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Feasibility Study for the Cryogenic Orbital Nitrogen Experiment (CONE)

Final Report for Phase A/B Study

Contract Period: February 1990 - October 1991

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FOREWORD

This Final Report summarizes the technical effort performed by Ball Aerospace Systems Group (BASG) in conjunction with its team members McDonnell Douglas Space Systems Company (MDSSC) and Boeing Aerospace and Engineering (BA&E) for NASA Lewis Research Center (LeRC) under Option Task V of contract number NAS3-25054. The contract was administered by LeRC and the following are the lead personnel involved with the study.

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LIST OF ACRONYMS

AC	Alernating Current
A/D	Analog-to-Digital
AFM	Air Force Manual
AFO	Abort From Orbit
AMP	Amplifier
AOA	Abort Once Around
ASPC	Attached Shuttle Payloads Center
ATP	Authorization To Proceed
ATVS	Active Thermodynamic Vent System
BAEC	Boeing Aerospace and Electronics Company
BASG	Ball Aerospace Systems Group
BBXRT	Broad-Band X-Ray Telescope
BIF	Bus Interface Processor Command Decoder Unit
BITE	Built In Test Equipment
BPS	Bits Per Second
BSSD	Ball Space Systems Division
C&DH	Command and Data Handling
CARS	Customer Accommodations and Requirements Specifications
CCGSE	Customer/Carrier Ground Support Equipment
CDHF	Central Data Handling Facility
CDR	Critical Design Review
CFM	Cryogenic Fluid Management
CFMFE	Cryogenic Fluid Management Flight Experiment
CG	Center of Gravity
CGSE	Customer Ground Support Equipment Cryogenic Ground Support Equipment
CITE	Cargo Integration Test Equipment
CL	Centerline
CLAES	Cryogenic Limb Atmospheric Etalon Spectrometer
CM	Center of Mass
CMD	Command
CMOS	Complimentary Metal-Oxide Semiconductor

LIST OF ACRONYMS (Continued)

COBE	Cosmic Background Explorer (satellite)
COLD-SAT	Cryogenic On-orbit Liquid Depot-Storage, Acquisition and Transfer
CONE	Cryogenic Orbital Nitrogen Experiment
CPR	Customer Payload Requirements
CRRES	Combined Release and Radiation Effects Satellite
CRT	Cathode Ray Tube
CSM	Critical Status Monitor
CVB	Cold Valve Box
CTCS	CONE Test and Control System
DC	Direct Current
DFRC	Dryden Flight Research Center
DSU	Data Storage Unit
DMA	Direct Memory Access
EAFB	Edwards Air Force Base
ECP	Experiment Control Processor
EDAC	Error Detecting and Correcting
EEPROM	Electrically Erasable Permanenta Read Only Memory
EGSE	Electrical Ground Support Equipment
EMC/EMI	Electromagnetic Compatibility/Interference
EMF	Electro-Motive Force (a voltage)
EMI	Electromagnetic Interference
EOM	End-Of-Mission
EPDS	Electrical Power Distribution Subsystem
ERBS	Earth Radiation Budget Satellite
FCI	Fluid Components Inc., an instrument maker
FS	Factor of Safety
FSC	Space Station Freedom Fluid SubCarrier
G	Gravity
GFM	Gas Flow Meter
GG	Gravity Gradient
GN_2	Gaseous Nitrogen
GSE	Ground Support Equipment

LIST OF ACRONYMS (Continued)

