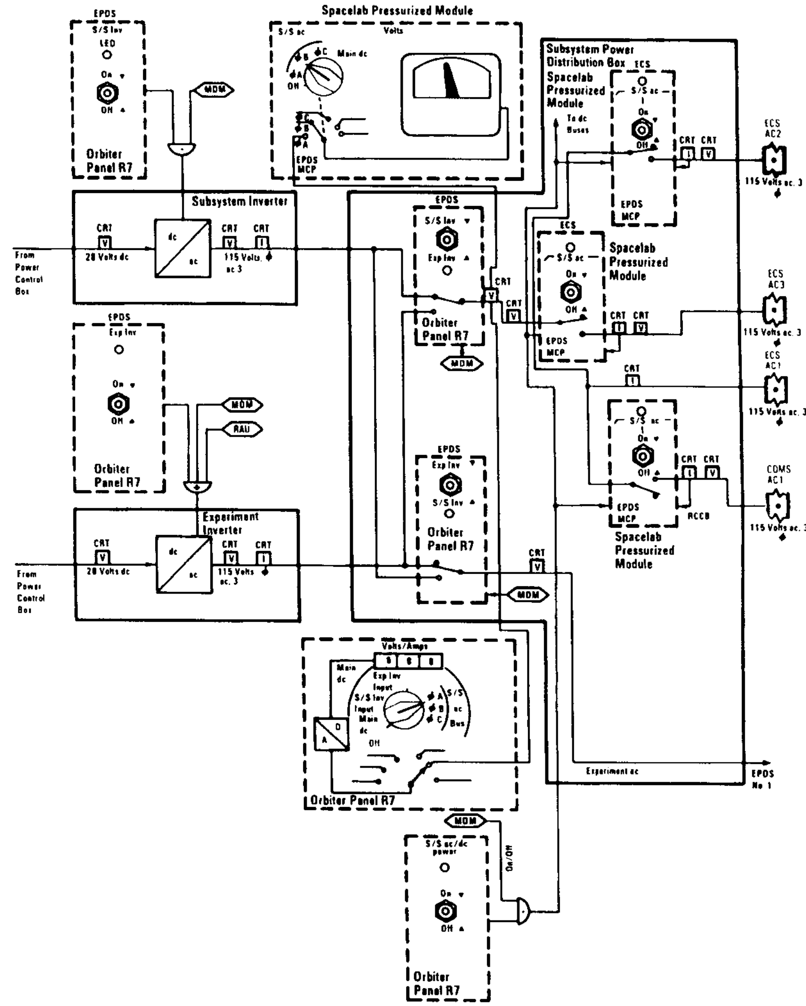
The Spacelab subsystem inverter is activated by the *S/S inv on/off* switch on panel R7 or by orbiter Spacelab CRT command. Positioning the switch to *on* activates the subsystem inverter, and a green LED above the switch on panel R7 is illuminated, indicating the inverter is operating. Positioning the momentary left *S/S inv, exp inv* switch to *S/S inv* permits the subsystem inverter to supply ac power to the Spacelab subsystem ac bus. Similarly, positioning the momentary right *S/S inv, exp inv* switch to *S/S inv* supplies ac power to the experiment ac bus, and the yellow light below the switch is illuminated to indicate the subsystem inverter is supplying the experiment ac bus.

The Spacelab experiment inverter is activated by the *exp inv on/off* switch on panel R7 or by orbiter Spacelab CRT command. Positioning the switch to *on* activates the experiment inverter, and a green LED light above the switch is illuminated, indicating the inverter is in operation. Positioning the momentary right *exp inv, S/S inv* switch to *exp inv* supplies ac power to the experiment ac bus. Positioning the momentary left *S/S inv, exp inv* switch to *exp inv* supplies ac power to the subsystem ac bus, and the yellow light below the switch is illuminated to indicate the experiment inverter is supplying the subsystem ac bus.

The switching of Spacelab inverters between the two ac power buses may also be commanded and monitored through the orbiter CRT Spacelab subsystem ac power supply. Readings presented on the orbiter CRT display include inverter on/off status, inverter output voltage, inverter input voltage, and inverter output current. The subsystem inverter input, experiment inverter input, and main dc amps are available via the digital readout and rotary switch on panel R7. The main dc and subsystem ac bus phase A, B, and C volts also are available via the digital readout and rotary switch on panel R7. In the Spacelab pressurized module configuration, the Spacelab EPDS monitoring and control panel provides a color readout of each subsystem ac phase.

The Spacelab inverters are protected against overvoltage and overcurrent. They are shut down automatically if the voltage exceeds 136 volts root mean square per phase. Current levels are limited to 12 amps rms per phase, and all three phases are shut down if one phase draws a current of 10 amps rms for 120 seconds.

In the pressurized module configuration, the subsystem power distribution box ac bus feeds several Spacelab subsystem power buses controlled by switches on the Spacelab EPDS MCP. All functions on this panel can be initiated simultaneously by the *S/S ac/dc power on/off* switch on orbiter panel R7 or by item commands from the orbiter CRT Spacelab displays. The status of the commanded relays is available via orbiter CRT Spacelab displays and indicated by the green LED light above the respective switch on panel R7.



Spacelab Electric Power Distribution—
Subsystem ac Power Distribution

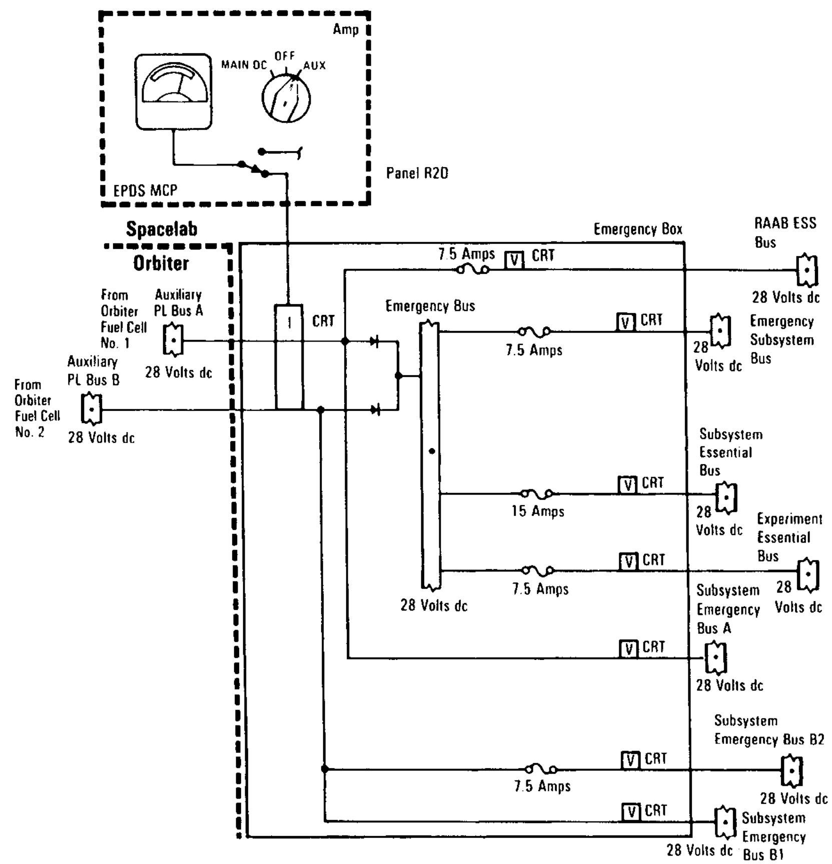
In the pallet-only configuration, subsystem ac bus power feeds several Spacelab subsystems' power buses, which can be initiated by the *S/S ac/dc power on/off* switch on orbiter panel R7 or by item commands from the orbiter CRT Spacelab displays. The status of the commanded relays is available via orbiter CRT Spacelab displays and the green LED light above the respective switches on panel R7.

Emergency and essential dc power for the pressurized module configuration is provided by the orbiter auxiliary payload buses A and B to the Spacelab emergency box. The Spacelab emergency box supplies emergency and essential power for Spacelab critical environmental control subsystem sensors and valves, fire and smoke suppression equipment, ECS water line heaters, module emergency lighting, tunnel emergency lighting, the Spacelab intercom system, and the Spacelab caution and warning panel. The outputs are protected by fuses. One separately fused outlet, an experiment essential bus, is dedicated to experiments. This power is available during all flight phases and when degraded power is delivered to Spacelab. The Spacelab emergency box is located in the subfloor of the core segment.

Emergency and essential dc power for the pallet-only configuration is also provided by orbiter auxiliary payload buses A and B, which send dc power to the Spacelab emergency box located in the igloo. The Spacelab emergency box provides emergency or essential power to Spacelab subsystem equipment. The outputs are protected by fuses. One separately fused outlet, an experiment essential bus, is dedicated to experiments. The Spacelab emergency box is in the igloo. This power is available during all flight phases and when degraded power is delivered to Spacelab.

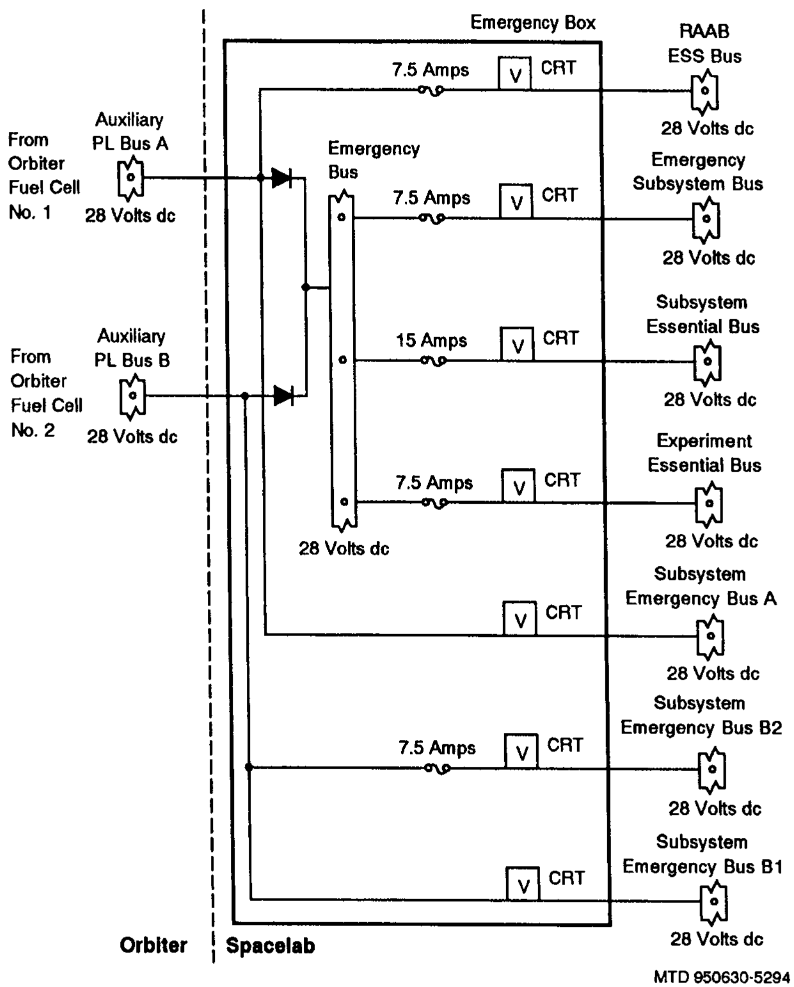
In the Spacelab pressurized module configuration, experiment power distribution boxes provide distribution, control, and monitoring facilities for the experiment electrical power distribution system, which consists of a nominal redundant 28-volt experiment main dc supply and a 115-volt, 400-hertz ac experiment supply. One distribution box (EPDB 1) is located under the core segment floor on a support structure; for the long module configuration, two additional units (EPDBs 2 and 3) are installed. In the pallet-only configuration, the experiment power distribution box is mounted with other assemblies with an adapter plate on a cold plate that is fitted on a support structure and attached to the pallet.

The orbiter pressurized module CRT Spacelab displays present emergency and essential bus current, voltages for auxiliary buses A and B, output voltages for Spacelab subsystem emergency buses, output voltage for the Spacelab subsystem essential bus, and output

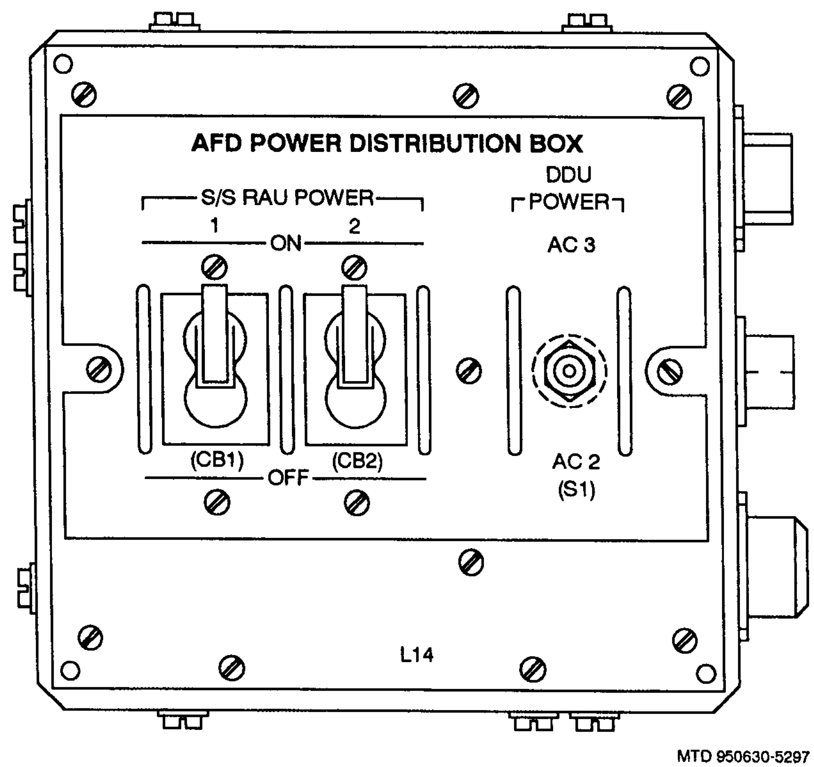


Spacelab Pressurized Module Emergency and Essential Power Distribution voltage for the Spacelab remote amplification and advisory box essential bus. The orbiter CRT Spacelab displays for activation/deactivation, subsystem dc power, and system summary indicate an undervoltage condition for auxiliary buses A and B. Nominal auxiliary bus amperage from the orbiter can be monitored on the *amps* meter (color zone only) of the Spacelab EPDS monitoring and control panel.

In the pallet-only configuration, the orbiter CRT Spacelab displays include emergency and essential bus current, voltages for auxiliary buses A and B, output voltages for Spacelab subsystem emergency buses, output voltage for the Spacelab subsystem essential bus, and output voltage for the Spacelab remote amplification and advisory box essential bus. The orbiter CRT Spacelab activate/deactivate, Spacelab subsystem dc power, and Spacelab system summary displays will indicate an undervoltage condition for auxiliary buses A and B.



Spacelab Pallet Emergency and Essential Power Distribution



Panel L14

The Spacelab power distribution box at the orbiter aft flight deck payload station distributes dc and ac power to the Spacelab subsystem remote acquisition unit and the Spacelab data display system (a data display unit and keyboard). When a Spacelab data display system is installed at the mission station, ac power is provided from orbiter ac bus 2 or 3 via the orbiter mission station distribution panel.

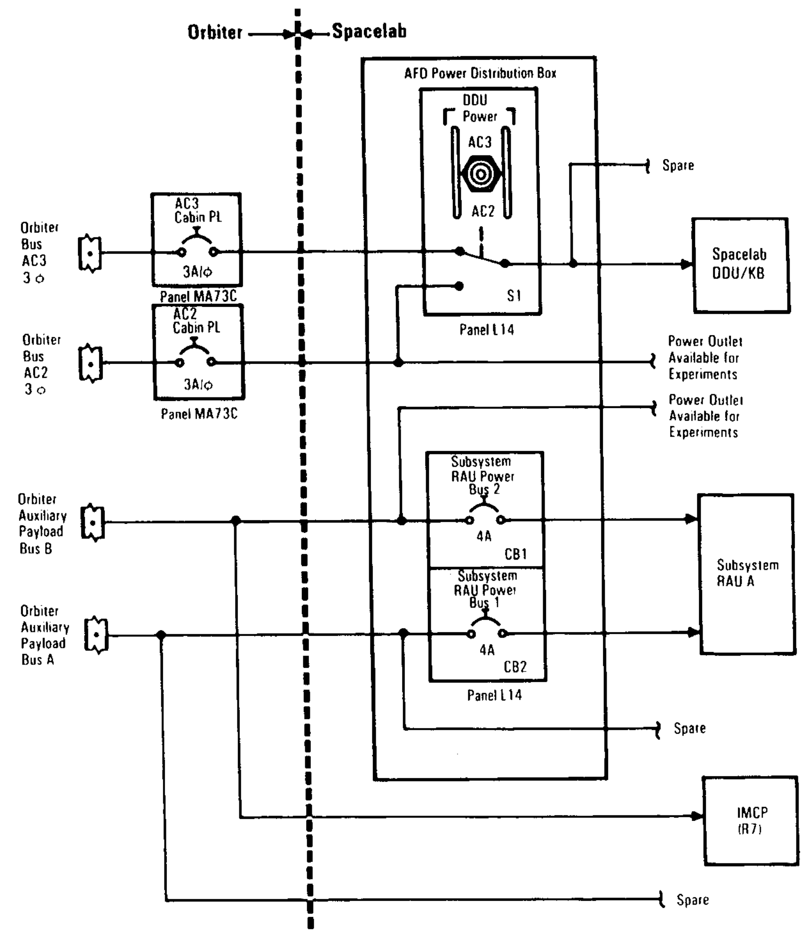
Spacelab subsystem remote acquisition unit dc power comes from orbiter fuel cell 1 main bus A through auxiliary payload bus A and from orbiter fuel cell 2 main bus B to auxiliary payload bus B through the payload station distribution panel. This power is not affected by the kill switch of the primary payload bus. The aft flight deck power distribution panel L14 *S/S RAU power 1 on/off* and *S/S RAU power 2 on/off* circuit breakers are used to feed power to the RAU from either bus.

Control of the ac power supplied to the Spacelab DDU and keyboard from orbiter ac buses 2 and 3 is made possible by positioning the panel L14 *DDU power* switch to *AC2* or *AC3*. This 115-volt ac, three-phase, 400-hertz power is available only during on-orbit flight phases. Panel L14 provides no fuse protection.

In the pallet-only configuration, ac power is supplied to the Spacelab pallet or pallets from orbiter ac buses 2 and 3 by positioning the panel L14 *DDU power* switch to *AC2* or *AC3*. This power (115 volts ac, three phase, 400 hertz) is available only during on-orbit flight phases.

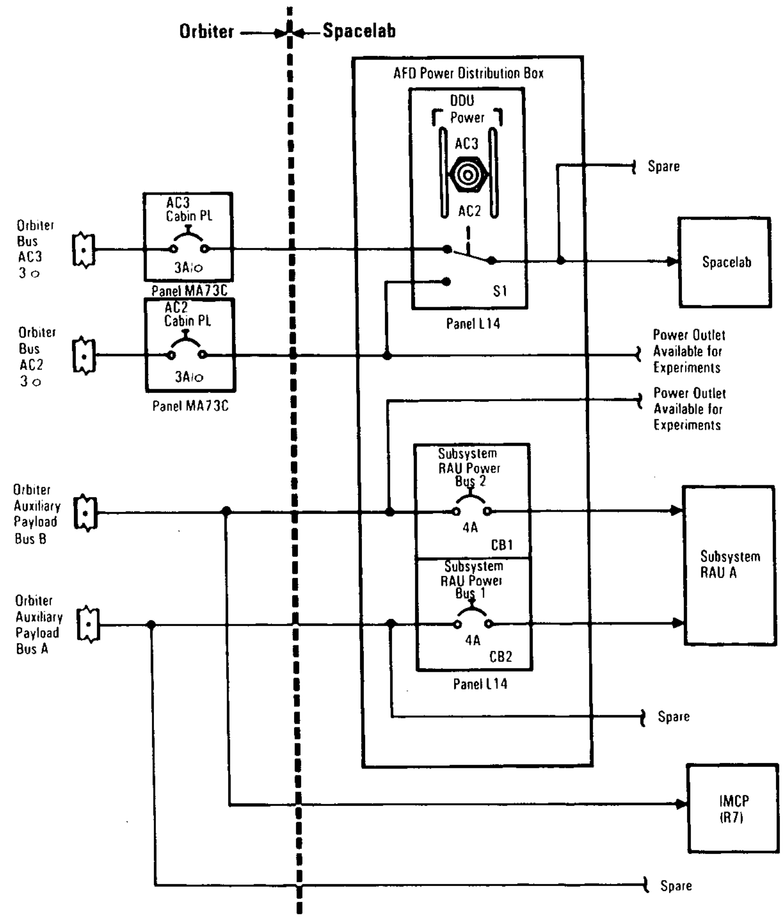
In the Spacelab module, the experiment power switching panel provides facilities for branching and switching dc and ac power delivered by a dedicated experiment power control box. The dc and ac output is distributed to experiments and experiment-supporting RAUs (dc only). The number of switching panels and their locations depend on the mission configuration.