GSFC	Goddard Space Flight Center
GVS	Generic Vent System
HH-M	Hitchhiker-M Carrier
HHSP	Hitchhiker Signal Panel
HLDC	High Level Digital Command
HX	Heat Exchanger
I&T	Integration and Test
ICD	Interface Control Document
I/F	Interface
I/O	Input / Output
IPS	Instructions Per Second
IRAS	Infrared Astronomical Satellite
IR&D or IRAD	Internal Research and Development
ISR	Interrupt Service Routine
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
J-T	Joule-Thomson Device
KBPS	Kilo-Bits Per Second
KSC	Kennedy Space Center
L/V	Liquid/Vapor sensor
LAD	Liquid Acquisition Device
LAN	Local Area Network
LeRC	Lewis Research Center
LFM	Liquid Flow Meter
LLDC	Low Level Digital Command
LN_2	Liquid Nitrogen
LV	Local-Vertical
MCE	Mixer Control Electronics
MDAC	McDonnell Douglas Astronautics Company
MGSE	Mechanical Ground Support Equipment
MDP	Maximum Design Pressure
MEMEX	Memory Expansion Card
MEOP	Maximum Expected Operating Pressure

LIST OF ACRONYMS (Continued)

MET	Mission Event Time
MLI	Multiple-Layer Insulation
MMC	Martin Marietta Corporation
MSLD	Mass Spectrometer Leak Detector
MPE	Mission Peculiar Equipment
MPESS	Mission Peculiar Equipment Support Structure
MS	Margin of Safety
MSFC	Marshall Space Flight Center
MSP	Modular Spacecraft Processor
MUX	Multiplexer
NASCOM	NASA Communications
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analyzer
NFPA	National Fire Protection Association
NHB	NASA Handbook
NIST	National Institute for Standards and Technology (formerly NBS)
NSTS	National Space Transportation System
O&C	Operations & Checkout
OAMP	Optical Airborne Measurement Platform
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OS	Outer Shell
PB	Pressurant Bottle
P/B	Playback
PCU	Power Control Unit / Power Distribution Unit
PDR	Preliminary Design Review
PDU	Power Control Unit / Power Distribution Unit
PIP	Payload Interface Plan
P/L	Payload
POCC	Payload Operations Control Center
PPF	Payload Processing Facility
PRCS	Primary Reaction Control System

LIST OF ACRONYMS (Continued)

PRD	Payload Requirements Document
PRSA	Power Reactant Storage Assembly
PTVS	Passive Thermodynamic Vent System
PV	Pressure Vessel
RAM	Random Access Memory
RCS	Reaction Control System
RdF	RdF, a temperature measurement vendor
RT	Real-Time
RTLS	Return to Launch Site
RTMS	Receiver Tank Mass Simulator
SAFIRE	Spectroscopy of the Atmosphere Using Far Infrared Emission
SCD	Source Control Drawing
S/D	Serial-Digital
SDP	Subsystem Dedicated Processor
SEU	Single Event Upset
SFI	Special Function Interface
SHOOT	Superfluid Helium On-Orbit Transfer
SI	Solar-Inertial
SINDA	System Improved Numerical Differencing Analyzer
SIR-A,B,C	Shuttle Imaging Radar - A, B, C
SLOC	Source Lines of Code
SME	Solar Mesosphere Explorer
SRR	System Requirements Review
SSF	Space Station Freedom
STE	Special Test Equipment
SSP	Standard Switch Panel
STD I/O	Standard Input/Output
STOL	Spacecraft Test and Operations Language
STS	Space Transportation System (Space Shuttle)
STV	Space Transfer Vehicle
S/W	Software
TAL	Transoceanic Abort Landing

LIST OF ACRONYMS (Continued)

TBD	To Be Determined
TCS	Thermal Control Subsystem
TD	Technical Directive
TDDW	Twilled Double Dutch Weave
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry
TOCC	Test Operations Control Center
TRASYS	
TVS	Thermodynamic Vent System
VAB	Vertical Assembly Building
VDU	Valve Driver Unit
VPF	Vertical Processing Facility
WVB	Warm Valve Box
XRS	X-Ray Spectrometer

Section 1

INTRODUCTION

An improved understanding of low-gravity cryogenic fluid behavior is critical for the continued development of space-based systems. Although early drop tower or Aerobee sounding rocket experiments provided some fundamental understanding of zero-gravity cryogenic fluid behavior, more extensive flight data are required to design space-based cryogenic liquid storage and transfer systems with confidence. As NASA's mission concepts evolve and now include hydrogen storage for nuclear propulsion as part of the lunar/Mars missions, the demand for optimized in-space cryogenic systems is increasing.