The orbiter crew compartment aft flight deck panel configurations vary for Spacelab pressurized module configurations and pallet-only configurations. A Spacelab pressurized module configuration may consist of a payload specialist station data display unit at panel L11, a standard switch panel at panel L12, a keyboard at panel L11, a systems management tone generator and interconnect station



Pressurized Module Configuration—Orbiter Aft Flight Deck Power Distribution at panel L14, a mission specialist station with a data display system and interconnect station at panel R14, and a floor-mounted remote acquisition unit at the payload station.

A pallet-only configuration may consist of a payload specialist station data display system at panel L11, a Spacelab-unique switch panel at panel L12, a video tape recorder at panel R11, a high-data-rate recorder at panel L10, a systems management tone generator and interconnect station at panel L14, a Spacelab power distribution box at panel L14, and a floor-mounted Spacelab RAU at the payload station.



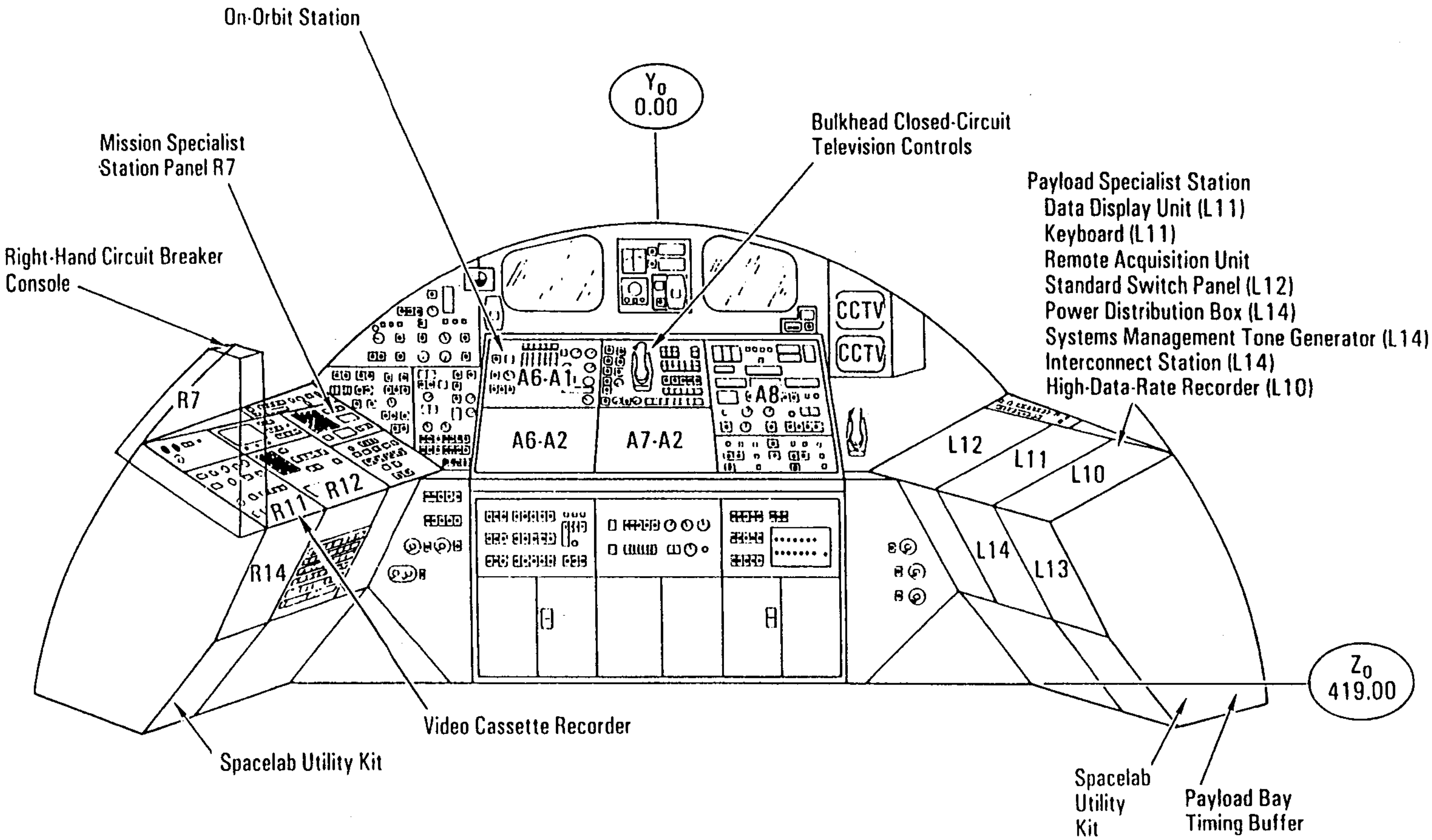
Pallet-Only Configuration—Orbiter Aft Flight Deck Power Distribution

COMMAND AND DATA MANAGEMENT SYSTEM

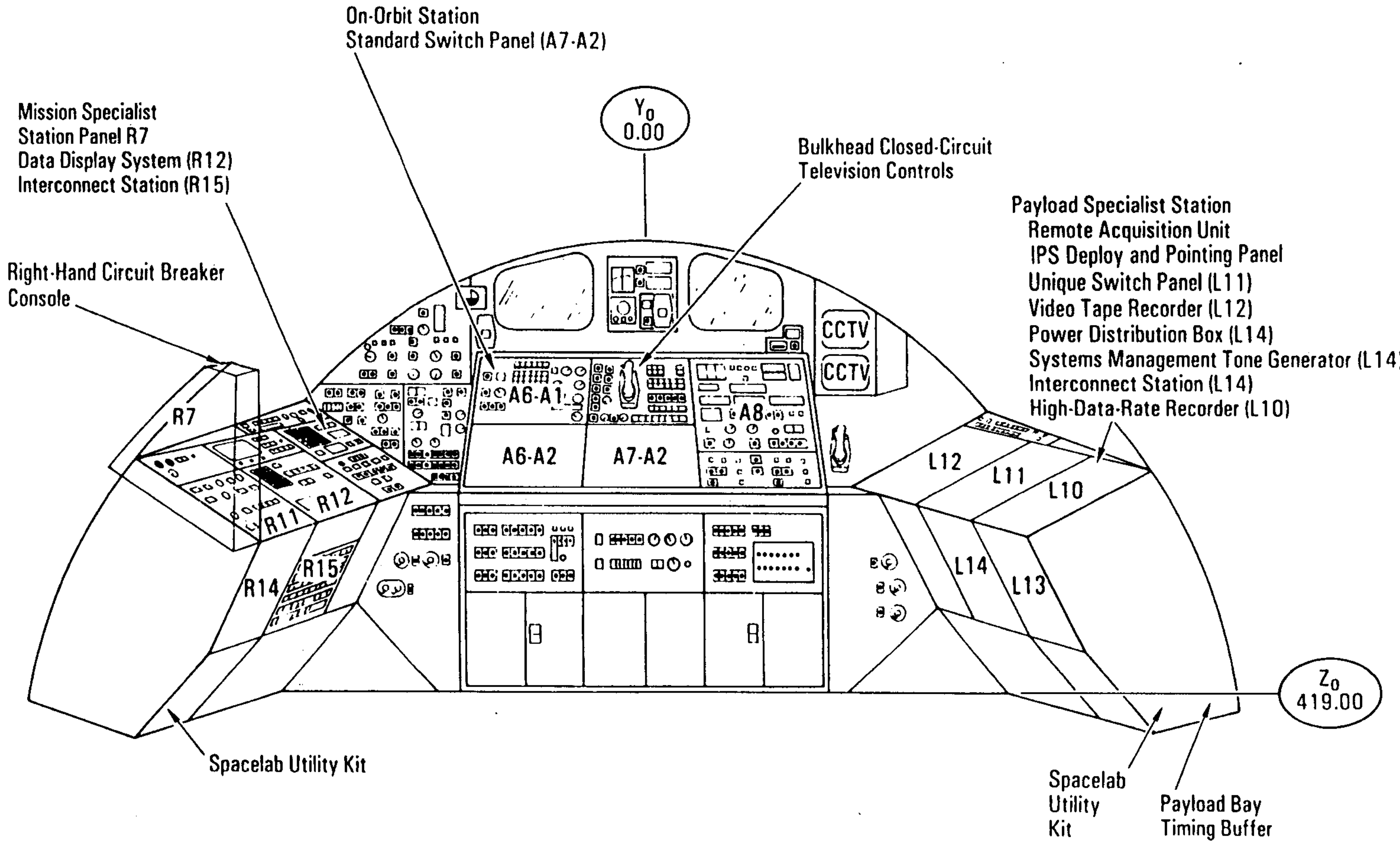
The Spacelab command and data management system provides a variety of services to Spacelab experiments and subsystems. Most of the CDMS commands are carried out through the use of the computerized system aboard Spacelab, called the data processing assembly. The DPA formats telemetry data and transfers the information to the orbiter for transmission, receives command data from the orbiter and distributes them to Spacelab subsystems, transfers data from the orbiter to experiments, and distributes timing signals from the orbiter to experiments.

The CDMS includes three identical computers and assorted peripherals. One computer is dedicated to Spacelab experiments, one supports Spacelab subsystems, and the third is a backup. The flight crew monitors and operates Spacelab subsystems and payload experiments through data display and keyboard units. The previously used three identical MATRA 125/MS computers have been changed to the upgraded AP-101SL orbiter computers. The experiment computer activates, controls, and monitors payload operations and provides experiment data acquisition and handling. The subsystem computer provides control and data management for basic Spacelab services that are available to support experiments, such as electrical power distribution, equipment cooling, and scientific airlock operations (in the case of the pressurized module). The backup computer can function in the place of either computer.

An input/output unit buffers all communications between the computer and the rest of the subsystem. The experiment computer also has at least one RAU (and as many as eight, depending on the



Example of a Spacelab Pressurized Module Aft Flight Deck Panel Configuration



Example of a Spacelab Pallet-Only Aft Flight Deck Panel Configuration payload) for interfacing between experiments and the subsystem. The subsystem computer may have as many as nine acquisition units, depending on the Spacelab configuration.

The experiment and subsystem computers and their associated input/output units, as well as the shared mass memory unit and backup computer, are located in the workbench rack of the pressurized module core segment. In the pallet-only configuration, they are located in the igloo.

Mass Memory Unit

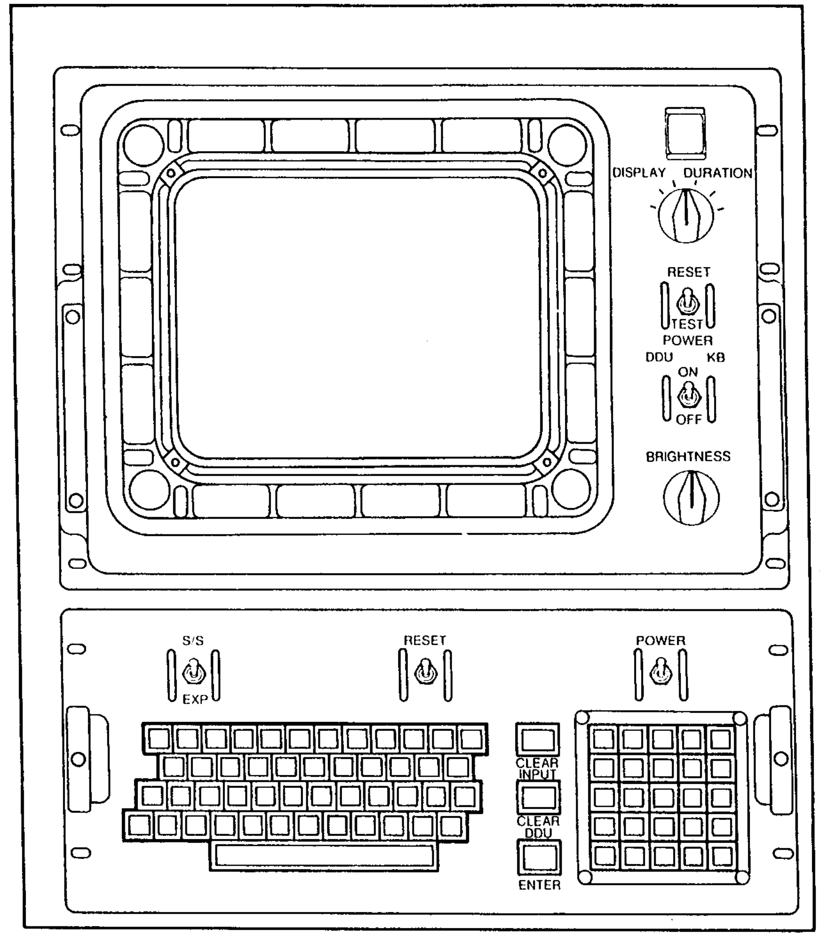
The MMU is a tape recorder that contains all of the operating system and applications software for the subsystem and experiment computers. The memory unit provides the initial program load for the Spacelab subsystem, experiment, and backup computers; it can also be used to completely reload computer memory if required. The MMU stores various files, time lines, and displays. Writing onto the unit during flight is possible. Approximately half of the unit's storage capability is available for software and data supporting Spacelab experiments.

Data Display Systems

The data display systems are the primary on-board interface between the CDMS and the Spacelab flight crew. Each display system consists of a keyboard and a CRT data display unit. One display is located at the orbiter aft flight deck station, one at the control center rack in the pressurized module, and, possibly, one at the experiment rack in the pressurized module. In the pallet-only configuration, two CRTs and DDUs can be located at the crew compartment aft flight deck station.

The keyboard consists of 25 function keys and 43 alphabet, numeral, punctuation, and symbol keys of the familiar standard typewriter keyboard as well as the standard typewriter action keys, such as space and backspace. The data display unit is a 12-inch diagonal CRT screen providing a 22-line display (47 characters per line) in three colors (green, yellow, and red). In addition to 128 alphanumeric symbols, the unit can also display vector graphics (1,024 different lengths and 4,096 angles). A high-intensity green flashing mode is also provided.

The display units are connected to the experiment and subsystem input/output units. Each data display unit can present informa-



Data Display Unit and Keyboard

tion from both computers simultaneously, and each keyboard can communicate with either computer. Flight crew members can call various displays onto the screen from the keyboard for experiment evaluation and control.

Command and data management system software consists of experiment computer software and subsystem computer software, each of which includes operating systems and applications. Within the experiment computer, both the operating system and the application software are wholly dedicated to the direct support of Spacelab payload experiments. The operating system provides such general services as activation, control, monitoring, and deactivation of experiments as well as experiment data acquisition, display, and formatting for transmission. Application software is developed for experiments that have data handling requirements beyond the capabilities of the operating system.

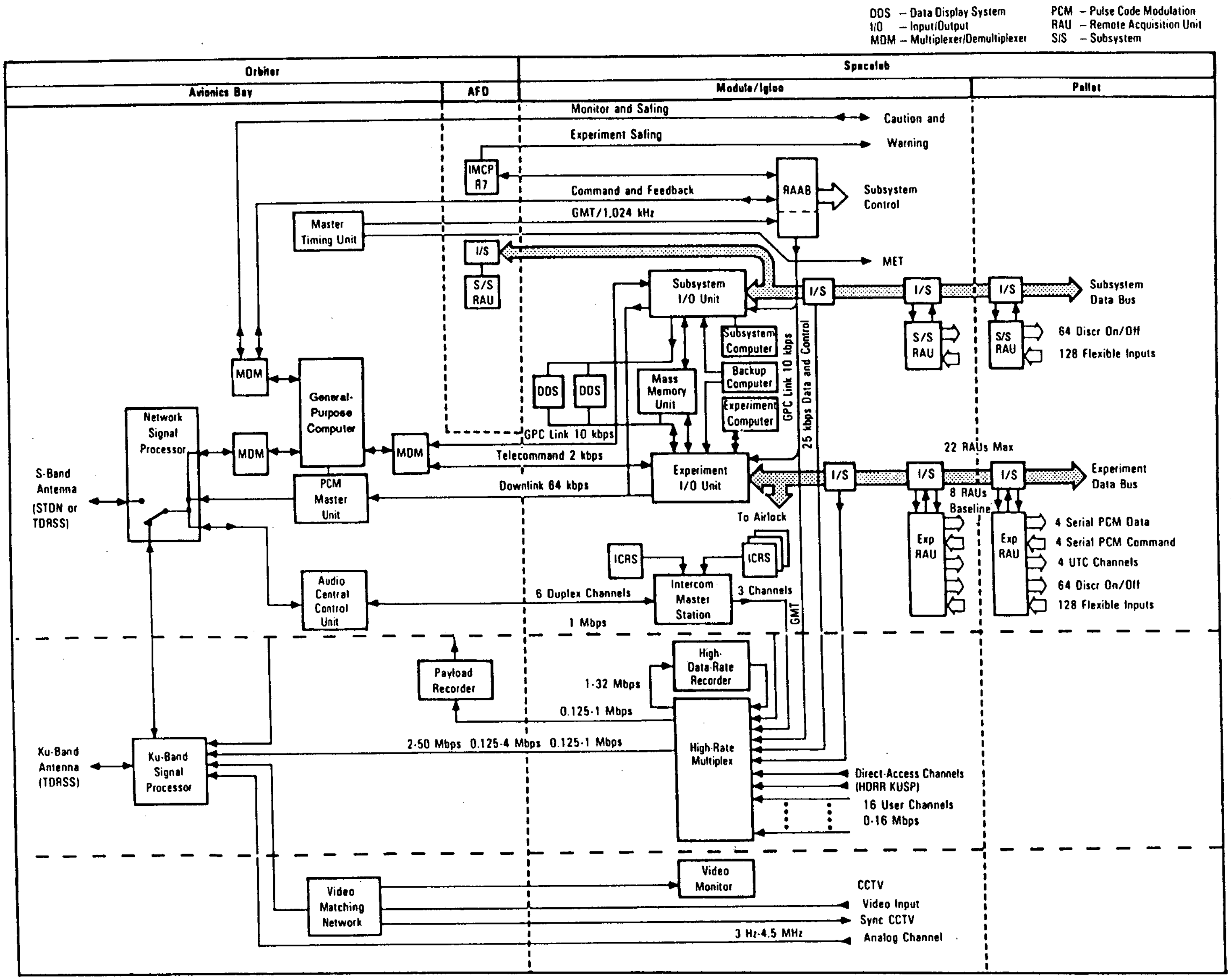
The subsystem computer functions mainly to monitor and control other Spacelab subsystems and equipment, such as the electrical power distribution subsystem and the environmental control subsystem. These functions are performed by the subsystem computer operating software.

Two orbiter payload multiplexers/demultiplexers (PF1 and PF2) are used for data communications between the orbiter general-purpose computers and the Spacelab CDMS computers. The payload MDMs are under orbiter GPC control. The orbiter pulse code modulation master units under control of the orbiter computers can access Spacelab data for performance monitoring and limit sensing. The PCMMUs contain a fetch command sequence and a random-access memory for storing fetched data. Data from the PCMMU RAM are combined with orbiter pulse code modulation data and sent to the orbiter network signal processors for transmission on the return link (previously referred to as downlink) through S-band or Ku-band. The 192-kbps data stream normally carries 64 kbps of Spacelab experiment and subsystem data.

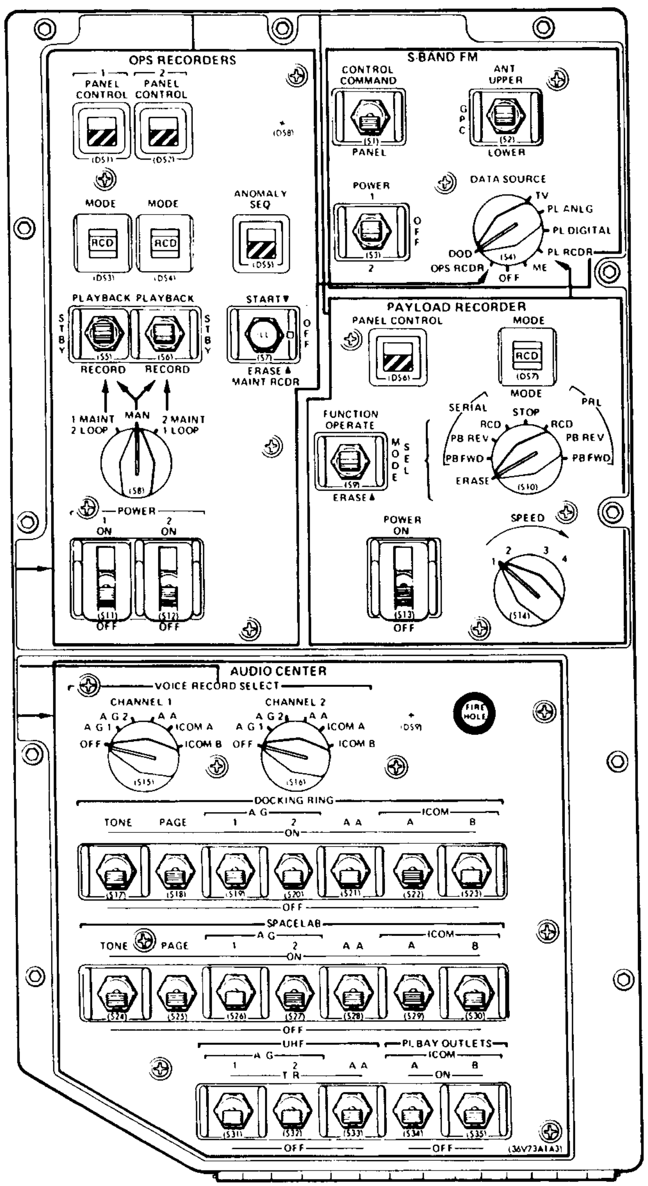
The Spacelab experiment computer interfaces with two telemetry systems. The orbiter PCMMU allows the orbiter to acquire data for on-board monitoring of systems and provides the Mission Control Center in Houston with system performance data for real-time display and recording through the orbiter network signal processor and S-band or Ku-band. The other telemetry system, the Spacelab high-rate multiplexer, is a high-rate link to the Ku-band signal processors that sends scientific data to the Payload Operations Control Center for real-time display and to the Goddard Space Flight Center for recording.

Spacelab high-rate data acquisition is provided by a high-rate multiplexer and a high-data-rate recorder. The HRM multiplexes up to 16 experiment channels, each with a maximum of 16 Mbps; two direct-access channels with data rates up to 50 Mbps; data from the Spacelab subsystem computer; experiment data from the Spacelab experiment computer; and up to three analog voice channels from the Spacelab intercom master station in the pressurized module configuration. The three digitized channels are premultiplexed onto a single 128-kbps channel for interleaving in the format along with Greenwich mean time signals from the orbiter master timing unit. This composite output data stream is routed to the Ku-band signal processor for transmission on Ku-band or is sent to one of the two recorders. The HRM is located on the control center rack in the pressurized module and in the igloo for the pallet-only configuration.

In the pressurized module, the high-data-rate recorder is located at the control center rack next to the data display system; in the pallet-only configuration, it is at the aft flight deck panel L10. It records real-time, multiplexed data or data from two direct-access channels and stores the information at rates from 1 to 32 Mbps during mission periods with no downlink capability or degraded downlink capability for playback when the capability is available. The HDRR dumps in reverse order at 2, 4, 8, 12, 16, 24, or 32 Mbps. At a rate of 32 Mbps, a tape runs for 20 minutes. The recorder can be changed manually by the flight crew; however, no tape changes are planned



Spacelab Command and Data Management System Interfaces With the Orbiter



Panel AIA3

because the time required to change tapes is very long and it is much more efficient to dump the tape.

The orbiter payload recorder serves as a backup for the Spacelab HDRR for data rates from 0.125 to 1 Mbps and can record only real-time, multiplexed data. The orbiter payload timing buffer provides mission elapsed time and Greenwich mean time; and the master timing unit provides 100-hertz, 1-kHz, 1,024-kHz, and 4,608-kHz timing signals to the Spacelab data processing assembly. Activation of the Spacelab DPA is controlled and monitored from the orbiter CRT Spacelab displays.

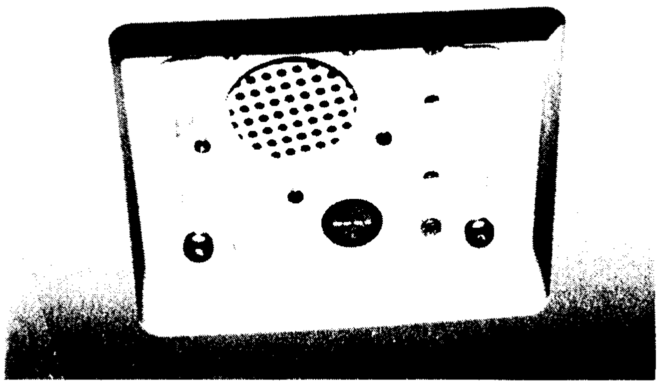
Closed-Circuit Television

The Spacelab pressurized module video system interfaces with the orbiter closed-circuit television system and the orbiter Ku-band signal processor. The orbiter CCTV system accepts three video inputs from the Spacelab system. The orbiter monitors the TV received and/or transmits it to telemetry. A sync command signal provided by the orbiter synchronizes and remotely controls cameras within Spacelab. The orbiter also has one video output for a Spacelab TV monitor. The Spacelab accommodates a video switching unit that enables Spacelab video recorder capability. The Spacelab analog channel for experiments is directed to the orbiter Ku-band signal processor at 3 to 4.5 MHz.

In the pallet-only configuration, the orbiter's CCTV can be used along with a video tape recorder. The TV cameras installed in the payload bay vary according to mission requirements. Television data downlinked on Ku-band channel 3 are time-shared by the orbiter's CCTV system, the Spacelab TV/analog output, and the Spacelab high-rate multiplexer data.

Pressurized Module Intercom

The Spacelab intercom master station interfaces with the orbiter audio central control unit and the orbiter EVA/ATC transceiver for communications through orbiter duplex (simultaneous talk and lis-



Spacelab Pressurized Module Aural Annunciator Located Below Panel L14

ten) audio channels. Audio channel 1 is air-to-ground 2, channel 2 is intercom B, and channel 3 is air-to-ground 1.

Each orbiter channel, with the exception of page, may be selected on each of the three Spacelab full-duplex channels—A/G 1 for the Payload Operations Control Center, Spacelab and A/G 2 for the orbiter/Mission Control Center—using rotary switches on the Spacelab intercom master station. The page channel is used for general address and calling purposes. Page signals can originate in the orbiter, Spacelab, or both.

Access to orbiter channels is controlled within the orbiter. Normal voice recordings are made on the orbiter operations recorders. The Spacelab talk and listen lines are combined for distribution to the Spacelab voice digitizer in the Spacelab high-rate multiplexer for all three Spacelab channels.

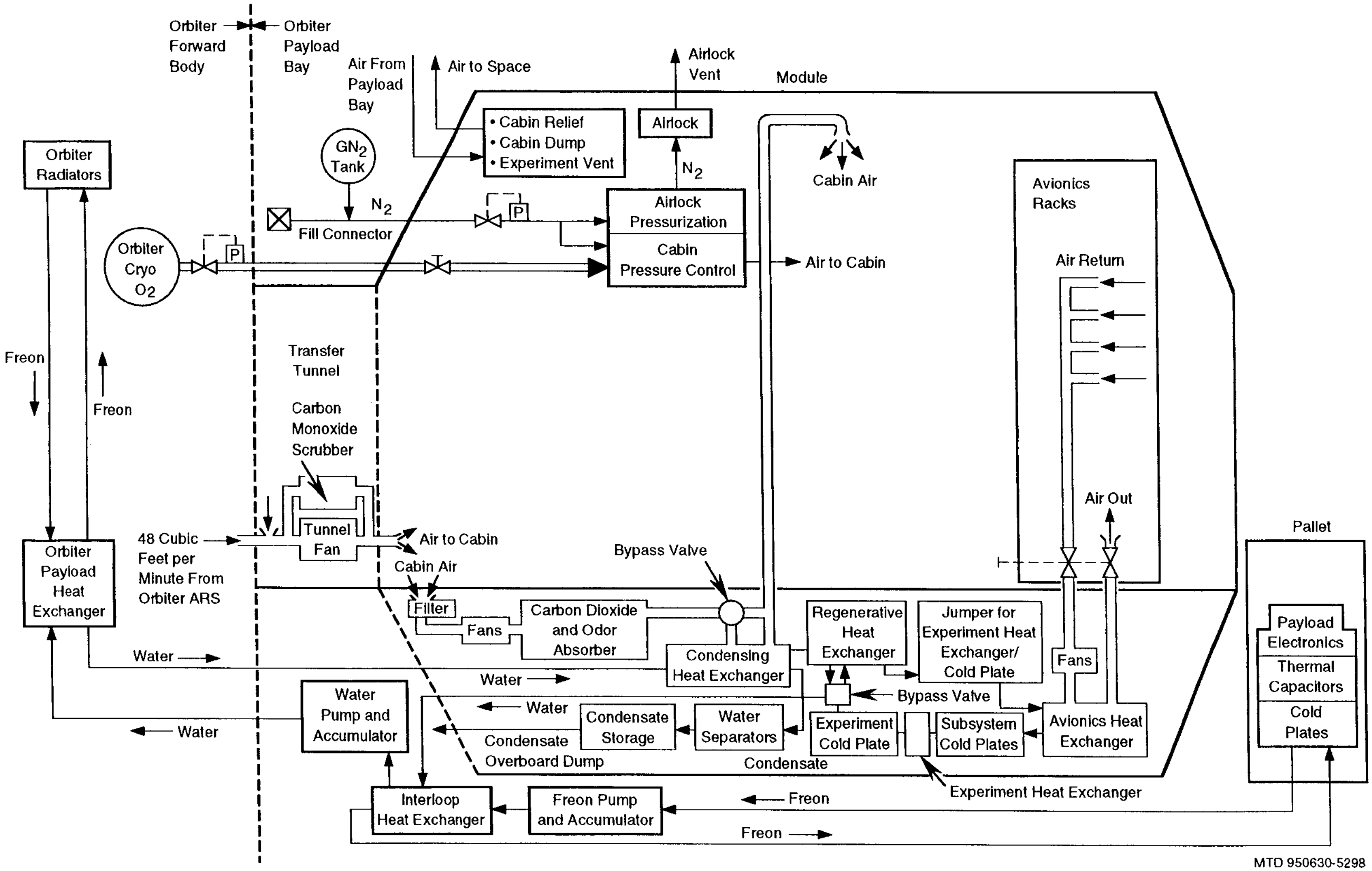
PRESSURIZED MODULE ENVIRONMENTAL CONTROL SUBSYSTEM AND LIFE SUPPORT

The Spacelab environmental control subsystem consists of the atmosphere storage and control subsystem and the atmosphere revitalization system.

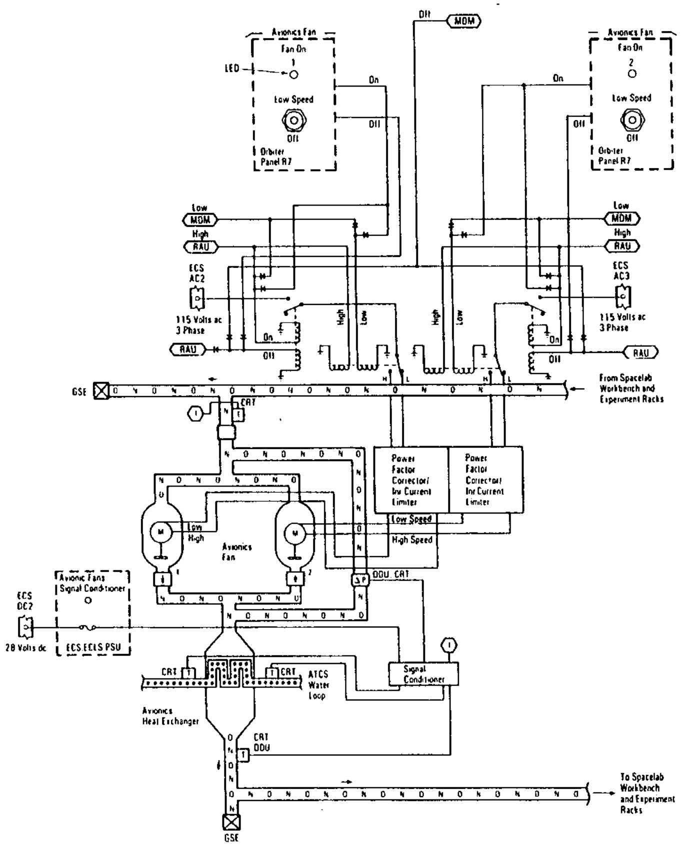
The atmosphere storage and control subsystem receives gaseous oxygen from the orbiter power reactant storage and distribution system and gaseous nitrogen from a tank located on the Spacelab module's exterior. The Spacelab ASCS regulates the gaseous oxygen and nitrogen pressure and flow rates to provide a shirt-sleeve environment for the Spacelab module compatible with the orbiter cabin atmosphere.

Gaseous oxygen from the orbiter PRSD enters the Spacelab module through the upper feedthrough in the Spacelab forward end cone at 100 psi and a maximum flow rate of 14 pounds per hour. A motor-controlled valve in the Spacelab module controls the flow of gaseous oxygen. This valve, operated by Spacelab RAU commands, opens when the *O_2 supply valve* switch on panel R7 is in the *cmd enable* position. It closes when the switch is in the *close* position for such situations as contingency cabin atmosphere dump. A yellow LED above the switch on panel R7 is illuminated to indicate that the valve is closed. The oxygen supply valve receives 28 volts from the Spacelab emergency bus.

The Spacelab cabin depressurization assembly is primarily for contingency dump of Spacelab cabin atmosphere in case of fire that cannot be handled by the Spacelab fire suppression system. It consists of a vent with two filters, a manual shutoff valve, and a motor-driven shutoff valve. The motor-driven shutoff valve is powered by the Spacelab environmental control subsystem emergency bus and controlled by the *cabin depress valve open/close* switch, a *cabin depress arm/safe* switch, and valve status LEDs on orbiter panel R7. The *cabin depress arm* switch arms the Spacelab cabin depressurization motor-driven valve; and when the *cabin depress valve* switch is positioned to *open*, the Spacelab cabin depressurization assembly in



Spacelab Pressurized Module and Orbiter Environmental Control and Life Support System Interface



Spacelab Avionics Loop

the Spacelab forward end cone opens, depressurizing the Spacelab module at 0.4 pound per second. The red LED above the switch on panel R7 is illuminated to indicate that the motor-operated depressurization valve is fully open. The yellow LED above the switch on panel R7 is illuminated to indicate that the Spacelab cabin depressurization valve is not closed when the *cabin depress* switch is in *arm* and the *cabin depress valve* switch is in the *closed* position.

Air in the Spacelab avionics air loop is circulated by one of two dual-redundant fans, with check valves to prevent recirculation through the inactive fan and a filter upstream to protect both fans. For ascent and descent flight phases, as well as low-power modes on orbit, the avionics fans operate when only a few experiments are operating and require cooling.

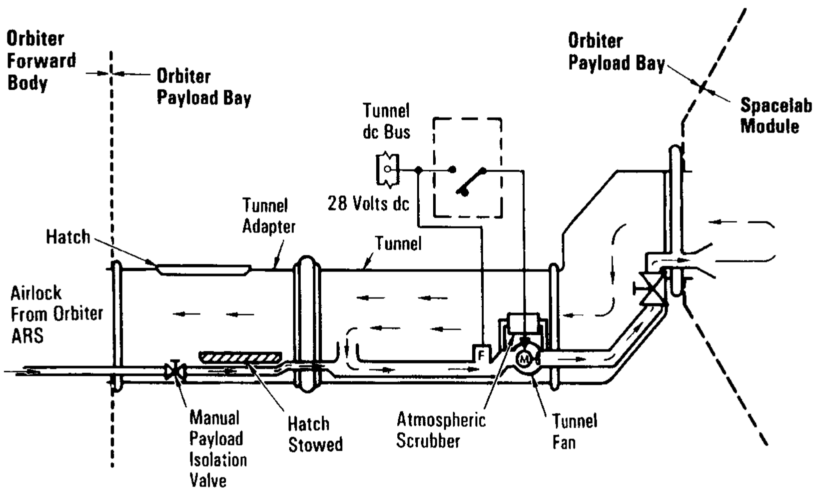
The fans are designed to switch from four-pole to eight-pole operation. The air flow through one fan is reduced from 1,923 to 639 pounds per hour, and the power is reduced from 643 to 110 watts. The two fans, powered by separate 115-volt ac buses, are activated and deactivated at low speed (eight-pole) by the *avionics fan 1/2 low speed/off* switches on orbiter panel R7. Each switch has a yellow LED that is illuminated above the respective switch to indicate that the respective fan is activated. The fans' on/off status is also available on orbiter CRT displays and the Spacelab DDU avionics power/cooling display.

The Spacelab avionics fans can also be activated in the low-speed mode by commands from the orbiter CRT keyboard. The fans are activated in the high-speed mode (four-pole) by commands from the orbiter CRT keyboards. The orbiter MDM deactivation command deactivates both fans simultaneously, and the Spacelab RAU deactivation command turns off each fan separately. The high-speed status of the Spacelab avionics fans is available on the orbiter CRT display and the Spacelab DDU display.

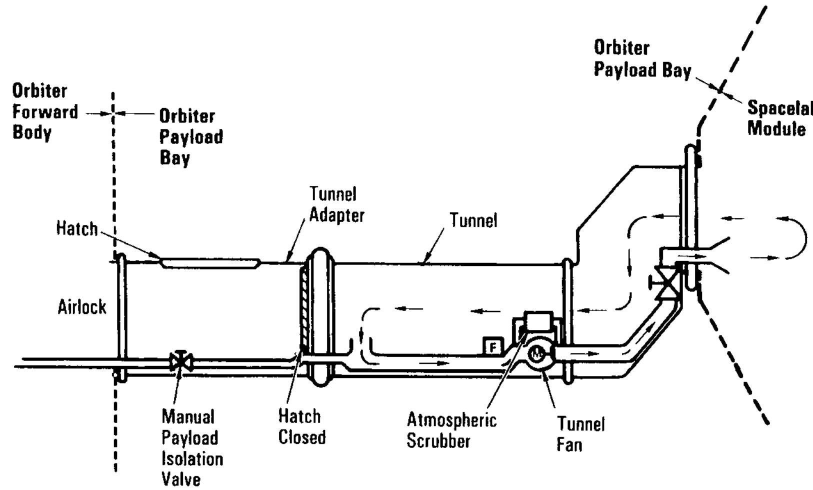
Pressurized Module/Tunnel Air Loop

The switch for the fan located in the transfer tunnel cannot be accessed until the tunnel/Spacelab hatch is opened and the flight crew initially transfers to the Spacelab from the orbiter.

When the airlock hatch and the tunnel adapter/Spacelab hatches are open, the orbiter air revitalization system provides air at 48 cubic feet per minute through a duct that branches off of the orbiter cabin air loop downstream of the orbiter cabin heat exchanger and enters the tunnel adapter. In the tunnel adapter, the duct can be controlled by a manual shutoff valve before it passes into the transfer tunnel itself. For the transfer tunnel to be entered, the tunnel adapter/Spacelab hatch must be opened and the duct passed through the tunnel hatch, where the duct expands. The fan located in the transfer tunnel



Tunnel Adapter Hatch Open—48-Cubic-Feet-Per-Minute Duct Operating



Tunnel Adapter Hatch Closed—48-Cubic-Feet-Per-Minute Duct Not Operating

draws additional air into the duct through an air inlet located just on the tunnel side of the tunnel adapter hatch.

The fan draws in additional air at a rate of 77 cubic feet per minute for a total nominal duct flow of 125 cubic feet per minute. This flow rate is delivered to the Spacelab cabin. The return air passes through the transfer tunnel itself, initially at 125 cubic feet per minute. However, 77 cubic feet per minute of air is sucked into the duct inlet at the Spacelab side of the tunnel/adapter hatch, and 48 cubic feet per minute of air enters the orbiter cabin through the tunnel adapter and airlock hatch. A scrubber in the tunnel duct removes carbon monoxide. The scrubber, located in parallel with the tunnel fan, produces an air flow of 1.5 to 4 cubic feet per minute.

The tunnel fan receives dc power from the Spacelab electrical power distribution subsystem. A delta pressure sensor located in the tunnel provides telemetry data for calculating air flow. If the Spacelab module is operating with the tunnel adapter hatch closed, air exchange is not possible. In this case, the tunnel fan can be used to circulate air at 125 cubic feet per minute in the tunnel.