CONE is an attached shuttle payload experiment designed to address major technological issues associated with on-orbit storage and supply of cryogenic liquids. During its 7-day mission, CONE will conduct experiments and technology demonstrations in active and passive pressure control, stratification and mixing, liquid delivery and expulsion efficiency, and pressurant bottle recharge. These experiments, conducted with liquid nitrogen as the test fluid, will substantially extend the existing low-gravity fluid database and will provide future system designers with vital performance data from an orbital environment.

1.1 BACKGROUND FOR LOW-G EXPERIMENTS

Low-gravity cryogenic systems can be divided into 4 broad classes: (1) supercritical systems (such as the PRSA shuttle tanks) which maintain cryogenic fluids above their critical points to facilitate expulsion of single-phase fluid, (2) superfluid helium systems (such as IRAS or COBE) that operate at reduced pressures and use thermal gradients through a porous plug to collect and transfer fluid, (3) solid cryogenic coolers (such as BBXRT) which provide cooling by maintaining a solid cryogen in the sublimation region, and (4) liquid cryogen systems which are stored at pressures less than 350 kPa (50 psia) near their boiling point and require special subsystems for venting (pressure control) and liquid expulsion. Of these four systems, the first three have extensive flight heritage, but liquid (2-phase) cryogenic systems have little or no flight heritage.

Storing cryogens as liquids at low pressures near their normal boiling points is more weight efficient for most applications; therefore, development of sub-critical cryogenic storage systems is essential. A flight experiment called Cryogenic Fluid Management Flight Experiment (CFMFE) was developed by NASA Lewis Research Center and the Martin Marietta Company in the early 1980's, but was ultimately rejected as a shuttle payload because of hydrogen safety-related issues. In the late 1980's, multiple concepts of a free-flying cryogenic hydrogen experiment called COLD-SAT were developed by contractor teams and NASA/ Lewis Research Center, but the program appeared to be too costly to develop at that time. The CONE experiment was conceived and designed as a substantial first step toward addressing critical cryogenic fluid technology issues associated with liquid storage and delivery.

1.1.1 Need for Low-Gravity Fluid Technology

Three fundamental issues for low-gravity two-phase liquid systems which must be addressed are: (1) tank pressure control while venting only vapor, (2) vapor-free liquid expulsion from the tank, and (3) chilldown and filling of a warm tank.

All cryogenic systems require some form of pressure control. Supercritical systems vent single-phase fluid directly; superfluid helium systems use porous plugs to achieve phase separation and control pressure; solid cryogen coolers vent vapor by sublimation. In 2-phase (liquid-vapor) systems a unique problem arises in the low-gravity environment: how to control pressure by venting vapor without discarding valuable liquid. The most promising technique for pressure control uses the thermodynamic vent system (TVS) either in a passive or an active mode with a fluid mixer. These systems are designed to vent vapor only and rely on effective heat transfer to the cryogen inside the tank to accomplish pressure control. It is very likely that all future liquid cryogen systems will use some type of TVS system.

Liquid cryogens must be stored on orbit for many reasons, including propellant supply, instrument cooling, and life support. To capitalize on the advantages of liquid storage, the liquid must be readily available for delivery and distribution from the storage vessel. In a low-gravity environment, surface-tension devices, such as fine-mesh screened channels, are the most promising approach for liquid delivery. Although these devices have been used successfully for conventional propellants (such as hydrazine), they have not flown in cryogenic systems.

Many future mission concepts require re-supply of cryogen storage vessels. In these concepts, a cryogen tank is empty and must be chilled and filled in the low-gravity environment. In ground-based systems, these operations are carried out routinely because vapor always vents out the top of the tank. In low gravity, vented tank fills require fluid settling using induced thrust, which is not desirable for most large systems. The charge-hold-vent chilldown and subsequent no-vent fill appear promising for on-orbit resupply operations.