Pressurized Module Active Thermal Control Subsystem

The Spacelab active thermal control subsystem consists of a water loop to remove heat from the Spacelab module and a Freon loop to remove heat from equipment on any pallets that may be flown with the pressurized module. The water loop is normally active only during on-orbit flight phases, but the need to cool experiments during ascent and descent requires operation of the water loop in a degraded performance mode during these phases.

The Spacelab water loop is circulated by a water pump package consisting of dual-redundant pumps (primary and backup) with inlet filters, manually adjustable bypass valves, check valves to prevent recirculation through the inactive pump, and an accumulator assembly to compensate for thermal expansion within the loop and maintain a positive pump inlet pressure.

The pump package is contained in a housing and mounted on the outside of the Spacelab module's forward end cone. The nominal flow rate through one pump is 500 pounds per hour.

The Spacelab water pumps are powered by separate 115-volt buses. They are activated and deactivated by the *H_2O loop pump 1/2 on/off* switches on orbiter panel R7 or by commands from the orbiter CRT keyboards. The green LED above each switch on panel R7 is illuminated to indicate that the pump is in operation. The on/off status of the Spacelab water pumps is also shown on the orbiter CRT displays.

The Spacelab Freon coolant loop removes heat from any pallets that may be flown with the pressurized module and transfers the heat of the interloop heat exchanger to the Spacelab water loop system. The flow rate is approximately 3,010 pounds per hour. From the Spacelab water loop system, the water passes through the orbiter payload heat exchanger, which transfers all the heat it has collected to the orbiter Freon coolant loops.

Pressurized Module Caution and Warning

The orbiter receives caution and warning inputs from Spacelab through the orbiter payload MDMs. Four channels in the Spacelab systems are dedicated to sending payload warning signals to the orbiter, and four channels in the Spacelab systems send payload caution signals to the orbiter. Nineteen remaining caution and warning input channels to the orbiter payload MDMs are available for Spacelab experiment limit sensing in the orbiter GPCs. The orbiter provides a maximum of 36 safing commands for use in response to Spacelab caution and warning conditions with 22 reserved for experiment safing commands. All safing commands are initiated at the orbiter CRT and keyboard.

The orbiter GPC can obtain data from the Spacelab command and data management system through the orbiter PCMMU as an alternative source for caution and warning.

Pressurized Module Emergency Conditions

There are two categories of Spacelab emergency conditions: fire/smoke in the Spacelab module and rapid Spacelab cabin depressurization. The orbiter and Spacelab annunciate these conditions and can issue safing commands if they occur. These signals are available during all flight phases.

Redundant Spacelab fire/smoke inputs are generated by two ionization chamber smoke sensors at three locations in the Spacelab. The six fire/smoke discrete signals are hard-wired to six annunciator indicators located on panel R7. These indicators are divided into three pairs labeled *left A&B*, *subfloor A&B*, and *right A&B*. The six *smoke annunciators enable/inhibit* switches on panel R7 can be used to inhibit each fire/smoke sensor's output individually. The *smoke sensor reset/norm/test* switch on panel R7 is used to reset or test all six sensors simultaneously.

Three signals, each from a different sensor location, are ORed (run through an OR gate) and connected to orbiter panel L1, which has a payload fire/smoke detection light. The three remaining signals are treated in the same manner.

When a Spacelab fire/smoke signal is detected, an emergency tone (siren) generated by the orbiter caution and warning circuitry is transmitted by the orbiter audio central control unit and announced in the Spacelab module by the loudspeaker, and the Spacelab *master alarm* light is illuminated. The six fire/smoke signals are also connected to six orbiter MDM inputs for display as emergency alert parameters on the orbiter CRT and for telemetry.

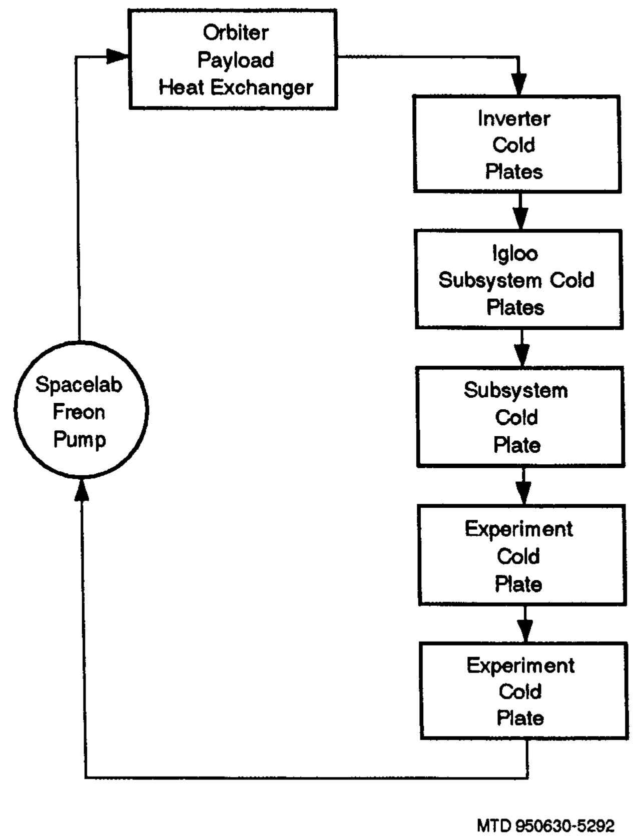
Two methods are provided for extinguishing a fire in the Spacelab module: discharging a fire suppressant into the affected area or dumping the Spacelab cabin atmosphere, when appropriate. The fire suppressant discharge consists of 15 orbiter-common fire suppression modules, each filled with the Freon 1301 suppressant agent.

The *agent discharge arm/safe* switch on orbiter panel R7 or the panel in the Spacelab module is used to safe or arm the discharge function. Each panel has a yellow indicator light that is illuminated when the discharge circuit is armed. The arming of the suppressant discharge function also shuts off the Spacelab module cabin and avionics fans to avoid diluting the suppressant's concentration. The agent can be discharged from either orbiter panel R7 or the panel in the Spacelab module by three identical sets of *agent discharge* switches, one each for the left, subfloor, and right areas. The switches are protected by individual guards. Positioning one of these switches completely discharges the contents of all suppressant bottles in the indicated area of the Spacelab module. In addition, the Spacelab module *O_2 supply valve close/cmd enable* switch on orbiter panel R7 can be used to close off the oxygen supply from the orbiter oxygen system to deprive the fire of oxygen. Spacelab cabin atmosphere dumping is controlled by the *cabin depress arm/safe* and *valve open/close* switches on orbiter panel R7. The Spacelab motor-controlled cabin dump valve's status is indicated by the yellow *not closed* and the red *full open* indicators on orbiter panel R7 as well as by the orbiter CRT.

PALLET-ONLY ENVIRONMENTAL CONTROL SUBSYSTEM

The environmental control subsystem provides thermal control of Spacelab experiments and subsystems. The Spacelab Freon-21 coolant loop services the pallet systems and collects heat dissipated by the subsystem and experiment equipment. The Spacelab Freon-21 coolant loop collects heat from the pallet-mounted subsystems and experiments through cold plates, some of which have thermal capacitors to store peak heat loads. The cold plates in the Freon loop are bolted to an intermediate support structure that is attached to the pallet. A maximum of eight cold plates can be used on the pallets for a particular mission.

The subsystem equipment mounted in the igloo is also serviced by the Freon loop, which interfaces directly with the orbiter's payload heat exchanger. The Freon pump package is mounted on the front frame of the first pallet (forward) in the orbiter payload bay. Thermal coatings are applied to minimize heat leakage and the effects of solar radiation. A special paint is used to reduce the hot-case temperature of the pallet structure itself. An insulated shield installed between the pallet-mounted cold plates and the pallet structure reduces radiation exchange between them. Multilayer insulation thermal tents also protect pallet-mounted subsystems; any unused tents are available for experiments.



Freon-21 Coolant Loop for Spacelab Pallets

ORBITAL ACCELERATION RESEARCH EXPERIMENT (OARE)

As the orbiter travels around the Earth, it is subject to our planet's gravitational pull. While it is in orbit, the shuttle's velocity changes because of this centripetal force and because of changes in the strength of Earth's gravity (gravity gradients). This experiment measures these perturbations as well as changes cause3d by atmospheric drag.

The data on atmospheric drag is extremely important because it could give scientists a better idea of the density of the upper atmosphere from 70 to 110 miles and could help to validate Shuttle aerodynamic models. OARE was originally designed to gather decleration data during orbiter reentry.

The OARE measures these variations and other disturbances very precisely with an accelerometer and records them for later analysis. By analyzing these and other types of microgravity disturbances, researchers can assess the influence of shuttle accelerations and vibrations on scientific experiments on board. The main application of the instrument is to help determine the orientation of the shuttle that will cause the least acceleration disturbances during flight.

The experiment has been flown successfully on shuttle missions as part of the Orbiter Experiment Program. The objectives of those missions were to provide scientists with important information about aerodynamic drag (friction with the atmosphere) and the density of the upper atmosphere (the thickness of the air at high altitudes), which is impossible to determine on Earth, and to study the high-velocity, low-density flight environment known as rarefied flow aerodynamics. This basic research has helped scientists better understand the upper atmosphere and aerodynamic behavior in it.

OARE is capable of sensing and recording accelerations one-billionth the acceleration of Earth's gravity at a rate of change (frequency) of less than once per second. These measurements will give scientists a more complete picture of the microgravity environment in the space shuttle so they can determine how the disturbances influence the behavior of their experiments.

OARE is designed to require minimal support services from the orbiter. It requires a stable mounting platform and accurate alignment with respect to the orbiter's principal body axes. The instrument consists of several components. The signal processor and control subsystem controls and monitors the operations of other electronic systems. The subplate assembly is the primary interface with orbiter avionics services and is also used for accurate position indexing and maintaining a constant rate of rotation of the sensor housing.

At the heart of the OARE system is the miniature electrostatic accelerometer (MESA). The MESA has a cylindrical mass (called a proof mass) suspended inside the accelerometer housing. The proof mass is pulled in different directions by static electric fields applied to electrodes in the housing. When the fields exert an equal pull in all directions on the proof mass, it floats between them. This is known as electrostatic suspension, which is very stable under conditions of varying temperature. An acceleration in any direction will cause the proof mass to move with respect to its enclosure, distorting the suspending electrostatic field. These field distortions are proportional to the applied acceleration and are measured and interpreted by OARE's electronics.

The accelerometer is mounted on a movable table, which enables it to be accurately aligned with respect to the shuttle's flight direction. In-flight calibration is also possible because the mounting system is movable. When the accelerometer is being calibrated, any inherent accelerometer error is determined and can be compensated for during postflight data analysis. OARE's nano-gravity sensitivity makes it impossible to calibrate the instrument on Earth because there is no place on the planet sufficiently vibration free at this level of acceleration.

The OARE sensor, with its unique calibration feature, can accurately measure very low-level vehicle accelerations, such as those resulting from aerodynamic drag, gravity gradients, crew activities and thrust from water discharges.

The OARE instrument will be used mainly to detect the residual acceleration (direction and magnitude) vector for possibly reorienting the orbiter in the direction of least disturbance. This information is downlinked in near real time (every three orbits) so that the orbiter's attitude can be corrected to satisfy the needs of any particular microgravity experiment.

The instrument is provided by NASA's Lewis Research Center in Cleveland, Ohio. The OARE project manager is Jose L. Christian, Jr.

EXTENDED-DURATION ORBITER (EDO)

Rockwell's Space Systems Division designed, developed, certified, and produced an EDO mission kit that allows a shuttle to remain in orbit for up to 16 days, plus a two-day contingency capability. (A nominal shuttle mission lasts eight days.) Columbia, the first shuttle to receive the EDO kit, flew the first four missions. The first EDO mission, STS-50, was flown in June and July of 1992. The primary payload on the 13-day, 19.5-hour flight was the United States Microgravity Laboratory (USML) 1. The second mission, STS-58, was flown in October and November of 1993. The primary payload on that 14-day flight was Spacelab Life Sciences (SLS) 2. The third EDO mission, STS-62, was flown in March 1994. The primary payloads on that 14-day flight were the United States Microgravity Payload 2 and Office of Aeronautics and Space Technology 2. The fourth EDO mission, STS-65, was flown in July 1994. The primary payload on that 14-day, 18-hour flight was the International Microgravity Laboratory (IML) 2. STS-67, the fifth EDO mission, was the first for Endeavour. The primary payload on that 16-day, 15-hour flight in March 1995 was the Ultraviolet Astronomy (ASTRO) 2. Columbia will fly the sixth EDO mission, STS-73.

The EDO modification program has several goals: to reduce the number of flights required to accomplish tasks; lower risks, costs, and vehicle wear; and substantially increase the volume of data that can be collected on a mission. Some of the areas that may benefit from additional on-orbit time are—

- Zero-gravity materials processing research in semiconductors, glasses, ceramics, biologicals, alloys, catalysts, and superpure materials

- Life sciences research in microgravity horticulture, basic physiology, and psychology, including human adaptation to zero gravity in preparation for longer spaceflights

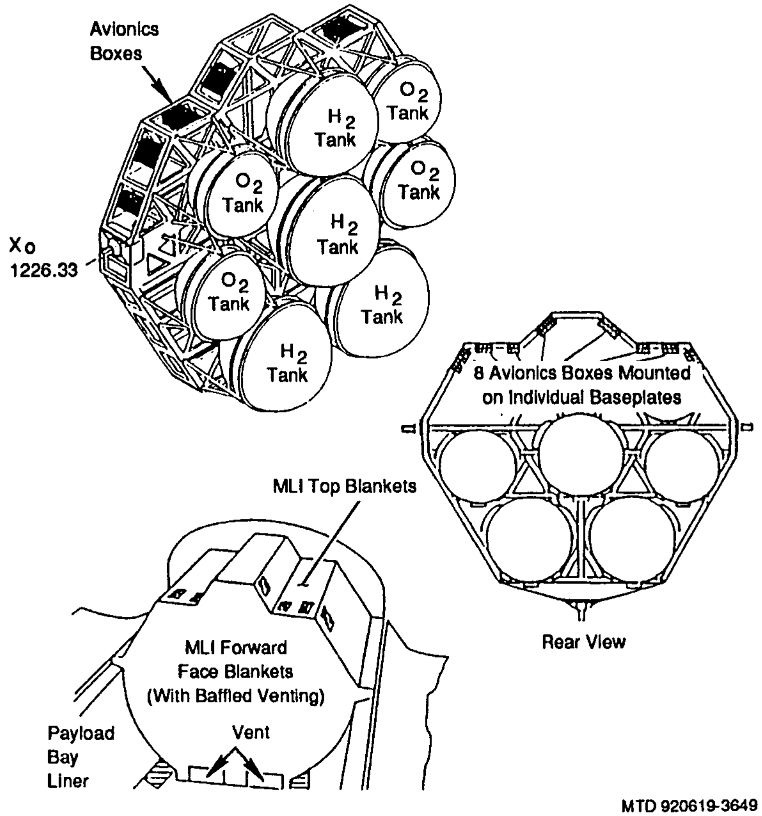
- Advanced space operations development, including assembly and on-orbit servicing and maintenance of the space station and other space structures

- Scientific observation missions in such areas as astrophysics and Earth remote sensing

Some of the major elements of the 16-day EDO mission kit produced by Rockwell are a set of cryogenic liquid hydrogen and liquid oxygen tanks mounted on a special pallet in the payload bay that provide supplemental reactants for the shuttle's electrical generation system, a regenerating system that removes carbon dioxide from the crew cabin atmosphere, an improved waste collection system, additional nitrogen tanks for the crew cabin atmosphere, and the creation of more habitable volume and equipment storage space in the crew cabin.

ADDITIONAL CRYOGENIC TANKS

Columbia has the internal connections for a 3,500-pound, 15-foot-diameter structural pallet that is installed in the rear of the orbiter's payload bay and holds four sets of hydrogen and oxygen tanks, associated control panels, and avionics equipment. The tanks, which supplement Columbia's five liquid hydrogen and liquid oxygen tank sets, store 368 pounds of liquid hydrogen at -418 degrees Fahrenheit and 3,125 pounds of liquid oxygen at -285 degrees Fahrenheit. Fully loaded, the pallet weighs approximately 7,000 pounds. Reactants from the EDO pallet are fed to Columbia's three electrical power fuel cells, which convert them into enough electrical energy to support the average four-person household for approximately six months (an average power level of approximately 19 kW for 16 days, with an additional two-day 12-kW contingency capability). In addition, approximately 3,500 pounds of pure drinking water is produced for crew consumption. For a 28-day mission, four additional tank sets would be required.



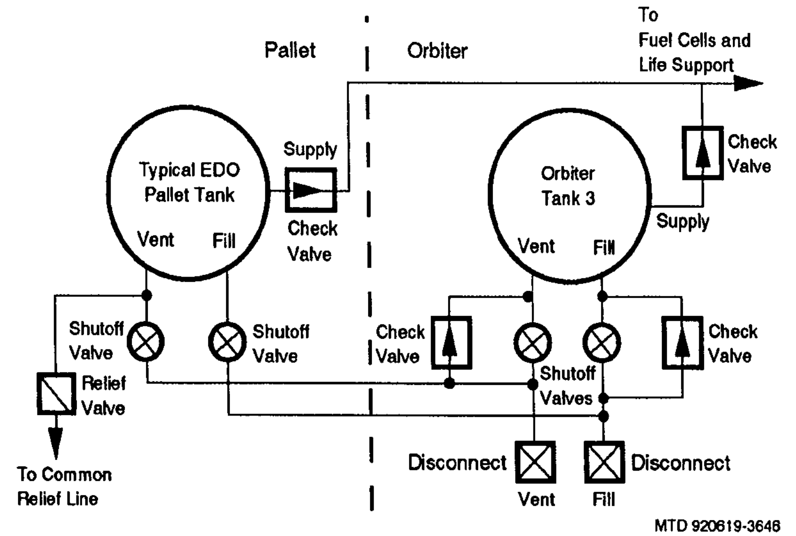
Extended-Duration Orbiter Cryogenic Pallet Structure

ADDITIONAL NITROGEN TANKS

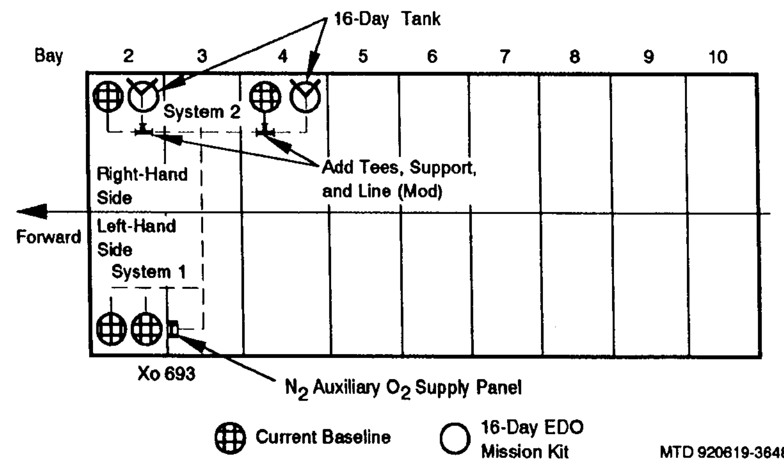
Additional nitrogen tanks have been installed near Columbia's original nitrogen tanks below the payload bay. The nitrogen is used to maintain the crew cabin atmosphere.

IMPROVED WASTE COLLECTION SYSTEM

Columbia has also been fitted to accommodate an improved waste collection system. The IWCS, which compacts human waste,

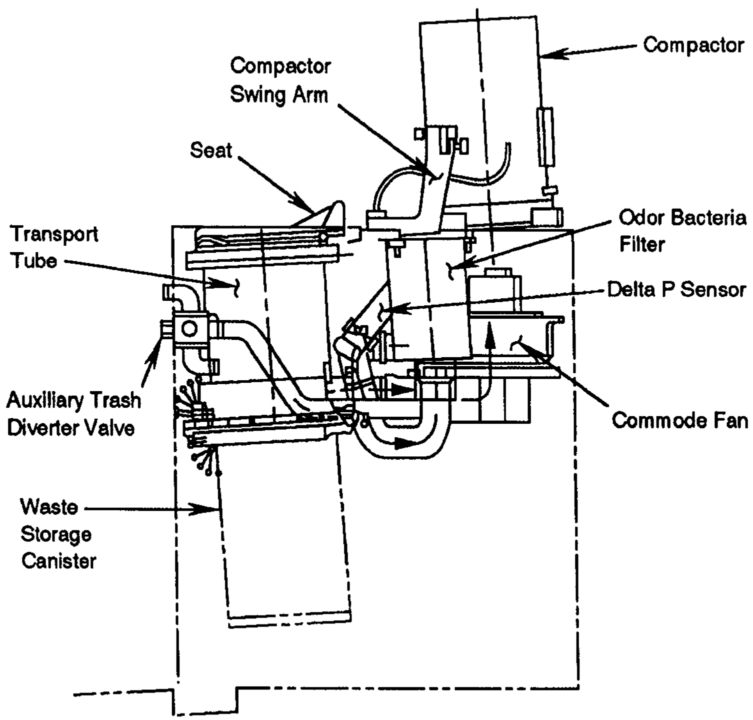


Typical EDO Pallet Tank Ties Into Orbiter Tank Set 3



EDO Nitrogen Supply System

has unlimited capacity and is more comfortable and sanitary. It also eliminates many of the mechanical problems experienced with the current toilet.

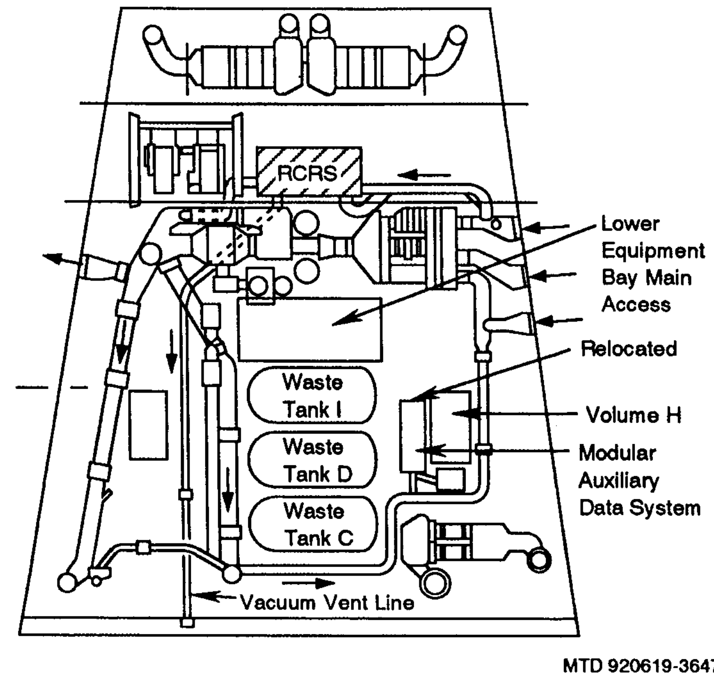


Improved Waste Collection System

REGENERABLE CARBON DIOXIDE REMOVAL SYSTEM

Columbia is outfitted with a regenerable carbon dioxide removal system (RCRS), which removes carbon dioxide and odors from the crew cabin atmosphere. The regenerative system eliminates the need to carry large amounts of lithium hydroxide (LiOH) canisters on long flights. Currently, the crew must change LiOH canisters daily as part of spacecraft housekeeping. On a typical shuttle mission, two or more canisters are used each day. A 16-day mission would require a prohibitive number of canisters.

The RCRS passes cabin air over one of the unit's two beds of solid amine every 15 minutes and exposes the other bed to space



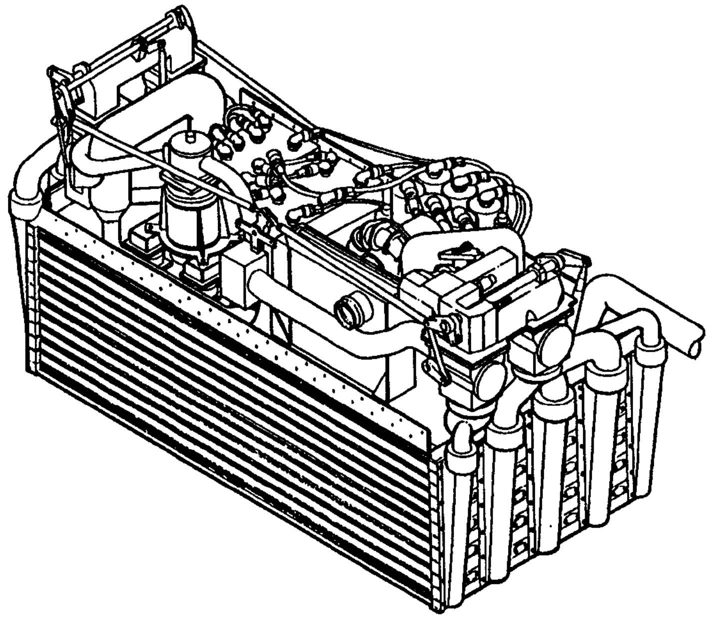
Regenerable Carbon Dioxide Removal System Location

through a series of valves. The absorption of carbon dioxide in the active bed generates heat, which warms the other bed and expels carbon dioxide into space. The RCRS also recovers some nitrogen for reuse. It is located under the middeck floor.

ADDITIONAL CABIN STOWAGE

Columbia's crew stowage volume has been expanded by adding an airlock stowage bay and removing the no-longer-needed lithium hydroxide canisters from the lower equipment bay. About 127 cubic feet of additional stowage space is needed for longer flights.

Major subcontractors to Rockwell on the EDO program include Hamilton Standard, South Windsor, Conn. (improved waste collection system, regenerable carbon dioxide removal system); Ball Aerospace Corporation, Boulder, Colo. (cryogenic pallet tanks);

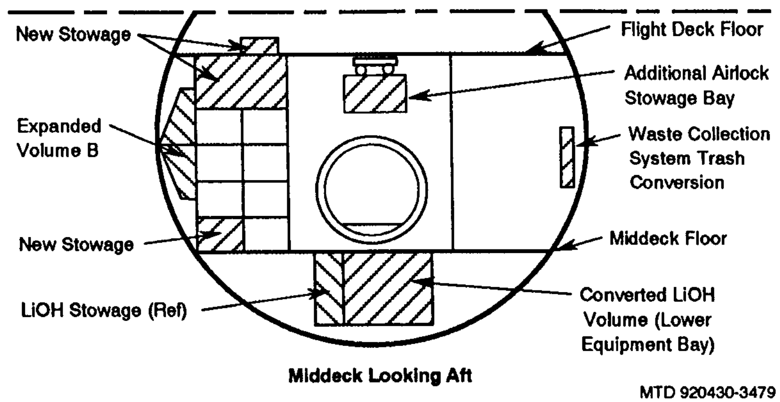


MTD 920618-3644

Regenerable Carbon Dioxide Removal System

Aerodyne Control Corporation, Long Island, N.Y. (cryogenic isolation valves); and Parker Hannifin, Irvine, Calif. (various valves).

Rockwell modified the shuttle orbiter Columbia for a 16-day EDO capability during a major modification period at Rockwell's Orbiter Assembly and Modification Facility in Palmdale, Calif., from August 1991 to February 1992.



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Expanded Crew Stowage

Endeavour was fitted with the internal plumbing and electrical provisions needed for EDO mission kits during its construction. It, along with Atlantis, is currently capable of accommodating EDO kits permitting missions of up to 28 days.

NASA will offer the use of the EDO mission kit as an optional service to all shuttle customers. Future near-term EDO flights include Tethered Satellite System/United States Microgravity Payload 3 (STS-75) in February 1996, Life and Microgravity Spacelab (LMS) 1 (STS-78) in June 1996; and SPARTAN 201 (STS-80) in November 1996.

In the future, NASA may authorize further expansions of on-orbit stay times.

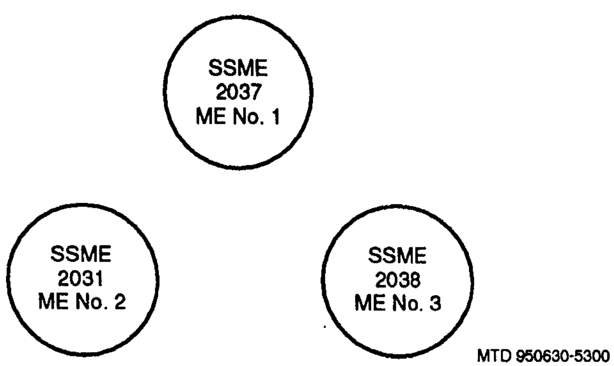
BLOCK 1 SPACE SHUTTLE MAIN ENGINE

STS-73 will be the second flight of an upgraded version of a space shuttle main engine (SSME), known as Block 1. Two Block 1 SSMEs will fly on STS-73. The other engine is the current SSME design (Phase II). The Block 1 engines are in the number one and number three positions. One Block 1 SSME flew on STS-70 and performed as expected.

The first flight on which three Block 1 engines are planned to be used is STS-77, currently targeted for May 1996.

The Block 1 configuration will greatly increase engine performance, reliability, and safety and reduce maintenance.

One enhancement is the new high-pressure liquid oxidizer turbopump built by Pratt & Whitney. The pump housing was produced by a unique casting process that eliminated all but six of the 300 welds in the current pump. This increases the safety margins and reliability of the main engines. The new turbopumps will not require a detailed inspection until they have flown 10 times. The high-pressure liquid oxygen pumps used in the current SSME must be removed after every flight for inspection.



Engine Configuration for STS-73

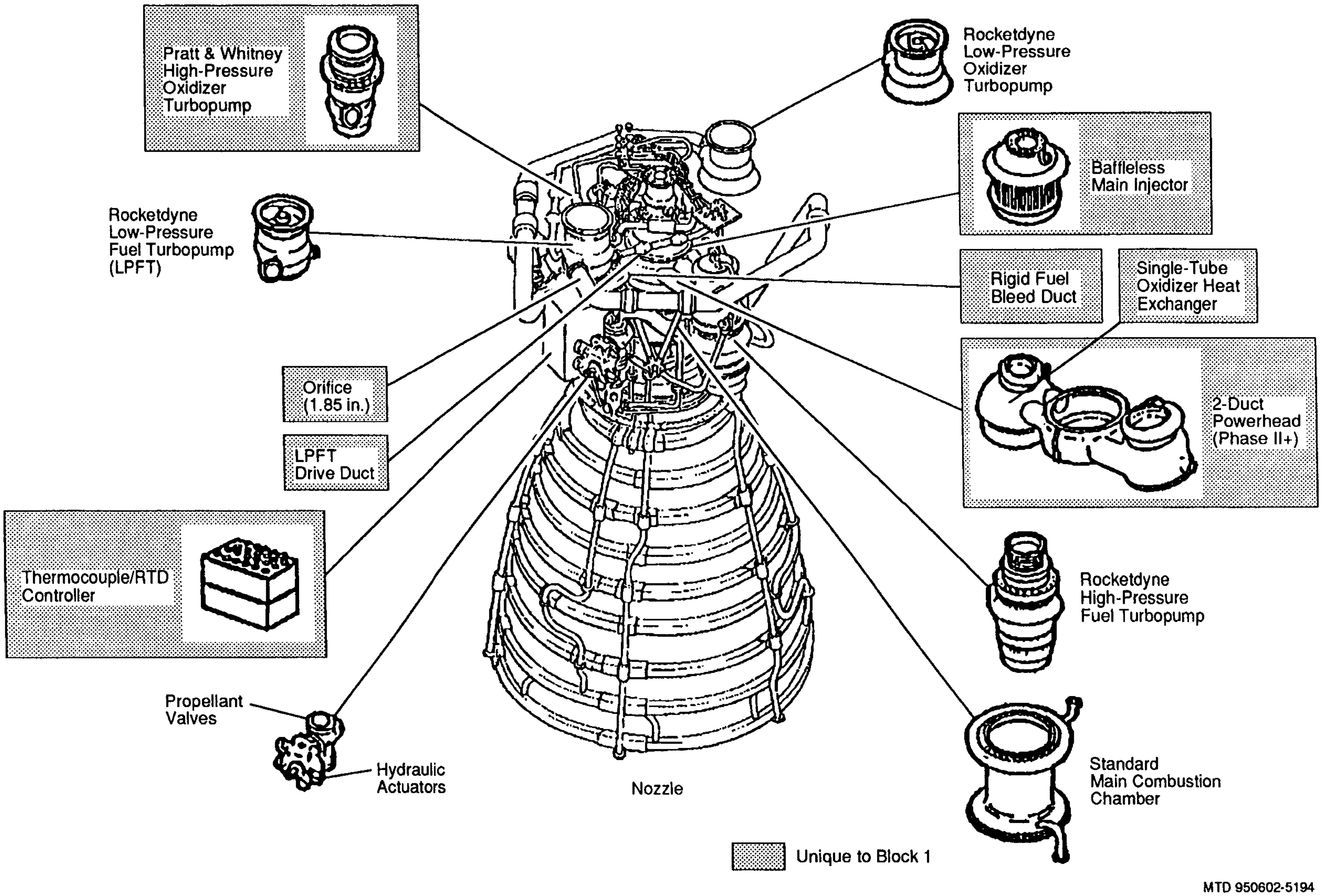
Flight certification of the turbopumps, which provide the oxidizer to the engine, was completed in March 1995. The new pumps underwent a test program equivalent to 40 space shuttle flights, a milestone in the final certification of the pumps for flight.

The improved pump design also incorporates new ball bearings of silicon nitride. The ceramic bearings are 30% harder and 40% lighter than steel and have an ultrasmooth finish, thus producing less friction during pump operation.

Another enhancement of the Block 1 engine is its two-duct powerhead. The powerhead contains the preburners that generate the gas to drive the turbopump turbines. It collects the hot gases of the turbines downstream and ducts them into the main injector. Three small fuel ducts were replaced with two larger ducts, which significantly improves fluid flows within the engine. Pressure and loads are decreased, turbulence is reduced, maintenance is eliminated, and inspections are minimized. The two-duct powerhead has fewer welds, which eliminates potential weak spots.

The powerhead also has a single-coil heat exchanger instead of the current two-coil design. The heat exchanger provides the pressure to the shuttle's external tank to feed propellants to the engines. The new configuration eliminates the seven weld joints inside the engine. The heat exchanger is constructed of a continuous piece of stainless steel alloy, which reduces wear on the tube and lessens the chance of damage. Maintenance and postflight inspections also are reduced.

The SSME project is managed by the Marshall Space Flight Center. Pratt & Whitney, West Palm Beach, Fla., developed and manufactured the new pump. Rockwell's Rocketdyne Division, Canoga Park, Calif., will integrate the pump into the main engine.



Block 1 SSME Components

Ascent wing structural capability evaluation (DTO 301D). The purpose of this DTO is to verify that the orbiter wing structure is at or near its design condition during lift-off and ascent with near-maximum-weight payloads. In the event that a design condition is reached, the structural instrumentation data will be used to verify that the vehicle is acceptable for reflight. It will determine flight loads and structural capability, identify any unacceptable dynamic effects, and verify that operational changes such as DOLILU II and/or modifications of the shuttle system do not invalidate orbiter structural certification. This is a data-collection-only test and requires no specific activity other than recording and returning specified data. DTO 301D is required for each flight of each vehicle; for Columbia only, body flap strain measurements are required on a minimum of six flights, including ferry flights. DTO 301D has previously been manifested on 60 flights.

Entry structural capability evaluation (DTO 307D). This DTO will collect structural load data for different payload weights and configurations to expand the data base of flight loads during entry, approach, and landing; verify the adequacy of the structure at or near design conditions; demonstrate structural system operational capability; determine flight loads; and verify the stress/temperature response of critical structural components. In the event that a design condition is reached, the structural instrumentation/data will be used to verify that the vehicle is acceptable for reflight. This data-collection-only test requires no specific activity other than recording and returning specified data. This DTO is required on each flight of each vehicle. For Columbia only, body flap strain measurements are required on a minimum of six flights, including ferry flights. DTO 307D has previously been manifested on 51 flights.

ET TPS performance, methods 1 and 3 (DTO 312). Photographs will be taken of the external tank and solid rocket boosters after separation to determine TPS charring patterns, identify regions of TPS material spallation, evaluate overall TPS performance, and identify TPS or other problems that may pose a debris hazard to the orbiter. For method 1, the 16mm and 35mm cameras are located in the orbiter's umbilical well; for method 3, the camera is located on the flight deck (hand-held Nikon camera). This DTO is required for each flight of each vehicle. This DTO has previously been manifested on 49 flights.

Orbiter/payload acceleration and acoustic environment data (DTO 319D). This DTO will obtain low-frequency (0 to 50 Hz) payload/orbiter interface data to develop computer techniques for predicting payload loads and responses. Acceleration and acoustic pressure data will be analyzed to verify the adequacy of shuttle structural dynamic loads analyses. Accelerometers and microphones are located in the orbiter crew module and the payload bay. This DTO is required on each flight of Columbia and Discovery. It has previously been manifested on 20 flights.

APU shutdown test, sequence B (shut down 2, then 1, then 3) (DTO 414). This DTO will explore the hypothesis that delays between shutting down individual auxiliary power units on ascent can lead to "backdriving" of the nonoperational hydraulic system's speed brake hydraulic motor. It will provide a data base of hydraulic system performance for sustaining engineering and maintenance of orbiter hardware. Reviews of mission data have shown that when an individual APU is shut down prematurely on ascent while the remaining APUs continue operating, extended hydraulic supply pressure could result (i.e., the hydraulic pressure of the shutdown system remains at an elevated level for a significant period of time). The explanation for this behavior is that the operational hydraulic systems are back-driving the speed brake hydraulic motor of the system that has been shut down. Performing this DTO during flight will produce the most representative data for this behavior. This DTO will be flown on multiple missions to create a representative data base. On STS-73, the APUs will be shut down in the following order: 2, 1, 3. The pilot will wait at least five seconds between each APU shutdown. This DTO requires 16 flights, with sequences A and B performed twice for each orbiter. It has previously been manifested on 14 flights.

Cabin air monitoring (DTO 623). The solid sorbent sampler will continuously sample the orbiter's atmosphere throughout the flight for possible impurities due to outgassing and particulate matter. The solid sorbent sampler is to be flown on all manned Spacelab flights. This DTO has previously been manifested on 19 flights.

Foot restraint evaluation (DTO 655). This DTO will evaluate a new conceptual design for foot restraints. Long periods of time in zero gravity are required to thoroughly assess and evaluate redesigned and improved attachment mechanisms for the foot loop restraint system used by crew members while performing tasks during space flight missions. This DTO is required on three Spacelab flights. It has been manifested on three previous flights.

Ku-band communications adapter demonstration (DTO 679). This DTO will demonstrate the capability of the Ku-band communications adapter (KCA) to provide high-speed bidirectional computer communications via the shuttle Ku-band system. This high-speed data transfer capability will improve the slower portable audio data modem transfer method that links a standard PGSC to the shuttle S-band system. The KCA will be able to support both shuttle operations (IFM procedures and daily mail traffic) and payload users. This DTO is required on three flights. It has been manifested on two previous flights.

Inertial vibration isolation system evaluation (DTO 682). This DTO will evaluate the effectiveness of the inertial vibration isolation system in reducing the magnitude of force transmitted to the orbiter as a result of exercising on the EDO cycle ergometer. It consists of hardware mounted with the cycle ergometer to help protect the microgravity environment during crew exercise. This isolation system has been designed based on the analysis of data from STS-65 and adds an inertial mass to counteract forces produced by exercise. Two flights are required. This is the second flight of DTO 682.

Crosswind landing performance (DTO 805). This DTO will continue to gather data for manually controlling landing with a 90-degree, 10- to 15-knot steady-state crosswind. This DTO can be performed regardless of landing site or vehicle mass properties. Following a crosswind landing, the drag chute will be deployed after nose gear touchdown when the vehicle is stable and tracking the centerline. This DTO has previously been manifested on 39 flights. It is being flown as a DTO of opportunity on STS-73.

Microgravity measuring device evaluation (DTO 913). This DTO will use an acceleration measuring system to evaluate the effectiveness of the inertial vibration isolation system. This DTO must be flown at least once with each exercise device/vibration isolation system configuration. It has been manifested on one previous mission.

Ground-to-air television demonstration (DTO 1121). The purpose of this DTO is to evaluate a prototype system and methodology for uplinking real-time, full-screen color television signals from MSFC and JSC to the orbiter. Video compression technology is now available in small-volume, low-power, low-cost hardware suitable for installation and use on the orbiter. From an operations perspective, this DTO will evaluate a variety of preplanned uplink TV scenarios under mission conditions and will also permit video-assisted support for actual mission situations. Although video uplink should improve mission results, this must be evaluated and proven under actual mission conditions before committing to a long-range architecture and permanent development costs. Demonstrating the feasibility and utility of uplink video is the first in a series of steps to improve the shuttle video capabilities that will eventually involve going to an all-digital system.

Significant operational benefits for in-flight maintenance, payload/science operations, medical, and extravehicular activity operations can be derived by sending color television with embedded audio from a control center to a manned orbiting spacecraft. For example, the time required to transmit information is reduced compared to existing operational communications methods, and significantly more information can be communicated in the same amount of time. Other benefits range from productivity enhancement (quality or quantity increase) to loss prevention or recovery. In addition, the "virtual presence" of ground equipment and personnel can clarify communications with the on-board crew. This hypothesis is especially applicable to extended-duration or contingency EVA missions where unforeseen problems are more likely to occur. Video transmission can take place over existing bandwidths without obstructing core voice communications (air-to-ground channels 1 and 2). Long-term implications for International Space Station operations (e.g., in-flight maintenance and on-board training) are significant.

A standard National Television Standards Committee (NTSC) TV signal will be digitized for uplink by a portable video encoder and sent on the Ku-band. The signal will be decoded and interfaced to orbiter/Spacelab closed-circuit TV and audio distribution systems via an on-board, locker-stowed video processor unit. The quality of video received on board will be essentially the same as that of a commercial VHS cassette recorder except that there will be some reduction in motion rendition (15 frames per second). The output of the on-board video decoder will be in standard NTSC format compatible with color TV monitoring and video taperecording by the orbiter/Spacelab TV systems.

Video source material may include the following: (1) test patterns (JSC and MSFC) with all uplink video recorded on board; (2) schematics, drawings (copy camera, computer image via NTSC converter); (3) prerecorded material; and (4) live transmission (one-way audio via GATV or one-way audio via audio; two-way conference downlink video via analog TV or two-way conference downlink video via digital means, if available; or two-way with remote H.320 site).

One crew member will connect and energize the GATV decoder unit and evaluate the uplink video system's performance and operational benefits indicated by the DTO scenarios and any ad hoc scenarios arising from actual mission execution. Video and audio routing will be controlled by in-situ systems. Data reception will be coordinated with the ground by using the operational voice channels (air-to-ground 1 or 2) or the audio stream embedded within the GATV uplink.

Immunological assessment of crew members (DSO 487). This DSO will examine the mechanisms of space-flight-induced alterations in the human immune function. As shuttle mission duration increases, the potential for the development of infectious illness in crew members during flight also increases. This investigation will use immune cells from the standard flight medicine blood draw. No on-orbit crew activities are associated with this DSO.

Characterization of microbial transfer among crew members during space flight (DSO 491). In order to minimize the spreading of infectious agents during space flight, a better understanding of microbial dissemination within the shuttle environment is needed. This DSO will serve three purposes: to adapt a method for epidemiological evaluation of microorganisms isolated from crew members and environmental sources; to assess the degree to which microbia are transferred among crew members, either directly or through the environment; and to assess the dissemination of crew microbia throughout the orbiter. The dissemination of normal crew microbia will be studied by tracking a specific target organism in samples collected from each crew member's nose and throat before and after flight. No in-flight crew activities are required.

Orthostatic function during entry, landing, and egress (DSO 603C).* This DSO documents the relationship between mission duration and changes in orthostatic function and skin temperature of crew members during the actual stresses of landing and egress from the seat and crew cabin. The heart rate and rhythm, blood pressure, cardiac output, and peripheral resistance of crew members will be monitored to develop and assess countermeasures designed to improve orthostatic tolerance upon return to Earth. This data will be used to determine whether precautions and countermeasures other than (or perhaps instead of) the operational saline countermeasure are needed to protect crew members if they have to leave the orbiter in an emergency. It will also be used to determine the effectiveness of proposed in-flight countermeasures. Crew members will don equipment before they put on the LES during deorbit preparations. Equipment consists of a blood pressure monitor, accelerometers, an impedance cardiograph, and transcranial Doppler hardware. The crew members wear the equipment and record verbal comments throughout entry.

Visual-vestibular integration as a function of adaptation, OI-3C and OI-1 (DSO 604).* The objective of this DSO is to investigate visual-vestibular and perceptual responses (changes in the function of vision and in the sense of balance) upon readaptation to gravity by crew members as a function of mission duration. The impact of these responses on the crew members' ability to conduct entry, landing, and egress procedures will also be investigated. The data will be used to develop training and/or countermeasures to ensure the safety and success of extended missions by promoting optimal neurosensory function needed for entry, landing, and possible emergency egress. No in-flight activities are required.

Postural equilibrium control during landing/egress (DSO 605).* This DSO will quantify the effects of in-flight neurosensory adaptations to zero g on postflight control of postural equilibrium. The subjects will perform a series of movement coordination tests and sensory organization tests just after landing. Sensors placed on one leg will record the subject's muscle activity during readaptation to gravity.

Air monitoring instrument evaluation and atmosphere characterization (microbial air sampler) (DSO 611).* This DSO is designed to evaluate and verify air monitoring equipment to ensure its proper function and operation during flight. Data collected on contaminant levels during missions of varying durations will be used to establish baseline levels and to evaluate potential risks to crew health and safety. Contaminants being detected include ther-

*EDO buildup—medical evaluation DSO

modegradation products, volatile organics, toxic compounds, airborne particulates, and airborne micro-organisms. The microbial air sampler configuration will be flown on STS-73. The MAS will evaluate the effect of the regenerable carbon dioxide removal system on air quality. Air samples from the middeck and flight deck will be collected on an early, mid, and late flight day.

In-flight use of Florinef to improve orthostatic intolerance after flight (DSO 621).* The purpose of this DSO is to evaluate the efficacy of Florinef, a blood plasma expander, on postflight orthostatic tolerance by measuring heart rate, blood pressure, stroke volume, and other cardiovascular responses to orthostatic stress. A cardiovascular profile will be determined before and after flight for crew members participating in this investigation. Crew members ingest a Florinef tablet and a potassium supplement tablet seven hours before landing and drink two quarts of fluid with meals during the last two days of the flight.

Pre- and postflight measurement of cardiorespiratory responses to submaximal exercise (DSO 624).* For this DSO, the crew members will wear heart watches during exercise and log exercise to help evaluate the changes in aerobic capacity before, during, and after flight. Submaximal exercise testing will correlate preflight and in-flight crew activity with postflight aerobic performance. These evaluations will help develop optimal exercise protocols to prevent decrements in nominal cardiorespiratory response.

Cardiovascular and cerebrovascular response to standing before and after space flight (DSO 626).* This DSO will characterize the integrated response of the arterial pressure control system to standing before and after space flight. This test includes the measurement of blood volume. There are no on-orbit crew activities associated with this DSO.

Educational activities (DSO 802). The purpose of this DSO is to use the attraction of space flight to capture the interest of students and motivate them toward careers in science, engineering, and mathematics. One objective is to produce interesting and motivational educational products, such as video lessons approximately 20 minutes long with scenes recorded both on orbit and on the ground. The on-orbit video will be approximately one third of the finished video product. This DSO will include videotaping of on-orbit educational activities performed by the flight crew as well as other educational activities that are deemed appropriate by the Educational Working Group and the flight crew. The other objective is to support the live TV downlink of educational activities performed by the flight crew. Typically, these activities will be limited to one or two 30-minute live downlinks.

During STS-73, students at four sites will discuss on-board microgravity experiments with the astronauts and compare them with similar ground-based experiments. The goal is to involve students in Shuttle investigations in an effort to generate excitement about physical science and chemistry.

The first live downlink with students is scheduled after flight day 12. Middle school students at the following sites will discuss mixing and crystal growth experiments with the Shuttle crew:

1. Museum of the Rockies, Bozeman, Mont.

2. Sierra Middle School, Las Cruces, N.M.

The second live downlink is scheduled for flight day 13. High school students from the following sites will discuss fluids and combustion experiments:

1. South High School, Worcester, Mass.

2. Louisville Science Center, Louisville, Ky.

Before the mission, NASA's education specialists visited the sites to work with students on their experiments.

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*EDO buildup—medical evaluation DSO

DSO 802 Student Questions

Settling and Mixing (Museum of the Rockies)	
What would happen if you shake the bag in space?	Garett
If you put the bag in a vacuum and shook it up and stopped, would the marshmallows and M&Ms separate or not?	Kelly Morgan
Why did you choose 50 M&Ms and 50 marshmallows?	Heather McPhie
What are the best methods for mixing in space?	Amber Vowell
Instead of shaking the bag, what would happen if you started spinning the bag?	Chris Hollewijn
What would happen if you changed the amount of marshmallows or M&Ms in the bag? Would they still separate?	Claire Weinrib, Marc Arensmeyer, Spencer Ward, Marshall Swearingen
If you had marshmallows and M&Ms that were the same weight, would the marshmallows go to the bottom?	Shawnee Skunkcap
What would happen if you put water in the bag with the marshmallows and M&Ms?	Sonya Scarff
Will Epsom salt and water make crystals in space? I made crystals on Earth this way in a crystal experiment.	Ryan Brutger
If you wanted to make bread or a cake, how would you get the ingredients and mix them together?	Maureen Bald, Erin Heare Irving
Try to mix salt and pepper and then separate them in space.	Luke Brody
What would happen if you mix vinegar and baking soda?	Meghan Bakwin
When you mix vinegar and baking soda it fizzes. Would the fizz float in the space shuttle?	Nikki Jo Morrison
Would a toxic gas form if you mix ammonia and bleach in space?	Tyler Bangs
Do blood and water mix or separate in space?	Mac Cole
What would happen if you tried to crush fresh herbs with a mortar and pestle? (On Earth they get gushy and wet.)	Brenna Boyd
Heat Packs (Sierra Middle School)	
When you try the heat packs in orbit, do the crystals go all around or just start in one place?	Toni Quintana
Why does the heat pack become hard?	Yuri Loyd
What kind of substance is in the heat pack?	Andrew Ganderson
Do the heat packs heat the same way as ours do?	Andrea Casanova
In your experiments, what geometric shape do most crystals form, and do they have symmetrical patterns?	Kimberlee Kerr, Tammy Ashieh
Do any types of crystals grow at high temperatures? If so, does it affect their formation?	Patrick Grooms, Fileman L. Aragon
Do you think the experiments you're doing now will affect the world in the future, and if so, how?	Courtney Harris
Do crystals form faster or slower in space?	Ryan Reynolds, Chris Hotovec
Do you think microgravity changes the structure and growth of crystals?	Stephanie Valercia, Nathan O. Acosta
Can the heat packs be used again?	Willie Hamilton Jr.
How much weight do you lose and does the food taste good?	Johnny Carabejal
How do astronauts take showers and is it true when you eat you have your body strapped down?	Maribel

DSO 802 Student Questions (Cont)

What do you feel like when you are taking off into space?	Stephanie Benavidaz
How much weight do you gain or lose and how long does it take?	Stephanie Rhinehart
How does it feel when you are in space orbiting Earth?	Marlena Romera
How long will it take the balloon to pop in freefall? Ours popped immediately.	Adam Joseph Brown
How tall do you grow? When does gravity stop and when does it start?	Joe Raymond Herrera
Contact Angle (South High School)	
What is the purpose of the contact angle experiment?	Hosai Nargis Hasham
Why does the water rise in the contact angle experiment and does this happen in space?	Eric Quinn, Stephen Sacovitch, Kuitim Beqiri, Ali Aham
How does microgravity affect the surface tension and contact angle of water?	Sarah Wally, Prema Srinivasan
How do you keep liquids confined and what factors need to be adjusted for the experiment to work in space?	Erin Goldstein, Billy Caraballo
How do the surface tension and contact angle react in space when soap is added, and why?	Steven Belec, Joshua Norberg, Nicholas Paquette, Reggie Hill, Tanisha Webster, Beth Quitadamo
In the contact angle experiment, what would happen if the slides were made of different materials and sizes, and would other liquids change the results?	Katie Elworthy, Igor Gurevich, Todd Dhavale
In the surface tension experiment, why did the pepper pile up on the bottom instead of spreading at the bottom?	Rosalyn Figueroa
Can the mass of an object break its surface tension?	Hong Trang
Is there a difference in velocity of the spreading pepper in space?	Juola Hejoni
If for every action there is a reaction, would a ball of water disperse if you put pepper into it?	Kathy Morales
FSDC (Louisville Science Center)	
Can fiber-supported drop combustion be used in the shuttle's engines to make maneuvering simpler, and are there any real-life applications?	Pubah Chakravarty, Brian
Do different flammable liquids form different shapes when they burn, and are the materials you are using different from ours?	Jill Fackler, Cassie Corbett, Wayne Erickson
Did your flames move around or vary in size and shape due to air currents, and do the flames produce any visible products, such as smoke?	Bert Griffin, Jessica Hutte, Ray Marquette, Ann Jonczy, Doug Lucas
What percentage of times did you get a good flame, and how long, on average, did your flames last?	Erin Creamer
Do you think anything, besides the difference in gravity, could cause the flames to differ?	Geralyn Waters
The experiment we conducted contained a wire filament that broke in two pieces when heated. If wire was used in space, would it break apart or just expand?	Alison Smith
Do you have to replace the filament after each time you burn the fluid?	Jared Schuetter
Does the type of filament have an effect on the results of the experiment?	Kate Gayhart
Is the flame isolated to the coil of the filament or does it move away from the filament so just the fluid is burning?	Mandy Dierking
Would the amount of electricity used change the rate of the combustion and does microgravity have any effect on this?	Tom Fulder

A preflight education video of the STS-73 crew conducting the ground-based experiments and an accompanying Microgravity Teacher's Guide with Activities for Physical Science are available through the NASA Teacher Resource Center network.

Documentary television (DSO 901). The purpose of DSO 901 is to provide live television transmission or VTR dumps of the following crew activities and spacecraft functions: payload bay views, crew activities, in-flight crew press conference, orbiter operations, payload deployment/retrieval and operations, Earth views, rendezvous and proximity operations, and unscheduled TV activities. Telecasts are planned for communication periods with seven or more minutes of uninterrupted viewing time. The broadcast uses operational air-to-ground and/or operational intercom audio. VTR recording may be used when live television is not possible.

Documentary motion picture photography (DSO 902). This DSO requires documentary and public affairs motion picture photography of significant activities that best depict the basic capabilities of the space shuttle and key flight objectives for a historical record and media release. This DSO includes photography of launch, payload bay activities, flight deck activities, middeck activities, and any unscheduled motion picture photography. This photography provides a historical record of the flight as well as material for release to the news media, independent publishers, and film producers.

Documentary still photography (DSO 903). This DSO requires still photography of crew activities, orbiter operations, payload deployment/retrieval and operations, Earth views, unscheduled items of interest, and mission-related scenes of general public and historical interest. 70mm format is used for exterior photography and a 35mm format is used for interior photography.

Assessment of human factors (configuration C) (DSO 904). This DSO will evaluate factors affecting human productivity and the ability to interface with machines, the environment, and other humans during space flight. Data from the digital sound level meter recording devices in the middeck, flight deck, and module will be analyzed in relation to crew comments and crew performance. Human-machine interactions during routine Spacelab operations, such as stowage, the use of hand and foot restraints, wire and cable interferences, and spacelab tunnel translation, will be evaluated. Sound and vibration data, crew comments, and crew performance will also be analyzed. Differences between preflight and in-flight performance will be examined.

PRELAUNCH COUNTDOWN TIME LINE

T - (MINUS) HR:MIN:SEC	EVENT
06:00:00	Verification of the launch commit criteria is complete at this time. The liquid oxygen and liquid hydrogen systems chill-down commences in order to condition the ground line and valves as well as the external tank (ET) for cryo loading. Orbiter fuel cell power plant activation is performed.
05:50:00	The space shuttle main engine (SSME) liquid hydrogen chill-down sequence is initiated by the launch processing system (LPS). The liquid hydrogen recirculation valves are opened and start the liquid hydrogen recirculation pumps. As part of the chill-down sequence, the liquid hydrogen prevalves are closed and remain closed until T minus 9.5 seconds.
05:30:00	Liquid oxygen chill-down is complete. The liquid oxygen loading begins. The liquid oxygen loading starts with a "slow fill" in order to acclimate the ET. Slow fill continues until the tank is 2-percent full.
05:15:00	The liquid oxygen and liquid hydrogen slow fill is complete and the fast fill begins. The liquid oxygen and liquid hydrogen fast fill will continue until that tank is 98-percent full.
05:00:00	The calibration of the inertial measurement units (IMUs) starts. The three IMUs are used by the orbiter navigation systems to determine the position of the orbiter in flight.
04:30:00	The orbiter fuel cell power plant activation is complete.
04:00:00	The Merritt Island (MILA) antenna, which transmits and receives communications, telemetry and ranging information, alignment verification begins.
03:45:00	The liquid hydrogen fast fill to 98 percent is complete, and a slow topping-off process is begun and stabilized to 100 percent.
03:30:00	The liquid oxygen fast fill is complete to 98 percent.
03:20:00	The main propulsion system (MPS) helium tanks begin filling from 2,000 psi to their full pressure of 4,500 psi.
03:15:00	Liquid hydrogen stable replenishment begins and continues until just minutes prior to T minus zero.
03:10:00	Liquid oxygen stable replenishment begins and continues until just minutes prior to T minus zero.
03:00:00	The MILA antenna alignment is completed.

T - (MINUS) HR:MIN:SEC	EVENT
03:00:00	The orbiter closeout crew goes to the launch pad and prepares the orbiter crew compartment for flight crew ingress.
03:00:00 <u>Holding</u>	Begin 2-hour planned hold. An inspection team examines the ET for ice or frost formation on the launch pad during this hold.
03:00:00 <u>Counting</u>	Two-hour planned hold ends.
02:55:00	Flight crew departs Operations and Checkout (O&C) Building for launch pad.
02:25:00	Flight crew orbiter and seat ingress occurs.
02:10:00	Postingress software reconfiguration occurs.
02:00:00	Checking of the launch commit criteria starts at this time.
02:00:00	The ground launch sequencer (GLS) software is initialized.
01:50:00	The solid rocket boosters' (SRBs') hydraulic pumping units' gas generator heaters are turned on and the SRBs' aft skirt gaseous nitrogen purge starts.
01:50:00	The SRB rate gyro assemblies (RGAs) are turned on. The RGAs are used by the orbiter's navigation system to determine rates of motion of the SRBs during first-stage flight.
01:35:00	The orbiter accelerometer assemblies (AAs) are powered up.
01:35:00	The orbiter reaction control system (RCS) control drivers are powered up.
01:35:00	The flight crew starts the communications checks.
01:25:00	The SRB RGA torque test begins.
01:20:00	Orbiter side hatch is closed.
01:10:00	Orbiter side hatch seal and cabin leak checks are performed.
01:01:00	IMU preflight align begins. Flight crew functions from this point on will be initiated by a call from the orbiter test conductor (OTC) to proceed. The flight crew will report back to the OTC after completion.
01:00:00	The orbiter RGAs and AAs are tested.
00:50:00	The flight crew starts the orbiter hydraulic auxiliary power units' (APUs') water boilers preactivation.
00:45:00	Cabin vent redundancy check is performed.
00:45:00	The GLS mainline activation is performed.
00:40:00	The eastern test range (ETR) shuttle range safety system (SRSS) terminal count closed-loop test is accomplished.

T - (MINUS) HR:MIN:SEC	EVENT
00:40:00	Cabin leak check is completed.
00:32:00	The backup flight control system (BFS) computer is configured.
00:30:00	The gaseous nitrogen system for the orbital maneuvering system (OMS) engines is pressurized for launch. Crew compartment vent valves are opened.
00:26:00	The ground pyro initiator controllers (PICs) are powered up. They are used to fire the SRB hold-down posts, liquid oxygen and liquid hydrogen tail service mast (TSM), and ET vent arm system pyros at lift-off and the SSME hydrogen gas burn system prior to SSME ignition.
00:25:00	Simultaneous air-to-ground voice communications are checked. Weather aircraft are launched.
00:22:00	The primary avionics software system (PASS) is transferred to the BFS computer in order for both systems to have the same data. In case of a PASS computer system failure, the BFS computer will take over control of the shuttle vehicle during flight.
00:21:00	The crew compartment cabin vent valves are closed.
00:20:00	A 10-minute planned hold starts.
<u>Hold 10 Minutes</u>	All computer programs in the firing room are verified to ensure that the proper programs are available for the final countdown. The test team is briefed on the recycle options in case of an unplanned hold.

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	The landing convoy status is again verified and the landing sites are verified ready for launch.
	The IMU preflight alignment is verified complete.
	Preparations are made to transition the orbiter on-board computers to Major Mode (MM)-101 upon coming out of the hold. This configures the computer memory to a terminal countdown configuration.
00:20:00	The 10-minute hold ends.
<u>Counting</u>	Transition to MM-101. The PASS on-board computers are dumped and compared to verify the proper on-board computer configuration for launch.
00:19:00	The flight crew configures the backup computer to MM-101 and the test team verifies the BFS computer is tracking the PASS computer systems. The flight crew members configure their instruments for launch.
00:18:00	The Mission Control Center-Houston (MCC-H) now loads the on-board computers with the proper guidance parameters based on the prestated lift-off time.
00:16:00	The MPS helium system is reconfigured by the flight crew for launch.
00:15:00	The OMS/RCS crossfeed valves are configured for launch.

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	All test support team members verify they are "go for launch."
00:12:00	Emergency aircraft and personnel are verified on station.
00:10:00	All orbiter aerosurfaces and actuators are verified to be in the proper configuration for hydraulic pressure application. The NASA test director gets a "go for launch" verification from the launch team.
00:09:00	A planned 10-minute hold starts.
<u>Hold 10 Minutes</u>	NASA and contractor project managers will be formally polled by the deputy director of NASA, Space Shuttle Operations, on the Space Shuttle Program Office communications loop during the T-minus-9-minute hold. A positive "go for launch" statement will be required from each NASA and contractor project element prior to resuming the launch countdown. The loop will be recorded and maintained in the launch decision records.
	All test support team members verify that they are "go for launch."
	Final GLS configuration is complete.
00:09:00 <u>Counting</u>	The GLS auto sequence starts and the terminal countdown begins.

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	From this point, the GLSs in the integration and backup consoles are the primary control until T-0 in conjunction with the on-board orbiter PASS redundant-set computers.
00:09:00	Operations recorders are on. MCC-H, Johnson Space Center, sends a command to turn these recorders on. They record shuttle system performance during ascent and are dumped to the ground once orbit is achieved.
00:08:00	Payload and stored prelaunch commands proceed.
00:07:30	The orbiter access arm (OAA) connecting the access tower and the orbiter side hatch is retracted. If an emergency arises requiring flight crew activation, the arm can be extended either manually or by GLS computer control in approximately 30 seconds or less.
00:06:00	APU prestart occurs.
00:05:00	Orbiter APUs start. The orbiter APUs provide pressure to the three orbiter hydraulic systems. These systems are used to move the SSME engine nozzles and aerosurfaces.
00:05:00	ET/SRB range safety system (RSS) is armed. At this point, the firing circuit for SRB ignition and destruct devices is mechanically enabled by a

T - (MINUS) HR:MIN:SEC	EVENT
	motor-driven switch called a safe and arm device (S&A).
00:04:30	As a preparation for engine start, the SSME main fuel valve heaters are turned off.
00:04:00	The final helium purge sequence, purge sequence 4, on the SSMEs is started in preparation for engine start.
00:03:55	At this point, all of the elevons, body flap, speed brake, and rudder are moved through a preprogrammed pattern. This is to ensure that they will be ready for use in flight.
00:03:30	Transfer to internal power is done. Up to this point, power to the space vehicle has been shared between ground power supplies and the on-board fuel cells. The ground power is disconnected and the vehicle goes on internal power at this time. It will remain on internal power through the rest of the mission.
00:03:25	The SSMEs' nozzles are moved (gimbaled) through a preprogrammed pattern to ensure that they will be ready for ascent flight control. At completion of the gimbal profile, the SSMEs' nozzles are in the start position.
00:02:55	ET liquid oxygen prepressurization is started. At this point, the liquid oxygen tank vent valve is closed and the ET liquid oxygen tank is pressurized to its flight pressure of 21 psi.

T - (MINUS) HR:MIN:SEC	EVENT
00:02:50	The gaseous oxygen arm is retracted. The cap that fits over the ET nose cone to prevent ice buildup on the oxygen vents is raised off the nose cone and retracted.
00:02:35	Up until this time, the fuel cell oxygen and hydrogen supplies have been adding to the on-board tanks so that a full load at lift-off is assured. This filling operation is terminated at this time.
00:02:30	The caution/warning memory is cleared.
00:01:57	Since the ET liquid hydrogen tank was filled, some of the liquid hydrogen has turned into gas. In order to keep pressure in the ET liquid hydrogen tank low, this gas was vented off and piped out to a flare stack and burned. In order to maintain flight level, liquid hydrogen was continuously added to the tank to replace the vented hydrogen. This operation terminates, the liquid hydrogen tank vent valve is closed, and the tank is brought up to a flight pressure of 44 psia at this time.
00:01:15	The sound suppression system will dump water onto the mobile launcher platform (MLP) at ignition in order to dampen vibration and noise in the space shuttle. The firing system for this dump, the sound suppression water power bus, is armed at this time.
00:01:00	The SRB joint heaters are deactivated.
00:00:55	The SRB MDM critical commands are verified.

T - (MINUS) HR:MIN:SEC	EVENT
00:00:47	The liquid oxygen and liquid hydrogen outboard fill and drain valves are closed.
00:00:40	The external tank bipod heaters are turned off.
00:00:38	The on-board computers position the orbiter vent doors to allow payload bay venting upon lift-off and ascent in the payload bay at SSME ignition.
	The SRB forward MDM is locked out.
00:00:37	The gaseous oxygen ET arm retract is confirmed.
00:00:31	The GLS sends "go for redundant set launch sequence start." At this point, the four PASS computers take over main control of the terminal count. Only one further command is needed from the ground, "go for main engine start," at approximately T minus 9.7 seconds. The GLS in the integration console in the launch control center still continues to monitor several hundred launch commit criteria and can issue a cutoff if a discrepancy is observed. The GLS also sequences ground equipment and sends selected vehicle commands in the last 31 seconds.
00:00:28	Two hydraulic power units in each SRB are started by the GLS. These provide hydraulic power for SRB nozzle gimbaling for ascent first-stage flight control.
	The orbiter vent door sequence starts.

T - (MINUS) HR:MIN:SEC	EVENT
00:00:21	The SRB gimbal profile is complete. As soon as SRB hydraulic power is applied, the SRB engine nozzles are commanded through a preprogrammed pattern to assure that they will be ready for ascent flight control during first stage.
00:00:21	The liquid hydrogen high-point bleed valve is closed.
	The SRB gimbal test begins.
00:00:18	The on-board computers arm the explosive devices, the pyrotechnic initiator controllers, that will separate the T-0 umbilicals, the SRB hold-down posts, and SRB ignition, which is the final electrical connection between the ground and the shuttle vehicle.
00:00:16	The sound suppression system water is activated.
00:00:15	If the SRB pyro initiator controller (PIC) voltage in the redundant-set launch sequencer (RSLS) is not within limits in 3 seconds, SSME start commands are not issued and the on-board computers proceed to a countdown hold.
00:00:13	The aft SRB MDM units are locked out. This is to protect against electrical interference during flight. The electronic lock requires an unlock command before it will accept any other command.
	SRB SRSS inhibits are removed. The SRB destruct system is now live.

T - (MINUS) HR:MIN:SEC	EVENT
00:00:12	The MPS helium fill is terminated. The MPS helium system flows to the pneumatic control system at each SSME inlet to control various essential functions.
00:00:10	LPS issues a "go" for SSME start. This is the last required ground command. The ground computers inform the orbiter on-board computers that they have a "go" for SSME start. The GLS retains hold capability until just prior to SRB ignition.
00:00:09.7	Liquid hydrogen recirculation pumps are turned off. The recirculation pumps provide for flow of fuel through the SSMEs during the terminal count. These are supplied by ground power and are powered in preparation for SSME start.
00:00:09.7	In preparation for SSME ignition, flares are ignited under the SSMEs. This burns away any free gaseous hydrogen that may have collected under the SSMEs during prestart operations. The orbiter goes on internal cooling at this time; the ground coolant units remain powered on until lift-off as a contingency for an aborted launch. The orbiter will redistribute heat within the orbiter until approximately 125 seconds after lift-off, when the orbiter flash evaporators will be turned on.
00:00:09.5	The SSME engine chill-down sequence is complete and the on-board computers command the three MPS liquid hydrogen prevalves to open. (The MPS's three liquid oxygen prevalves were opened during ET tank loading to permit engine chill-down.) These valves allow liquid hydrogen and oxygen flow to the SSME turbopumps.
00:00:09.5	Command decoders are powered off. The command decoders are units that allow ground control of some on-board components. These units are not needed during flight.
00:00:06.6	The main fuel and oxidizer valves in each engine are commanded open by the on-board computers, permitting fuel and oxidizer flow into each SSME for SSME start. All three SSMEs are started at 120-millisecond intervals (SSME 3, 2, then 1) and throttle up to 100-percent thrust levels in 3 seconds under control of the SSME controller on each SSME.
00:00:04.6	All three SSMEs are verified to be at 100-percent thrust and the SSMEs are gimbaled to the lift-off position. If one or more of the three SSMEs does not reach 100-percent thrust at this time, all SSMEs are shut down, the SRBs are not ignited, and an RSLS pad abort occurs. The GLS RSLS will perform shuttle and ground systems safing. Vehicle bending loads caused by SSME thrust buildup are allowed to initialize before SRB ignition. The vehicle moves towards ET including ET approximately 25.5 inches.

T - (MINUS) HR:MIN:SEC	EVENT
00:00:00	The two SRBs are ignited under command of the four on-board PASS computers, the four hold-down explosive bolts on each SRB are initiated (each bolt is 28 inches long and 3.5 inches in diameter), and the two T-0 umbilicals on each side of the spacecraft are retracted. The on-board timers are started and the ground launch sequence is terminated. All three

T - (MINUS) HR:MIN:SEC	EVENT
	SSMEs are at 104-percent thrust. Boost guidance in attitude hold.
00:00	Lift-off.

STS-73 MISSION HIGHLIGHTS TIME LINE

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
	DAY ZERO
0/00:00:07	Tower is cleared (SRBs above lightning-rod tower).
0/00:00:10	180-degree positive roll maneuver (right-clockwise) is started. Pitch profile is heads down, wings level.
0/00:00:19	Roll maneuver ends.
0/00:00:27	All three SSMEs throttle down from 104 to 67 percent for maximum aerodynamic load (max q).
0/00:00:59	All three SSMEs throttle to 104 percent.

Editor's Notes: This time line lists selected highlights only. For full detail, please refer to the NASA Mission Operations Directorate STS-73 Flight Plan, Ascent Checklist, Post Insertion Checklist, Deorbit Prep Checklist, and Entry Checklist.

On every shuttle mission, some day-to-day replanning takes place to adjust crew and event time lines according to unforeseen developments or simply to optimize the use of time in orbit. Each day's replanning effort will produce an execute plan defining the approach for the next day's activities in space and on the ground.

All orbiter maneuvers are recalculated in real time and the burn values are frequently updated during the mission. Also, some burns may not be needed and could be deleted in real time.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/00:01:05	Max q occurs.
0/00:02:05	SRBs separate.
	When chamber pressure (Pc) of the SRBs is less than 50 psi, automatic separation occurs with manual flight crew backup switch to the automatic function (does not bypass automatic circuitry). SRBs descend to approximately 15,400 feet, when the nose cap is jettisoned and drogue chute is deployed for initial deceleration.
	At approximately 6,600 feet, drogue chute is released and three main parachutes on each SRB provide final deceleration prior to splashdown in Atlantic Ocean, where the SRBs are recovered for reuse on another mission. Flight control system switches from SRB to orbiter RGAs.
0/00:03:59	Negative return. The vehicle is no longer capable of return-to-launch site abort at Kennedy Space Center runway.
0/00:06:58	Single engine press to main engine cutoff (MECO).
0/00:08:24	All three SSMEs throttle down to 67 percent for MECO.
0/00:08:31	MECO occurs at approximate velocity 25,861 feet per second, 42 by 146 nautical miles (48 by 168 statute miles).

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/00:08:36	Zero thrust.
0/00:08:50	ET separation is automatic with flight crew manual backup switch to the automatic function (does not bypass automatic circuitry).
	The orbiter forward and aft RCSs, which provide attitude hold and negative Z translation of 11 fps to the orbiter for ET separation, are first used.
	Orbiter/ET liquid oxygen/liquid hydrogen umbilicals are retracted.
	Negative Z translation is complete.
	In conjunction with this thrusting period, approximately 1,700 pounds of liquid hydrogen and 3,700 pounds of liquid oxygen are trapped in the MPS ducts and SSMEs, which results in an approximate 7-inch center-of-gravity shift in the orbiter. The trapped propellants would sporadically vent in orbit, affecting guidance and creating contaminants for the payloads. During entry, liquid hydrogen could combine with atmospheric oxygen to form a potentially explosive mixture. As a result, the liquid oxygen is dumped out through the SSME combustion chamber nozzles, and the liquid hydrogen is dumped out through the right-hand T-minus-zero umbilical overboard fill and drain valves.
	MPS dump terminates.
	APUs shut down.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
	MPS vacuum inerting occurs. — Remaining residual propellants are vented to space vacuum, inerting the MPS. — Orbiter/ET umbilical doors close (one door for liquid hydrogen and one door for liquid oxygen) at bottom of aft fuselage, sealing the aft fuselage for entry heat loads. — MPS vacuum inerting terminates.
0/00:42	OMS-2 thrusting maneuver is performed, approximately 2 minutes in duration, at 186 fps, 147 by 153 nautical miles.
0/00:51	Commander closes all current breakers, panel L4.
0/00:53	Mission specialist (MS), payload specialist seat egress.
0/00:54	Commander and pilot configure GPCs for OPS-2.
0/00:57	MS configures preliminary middeck.
0/00:59	MS configures aft flight station.
0/01:02	MS unstows, sets up, and activates PGSC.
0/01:04	MS configures for payload bay door operations.
0/01:05	Pilot activates payload bus (panel R1).
0/01:08	Commander and pilot don and configure communications.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/01:10	Pilot maneuvers vehicle to payload bay door opening attitude, biased negative Z local vertical, negative Y velocity vector attitude.
0/01:17	Commander activates radiators.
0/01:28	MS opens payload bay doors.
0/01:30	Commander configures payload communications.
0/01:35	Mission Control Center (MCC), Houston (H), informs crew to "go for orbit operations."
0/01:37	Commander and pilot seat egress.
0/01:38	Commander and pilot clothing configuration.
0/01:39	MS/PS clothing configuration.
0/01:52	Commander begins post-payload bay door operations and radiator configuration.
0/01:53	MS/PS remove and stow seats.
0/01:54	Commander activates star tracker and opens door.
0/01:56	MS configures and activates WCS.
0/01:57	MS activates switch configuration/galley.
0/01:58	MS stows escape pole.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/02:02	Pilot activates auxiliary power unit steam vent heater, panel R2, boiler controller/heater, 3 to A, power, 3 to ON.
0/02:05	Commander configures vernier controls.
0/02/09	MCC informs crew to go for Spacelab activation.
0/02:10	Pilot, MS1 begin Spacelab activation.
0/02:10	Blue team begins presleep activities.
0/02:11	Ku-band antenna deployment.
0/02:13	Commander, pilot configure controls for on-orbit.
0/02:18	Pilot enables hydraulic thermal conditioning.
0/02:21	Ku-band activation.
0/02:22	EDO pallet activation.
0/02:26	MS resets caution/warning (C/W).
0/02:28	Pilot plots fuel cell performance.
0/02:35	-X RCS trim burn.
0/03:15	Spacelab ingress.
0/03:30	Spacelab module preparation.
0/03:30	Blue team begins seven-hour sleep period.
0/03:55	HUD calibration.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/04:40	Priority Group B power down.
0/04:40	Payload activation.

(Note: Red team Flight Day 1 USML-2 activities include CGBA, CGF, HI-PAC, SAMS, 3-DMA, APCF, CPCG)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/06:10	Shuttle emergency eyewash.
0/06:35	DTO 679.
0/08:45	Red team begins presleep activities.
0/10:30	Blue team wakeup.

(Note: Blue team Flight Day 2 USML-2 activities include SPCG, CGF, ASC, 3-DMA, CPCG, CGBA, GBX, STDCE, DCAM, APCF, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/10:45	Red team handover to blue team.
0/11:00	Red team begins sleep period.
0/13:55	Ergometer setup.
0/14:25	DTO 682.
0/14:40	DTO 913.
0/17:40	ESC operations.
0/19:00	Red team wakeup.

(Note: Red team Flight Day 2 USML-2 activities include SAMS, DPM, GFFC, GBX, ASC, CGBA, ZCG, 3-DMA, APCF, DCAM, CPCG, SPCG, CGF)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
0/19:30	DSO 904.
0/20:45	DTO 1121.
0/21:05	GATV operations.
0/21:30	DSO 624.
0/21:45	Blue team handover to red team.
0/22:30	Blue team begins presleep activities.
0/23:15	DSO 604.

MET DAY ONE

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
1/00:30	Blue team begins sleep period.
1/01:40	DSO 624.
1/04:00	DSO 604.
1/08:30	Blue team wakeup.

(Note: Blue team Flight Day 3 USML-2 activities include GFFC, ZCG, ASC, STDCE, GBX, CPCG, SPCG, 3-DMA, APCF, DCAM, SAMS, CGBA)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
1/09:05	PAO event (radio only—crew members determined real time).
1/09:45	Red team begins presleep activities.
1/10:00	Red team handover to blue team.
1/11:10	ESC check.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
1/12:00	Red team begins sleep period.
1/17:00	DSO 604.
1/20:00	Red team wakeup.

(Note: Red team Flight Day 3 USML-2 activities include ZCG, SAMS, ASC, GBX, CGBA, CPCG, SPCG, 3-DMA, APCF, DCAM, STDCE)

1/20:25	PAO event.
1/21:45	Blue team handover to red team.
1/22:00	Blue team begins presleep activities.
1/22:00	DSO 624.
1/22:10	DTO 679.

MET DAY TWO

2/00:00	Blue team begins sleep period.
2/01:05	ESC operations.
2/02:15	DTO 667.
2/05:00	DSO 611.
2/07:30	PAO event.
2/08:00	Blue team wakeup.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT

(Note: Blue team Flight Day 4 USML-2 activities include ZCG, STDCE, DPM, GBX, CPCG, SPCG, 3-DMA, SAMS, APCF, DCAM)

2/08:20	DTO 1121.
2/09:05	DTO 679.
2/09:45	Red team handover to blue team.
2/10:00	Red team begins presleep activities.
2/10:25	DTO 623.
2/12:00	Red team begins sleep period.
2/17:30	DSO 904.
2/20:00	Red team wakeup.

(Note: Red team Flight Day 4 USML-2 activities include DPM, STDCE, CGBA, ZCG, GBX, ASC, CPCG, SPCG, 3-DMA, SAMS, APCF, DCAM)

2/21:45	Blue team handover to red team.
2/22:00	Blue team begins presleep activities.
2/22:20	DSO 624.
2/23:35	DTO 1121.

MET DAY THREE

3/00:00	Blue team begins sleep period.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
3/00:00	ESC operations.
3/08:00	Blue team wakeup.

(Note: Blue team Flight Day 5 USML-2 activities include GBX, ZCG, STDCE, GFFC, 3-DMA, PCGG, CPCG, SPCG, CGBA, APCF, DCAM, SAMS, DPM)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
3/09:45	Red team handover to blue team.
3/10:00	Red team begins presleep activities.
3/10:40	PAO event.
3/12:00	Red team begins sleep period.
3/20:00	Red team wakeup.

(Note: Red team Flight Day 5 USML-2 activities include STDCE, DPM, SAMS, CGBA, ASC, PCGG, CPCG, SPCG, 3-DMA, APCF, DCAM, GBX, GFFC, ZCG)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
3/21:45	Blue team handover to red team.
3/22:00	Blue team begins presleep activities.
3/22:20	DSO 624.
3/23:40	ESC operations.

MET DAY FOUR

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
4/00:00	Blue team begins sleep period.
4/00:00	DTO 1211.
4/01:30	DTO 667.
4/02:00	DSO 611.
4/06:15	DSO 624.
4/08:00	Blue team wakeup.

(Note: Blue team Flight Day 6 USML-2 activities include GFFC, STDCE, DPM, ZCG, CPCG, SPCG, STDCE, CGBA, 3-DMA, SAMS, APCF, DCAM)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
4/08:10	PAO event.
4/09:45	Red team handover to blue team.
4/10:00	Red team begins presleep activities.
4/12:00	Red team begins sleep period.
4/14:30	DTO 623.
4/20:00	Red team wakeup.

(Note: Red team Flight Day 6 USML-2 activities include PCGG, GBX, ZCG, GFFC, ASC, CGBA, CPCG, SPCG, CGF, STDCE, 3-DMA, APCF, DCAM, SAMS, STABLE)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
4/20:00	ESC operations.
4/20:50	PAO event.
4/21:45	Blue team handover to red team.
4/22:00	Blue team begins presleep activities.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
4/22:20	DSO 624.
4/23:05	MS3 off duty.
4/23:30	Commander off duty.

MET DAY FIVE

5/00:00	Blue team begins sleep period.
5/05:45	PS2 off duty.
5/08:00	Blue team wakeup.

(Note: Blue team Flight Day 7 USML-2 activities include ZCG, STDCE, GFFC, CPCG, SPCG, 3-DMA, CGBA, APCF, DCAM, SAMS, STABLE)

5/08:35	DSO 624.
5/09:45	Red team handover to blue team.
5/10:00	Red team begins presleep activities.
5/11:00	MS1 off duty.
5/12:00	Red team begins sleep period.
5/15:45	PS1 off duty.
5/20:00	Red team wakeup.

(Note: Red team Flight Day 7 USML-2 activities include ZCG, CPCG, SPCG, GBX, ASC, 3-DMA, APCF, DCAM, SAMS, STDCE, STABLE, CGBA)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
5/20:45	Blue team begins presleep activities.
5/21:45	Blue team handover to red team.
5/22:00	DSO 624.
5/23:00	Blue team begins sleep period.

MET DAY SIX

6/00:30	ESC operations.
6/01:25	DSO 611.
6/02:10	DTO 667.
6/07:00	Blue team wakeup.

(Note: Blue team Flight Day 8 USML-2 activities include GFFC, STDCE, STABLE, DPM, ZCG, CPCG, SPCG, 3-DMA, APCF, DCAM, SAMS, PCGG, CGBA, GBX)

6/08:10	PAO event.
6/08:30	Red team begins presleep activities.
6/08:45	Red team handover to blue team.
6/11:00	Red team begins sleep period.
6/18:50	DTO 623.
6/19:00	Red team wakeup.

(Note: Red team Flight Day 8 USML-2 activities include GFFC, ZCG, STDCE, ASC, PCGG, SAMS, 3-DMA, GBX, CPCG, SPCG, APCF, DCAM)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
6/19:45	Blue team begins presleep activities.
6/20:45	Blue team handover to red team.
6/21:20	DSO 624.
6/22:00	Blue team begins sleep period.
6/22:40	ESC operations.
6/23:30	PAO event.

MET DAY SEVEN

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
7/03:00	Pilot off duty.
7/03:30	DTO 667.
7/06:00	Blue team wakeup.

(Note: Blue team Flight Day 9 USML-2 activities include ZCG, SAMS, STDCE, GFFC, STABLE, GBX, CPCG, SPCG, 3-DMA, APCF, DCAM)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
7/06:15	DSO 624.
7/07:45	Red team handover to blue team.
7/08:00	Red team begins presleep activities.
7/10:00	Red team begins sleep period.
7/11:00	DSO 611.
7/14:00	MS2 off duty.
7/18:00	Red team wakeup.

(Note: Red team Flight Day 9 USML-2 activities include GFFC, ZCG, GBX, STDCE, ST, CPCG, SPCG, CGF, 3-DMA, DCAM, APCF, SAMS, ASC)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
7/18:45	Blue team begins presleep activities.
7/19:45	Blue team handover to red team.
7/20:50	DSO 624.
7/21:00	Blue team begins sleep period.
7/22:40	DTO 667.
7/23:10	PAO event.

MET DAY EIGHT

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
8/03:00	ESC operations.
8/05:00	Blue team wakeup.

(Note: Blue team Flight Day 10 USML-2 activities include ZCG, GFFC, GBX, HI-PAC, ASC, 3-DMA, SAMS, APCF, DCAM, DPM, CPCG, SPCG, CDOT, CGBA, ASC)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
8/05:05	DSO 624.
8/06:45	Red team handover to blue team.
8/07:00	Red team begins presleep activities.
8/09:00	Red team begins sleep period.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
8/17:00	Red team wakeup.

(Note: Red team Flight Day 10 USML-2 activities include GFFC, ZCG, CGBA, GBX, DPM, 3-DMA, APCF, DCAM, SAMS, CPCG, SPCG, GBX, ASC)

8/18:45	Blue team handover to red team.
8/19:00	Blue team begins presleep activities.
8/20:50	ESC operations.
8/21:00	Blue team begins sleep period.
8/22:30	DTO 623.

MET DAY NINE

9/04:35	DSO 624.
9/05:00	Blue team wakeup.

(Note: Blue team Flight Day 11 USML-2 activities include DPM, ZCG, GFFC, GBX, 3-DMA, APCF, DCAM, SAMS, STABLE, CGBA, CPCG, SPCG)

9/06:45	Red team handover to blue team.
9/07:00	Red team begins presleep activities.
9/07:45	DSO 904.
9/08:30	DSO 611.
9/09:00	Red team begins sleep period.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
9/11:10	PAO event.
9/17:00	Red team wakeup.

(Note: Red team Flight Day 11 USML-2 activities GFFC, ZCG, DPM, ASC, CGBA, CPCG, SPCG, 3-DMA, GFFC, APCF, DCAM, SAMS, STABLE, GBX)

9/18:45	Blue team handover to red team.
9/19:00	Blue team begins presleep activities.
9/19:20	DSO 624.
9/21:00	Blue team begins sleep period.
9/21:55	PAO event.

MET DAY TEN

10/00:15	DTO 667.
10/02:30	DSO 624.
10/03:05	ESC operations.
10/05:00	Blue team wakeup.

(Note: Blue team Flight Day 12 USML-2 activities include GFFC, DPM, HI-PAC, ZCG, GBX, STABLE, CPCG, SPCG, 3-DMA, APCF, DCAM, SAMS, CGBA)

10/06:45	Red team handover to blue team.
10/07:00	Red team begins presleep activities.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
10/09:00	Red team begins sleep period.
10/11:40	PAO event.
10/16:40	ESC operations.
10/17:00	Red team wakeup.

(Note: Red team Flight Day 12 USML-2 activities include ZCG, ASC, SAMS, GFFC, DPM, CPCG, SPCG, GBX, 3-DMA, APCF, DCAM, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
10/18:45	Blue team handover to red team.
10/19:00	Blue team begins presleep activities.
10/20:00	Commander off duty.
10/20:00	DSO 624.
10/20:00	PS2 off duty.
10/21:00	Blue team begins sleep period.
10/22:55	PAO event.

MET DAY ELEVEN

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
11/00:00	DTO 623.
11/02:15	Pilot, MS3 off duty.
11/04:10	DSO 624.
11/05:00	Blue team wakeup.

(Note: Blue team Flight Day 13 USML-2 activities include ZCG, GFFC, CPCG, SPCG, CGBA, 3-DMA, DPM, CGBA, GBX, APCF, DCAM, SAMS, GFFC)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
11/06:45	Red team handover to blue team.
11/07:00	Red team begins presleep activities.
11/08:00	PS1 off duty.
11/09:00	Red team begins sleep period.
11/13:10	MS1 off duty.
11/17:00	Red team wakeup.

(Note: Red team Flight Day 13 USML-2 activities include GFFC, ZCG, CPCG, SPCG, 3DMA, APCF, DCAM, GFFC, CGBA, ASC, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
11/17:30	ESC operations.
11/18:10	ESC operations.
11/18:45	Blue team handover to red team.
11/19:00	DSO 624.
11/19:00	Blue team begins presleep activities.
11/21:00	Blue team begins sleep period.
11/21:10	DSO 611.
11/21:55	PAO event.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
11/22:15	DTO 667.

MET DAY TWELVE

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
12/01:30	DSO 802.
12/05:00	Blue team wakeup.

(Note: Blue team Flight Day 14 USML-2 activities include ZCG, DPM, GFFC, GBX, CPCG, SPCG, ZCG, 3-DMA, APCF, DCAM, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
12/06:45	Red team handover to blue team.
12/07:00	Red team begins presleep activities.
12/07:30	DSO 802.
12/09:00	Red team begins sleep period.
12/12:40	MS2 off duty.
12/17:00	Red team wakeup.

(Note: Red team Flight Day 14 USML-2 activities include GBX, GFFC, DPM, ZCG, SAMS, CPCG, SPCG, DCAM, ASC, CGBA, 3-DMA, APCF, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
12/18:45	Blue team handover to red team.
12/19:00	Blue team begins presleep activities.
12/19:20	DSO 624.
12/20:30	DSO 904.
12/21:00	Blue team begins sleep period.
12/21:00	ESC operations.

MET DAY THIRTEEN

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
13/03:30	DTO 623.
13/04:20	DSO 802.
13/05:00	Blue team wakeup.

(Note: Blue team Flight Day 15 USML-2 activities include GFFC, DPM, ZCG, ASC, CPCG, SPCG, 3-DMA, GBX, APCF, DCAM)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
13/06:45	Red team handover to blue team.
13/07:00	Red team begins presleep activities.
13/09:00	Red team begins sleep period.
13/16:30	ESC operations.
13/17:00	Red team wakeup.

(Note: Red team Flight Day 15 USML-2 activities include ZCG, GFFC, ASC, DPM, CPCG, SPCG, CGBA, 3-DMA, APCF, DCAM, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
13/18:15	DSO 904 stow.
13/18:45	Blue team handover to red team.
13/19:00	Blue team begins presleep activities.
13/19:00	DTO 667.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
13/19:30	Crew press conference.
13/21:20	DSO 624.
13/22:00	Blue team begins sleep period.

MET DAY FOURTEEN

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
14/01:30	DSO 604.
14/04:35	DSO 624.
14/05:25	PAO event.
14/05:45	Red team begins presleep activities.
14/06:00	Blue team wakeup.

(Note: Blue team Flight Day 16 USML-2 activities include STDCE, GFFC, SAMS, CGBA, ZCG, CPCG, SPCG, CGBA, APCF, DCAM, GBX, 3-DMA)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
14/06:45	Red team handover to blue team.
14/08:00	Red team begins sleep period.
14/08:40	PAO event.
14/13:55	DSO 611.
14/14:45	DSO 604.
14/16:00	Red team wakeup.

(Note: Red team Flight Day 16 USML-2 activities include ASC, CPCG, SPCG, 3-DMA, DCAM, SAMS)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
14/17:30	Blue team handover to red team.
14/17:45	Deorbit preparation briefing.
14/18:15	DTO 667.
14/19:10	Priority Group B powerup.
14/19:30	FCS checkout.
14/20:40	RCS hot fire.
14/20:55	Blue team begins presleep activities.
14/21:05	SAMS OARE.
14/21:50	Priority Group B powerdown.
14/22:55	Blue team begins sleep period.

MET DAY FIFTEEN

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
15/00:00	DSO 624.
15/02:15	Cabin stow.
15/05:10	Red team begins presleep activities.
15/06:55	Red team handover to blue team.
15/07:10	Red team begins sleep period.
15/07:10	Blue team wakeup.

(Note: Blue team Flight Day 17 USML-2 activities include 3-DMA, CPCG, SPCG, DCAM, SAMS, CGF, HI-PAC)

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
15/08:55	DTO 679 deactivation.
15/09:10	Cabin stow continues.
15/12:15	DTO 623.
15/12:20	Priority Group B powerup.
15/12:45	Payload deactivation.
15/13:05	DTO 913 stow.
15/13:20	DTO 682 stow.
15/13:35	Ergometer stow.
15/13:45	Spacelab deactivation.
15/14:20	DTO 1121 stow.
15/14:45	Spacelab egress.
15/15:00	Orthostatic entry preparation.
15/15:10	Red team wakeup.
15/15:50	DSO 621.
15/16:50	DSO 603C.
15/16:55	Crew begins deorbit preparation.
15/16:55	CRT timer setup.
15/17:05	Commander initiates coldsoak.

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
15/17:15	Stow radiators, if required.
15/17:33	Commander configures DPS for deorbit preparation.
15/17:36	Mission Control Center updates IMU star pad, if required.
15/17:45	MS configures for payload bay door closure.
15/17:55	Ku-band antenna stow.
15/17:56	MCC-H gives "go/no-go" command for payload bay door closure.
15/18:04	Maneuver vehicle to IMU alignment attitude.
15/18:20	IMU alignment/payload bay door operations.
15/18:33	MCC gives the crew the go for OPS 3.
15/18:45	Pilot starts repressurization of SSME systems.
15/18:49	Commander and pilot perform DPS entry configuration.
15/18:58	MS deactivates ST and closes ST doors.
15/19:00	All crew members verify entry payload switch list.
15/19:15	All crew members perform entry review.
15/19:17	Crew begins fluid loading, 32 fluid ounces of water with salt over next 1.5 hours (2 salt tablets per 8 ounces).

T + (PLUS) DAY/ HR:MIN:SEC	EVENT
15/19:32	Commander and pilot configure clothing.
15/19:47	MS/PS configure clothing.
15/19:58	Commander and pilot seat ingress.
15/20:00	Commander and pilot set up heads-up display (HUD).
15/20:02	Commander and pilot adjust seat, exercise brake pedals.
15/20:10	Final entry deorbit update/uplink.
15/20:16	OMS thrust vector control gimbal check is performed.
15/20:20	APU prestart.
15/20:25	Close vent doors.
15/20:29	MCC-H gives "go" for deorbit burn period.
15/20:36	Maneuver vehicle to deorbit burn attitude.
15/20:39	MS/PS ingress seats.
15/20:50	First APU is activated.
15/20:55	Deorbit burn.
15/21:00	Initiate post-deorbit burn period attitude.
15/21:04	Terminate post-deorbit burn attitude.
15/21:12	Dump forward RCS, if required.
15/21:18	Activate remaining APUs.
15/21:24	Entry interface, 400,000 feet altitude.
15/21:28	Automatically deactivate RCS roll thrusters.
15/21:35	Automatically deactivate RCS pitch thrusters.
15/21:39	Initiate first roll reversal.
15/21:43	Initiate second roll reversal.
15/21:44	TACAN acquisition.
15/21:47	Initiate third roll reversal.
15/21:48	Initiate air data system (ADS) probe deploy.
15/21:49	Begin entry/terminal area energy management (TAEM).
15/21:49	Initiate payload bay venting.
15/21:51	Automatically deactivate RCS yaw thrusters.
15/21:54	TAEM/approach and landing interface.
15/21:54	Initiate landing gear deployment.
15/21:55	Vehicle has weight on main landing gear.
15/21:55	Vehicle has weight on nose landing gear.
15/21:55	Initiate main landing gear braking.
15/21:56	Wheel stop.

GLOSSARY

A/G	air-to-ground
AA	accelerometer assembly
ACS	active cooling system
ADACS	attitude determination and control system
ADS	air data system
AFB	Air Force base
AFD	aft flight deck
AG	airglow
A/L	approach and landing
AOS	acquisition of signal
APC	autonomous payload controller
APCF	advanced protein crystallization facility (USML-2)
APCS	autonomous payload control system
APU	auxiliary power unit
ASC	Astroculture (USML-2)
ASE	airborne support equipment
BFS	backup flight control system
BHPS	boiling heater power supply
BPM	bioprocessing modules
CCD	charge-coupled device
CCTV	closed-circuit television
CDMS	command and data management subsystem
CGBA I&PU	commercial generic bioprocessing apparatus incubation and processing unit (USML-2)
CGF	crystal growth furnace (USML-2)
COAS	crewman optical alignment sight
CP	condenser profile
CPCG	commercial protein crystal growth
CRIM	commercial refrigerator/incubator module
CRT	cathode ray tube
CSI	control structure integration
CST	controlled structures technology
C/W	caution/warning
DACA	data acquisition and control assembly
DA	detector assembly
DACS	data acquisition and control system
DAP	digital autopilot
DC	detector controller
DOD	Department of Defense
DPM	drop physics module (USML-2)
DPS	data processing system
DSO	detailed supplementary objective
DTO	development test objective
EAFB	Edwards Air Force Base
ECLSS	environmental control and life support system
EDO	extended duration orbiter
EDOMP	extended duration orbiter medical project
EHF	extremely high frequency
ELV	expendable launch vehicle
EMP	enhanced multiplexer/demultiplexer pallet
EMU	extravehicular mobility unit
EOM	end of mission
EOS	Earth observing system
EPS	electrical power system
EPS	electrical power subsystem
ESA	European Space Agency
ESS	equipment support section
ET	external tank
ETR	Eastern Test Range
EUV	extreme ultraviolet
EV	extravehicular

EVA	extravehicular activity
FC	fuel cell
FCP	fuel cell power plant
FCS	flight control system
FDF	flight data file
FES	flash evaporator system
FF	flight forward
FPS	feet per second
FRCS	forward reaction control system
FSTV	fast-scan TV
FTS	force torque sensor
GAS	getaway special
GBA	getaway special bridge assembly
GBX	glovebox (USML-2)
GFFC	geophysical fluid flow cell (USML-2)
GLS	ground launch sequencer
GMT	Greenwich Mean Time
GN&C	guidance, navigation, and control
GPC	general-purpose computer
GPS	global positioning system
GSE	ground support equipment
GSFC	Goddard Space Flight Center
HAINS	high accuracy inertial navigation system
HI-PAC	high-packed digital television demonstration (USML-2)
HRM	high-rate multiplexer
HUD	heads-up display
IFM	in-flight maintenance
IMU	inertial measurement unit
I/O	input/output
IR	infrared
IUS	inertial upper stage
IV	intravehicular
IVIS	inertial vibration isolation system
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KEAS	knots equivalent air speed
KSC	Kennedy Space Center
LCD	liquid crystal display
LES	launch escape system
LMA	liquid mixing assemblies
LPS	launch processing system
LRU	line replaceable unit
MCC-H	Mission Control Center—Houston
MCP	microchannel plate
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MEE	magnetic end effector
MET	mission elapsed time
MILA	Merritt Island
MLP	mobile launcher platform
MM	major mode
MOD	Mission Operations Directorate
MPESS	multi-purpose experiment support structure
MPM	manipulator positioning mechanism
MPS	main propulsion system
MS	mission specialist
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NCC	corrective combination maneuver
NH	differential height adjustment that adjusts the altitude of orbiter's orbit
NIH	National Institutes of Health

NLO	non-linear optical
nm	nanometer
NMI	nautical miles
NOR	Northrup Strip
NSR	coelliptic maneuver that circularizes orbiter's orbit
O&C	operations and checkout
OAA	orbiter access arm
OARE	orbital acceleration research experiment
OAST	Office of Aeronautics and Space Technology
OCP	Office of Commercial Programs
OG	orbiter glow
OMS	orbital maneuvering system
OPF	orbiter processing facility
OTC	orbiter test conductor
PAO	public affairs officer
PASS	primary avionics software system
PC	proportional counter
PCIS	passive cycle isolation system
PCMMU	pulse code modulation master unit
PCS	pressure control system
PCU	power control unit
PDI	payload data interleaver
PDU	playback/downlink unit
PGSC	payload and general support computer
PI	payload interrogator
PIC	pyro initiator controller
PLBD	payload bay door
PMCU	payload measurement and control unit
POCC	Payload Operations Control Center
PRCS	primary reaction control system
PRD	payload retention device
PRLA	payload retention latch assembly
PRSD	power reactant storage and distribution
PS	payload specialist
PTI	preprogrammed test input
P/TV	photo/TV
RAAN	right ascension of the ascending node
RAM	random access memory
RCRS	regenerable carbon dioxide removal system
RCS	reaction control system
REM	release engage mechanism
RF	radio frequency
RGA	rate gyro assembly
RMS	remote manipulator system
ROEU	remotely operated electrical umbilical
RPM	revolutions per minute
RSS	range safety system
RTLS	return to launch site
S&A	safe and arm
SA	solar array
SAF	Secretary of the Air Force
SAMS	space acceleration measurement system (USML-2)
SDA	sealed door assembly
SHF	superhigh frequency
SM	statute miles
SPASP	small payload accommodations switch panel
SPCG-STES	single-locker protein crystal growth—single-locker thermal enclosure system (USML-2)
SRB	solid rocket booster
SRM	solid rocket motor
SRSS	shuttle range safety system
SSME	space shuttle main engine
SSP	standard switch panel
SSPP	Shuttle Small Payload Project
SSPP	solar/stellar pointing platform
SSTV	slow scan TV

ST	star tracker
STA	structural test article
STABLE	suppression of transient accelerations by levitation evaluation experiment (USML-2)
STDCE	surface tension driven convection experiment (USML-2)
STS	Space Transportation System
SURS	standard umbilical retraction/retention system
TAEM	terminal area energy management
TAGS	text and graphics system
TAL	transatlantic landing
TDRS	tracking and data relay satellite
TDRSS	tracking and data relay satellite system
TFL	telemetry format load
TI	thermal phase initiation burn
TIG	time of ignition
TIPS	thermal impulse printer system
TPS	thermal protection system
TRAC	targeting and reflective alignment concept
TSM	tail service mast
TT&C	telemetry, tracking, and communications
TV	television
TVC	thrust vector control
UHF	ultrahigh frequency
USML-2	United States Microgravity Laboratory 2
VBAR	along the velocity vector
VRCS	vernier reaction control system
VTR	videotape recorder
WCCS	wireless crew communication system
WCS	waste collection system
WRAIR	Walter Reed Army Institute of Research
ZCG	zeolite crystal growth (USML-2)
3-DMA	three-dimensional microgravity accelerometer (USML-2)