1.1.2 Previous Work on Low-Gravity Fluid Cryogenic Management

Low-gravity cryogenic fluid management technology has been under development for over twenty years. Self-pressurization studies were conducted in Aerobee sounding rockets in the mid-1960's to determine the effects of heating on cryogenic storage tanks. Numerous TVS system concepts have been developed by different contractors. However, ground testing of TVS systems cannot demonstrate on-orbit performance for controlling tank pressure; therefore, actual flight data is required to validate the TVS concepts.

Surface tension devices have been studied extensively by the McDonnell Douglas Company, the Martin Marietta Company, and recently, other contractors have initiated development programs for screened-channel liquid acquisition devices (LADs). Flight data for LADs in hydrazine and water tanks has shown that these devices are effective for collection and expulsion of liquid in a low-gravity environment. Cryogenic systems, however, are more sensitive to heating from the external environment or from warm pressurant introduced for liquid expulsion, and their breakdown thresholds are lower than for storable fluids.

Chilldown and filling of warm tanks have not been tested in low gravity. These processes are not amenable to short tests (such as drop-tower tests) due to the time required to conduct a chill or fill operation. However, extensive modeling efforts sponsored by the Lewis Research Center have been underway since 1980, and recent ground-tests at the NASA Plumbrook facility have demonstrated the feasibility of the processes and have helped to define the critical range of operating parameters.

Although considerable work has been done on low-gravity fluid management, more extensive flight experiments are vital to provide engineering data and to validate proposed technology. The existing database is not adequate to provide system designs for missions in the late 1990's and beyond. The CONE will be a major milestone in cryogenic fluid technology development for low-gravity applications and will be a substantial step toward flying two-phase liquid cryogen systems.

1.2 CONE SPECIFIC OBJECTIVES

In general, CONE will demonstrate critical technologies in a low-gravity environment and will acquire experimental data to validate and refine new and existing models for low-gravity fluid behavior. Specifically, the technical objectives of the CONE mission are:

Active Thermodynamic Vent System: To evaluate the effectiveness of a TVS heat exchanger coupled with a fluid mixer to maintain or reduce tank pressure.

Stratification: To measure the degree of thermal stratification and rate of pressure rise in cryogenic tanks as a function of imposed heat flux and liquid fill level.

Mixing: To characterize low-gravity fluid mixing and to evaluate the ability of a fluid mixer to reduce the rate of pressure rise.

Liquid Outflow: To demonstrate and evaluate liquid outflow from a screen device under low-gravity conditions.

Liquid Expulsion Efficiency: To demonstrate high expulsion efficiency from a cryogen storage tank in a low-gravity environment.

Passive Thermodynamic Vent System: To demonstrate tank pressure control using a passive TVS at multiple fill levels.

Subcooled Liquid Outflow: To evaluate the effectiveness of a high-flow TVS coupled to a heat exchanger to subcool outflowing liquid.

Pressurant Bottle Recharge: To demonstrate resupply of a high-pressure gaseous pressurant bottle by injection of a metered quantity of liquid cryogen.

Pressurization: To determine low-gravity pressurant requirements and pressure collapse rates using a condensable pressurant gas.

1.3 CONE SYSTEM DESIGN SUMMARY

To meet these low-gravity cryogenic fluid management technical objectives, the Ball Aerospace team has designed the CONE concept shown in Figure 1-1. Mounted to a Hitchhiker-M carrier, the total CONE launch weight is 2,201 kg (4,853 lb) which includes 907 kg (2,000 lb) for the carrier, 411 kg (907) lb of liquid nitrogen, and 172 kg (378 lb) for a receiver-tank mass simulator. The mass simulator is provided to allow future addition of a cryogen transfer experiment with minimal system impact.

The CONE flight hardware consists of the experiment subsystem and three supporting subsystems: (1) structural, (2) thermal control, and (3) avionics. The payload is modular to simplify reconfiguration in response to new mission requirements, providing, in effect, an orbital testbed for CFM experiments. A single flight computer performs all required experiment control functions in addition to data acquisition and transmission, command processing, and system monitoring.

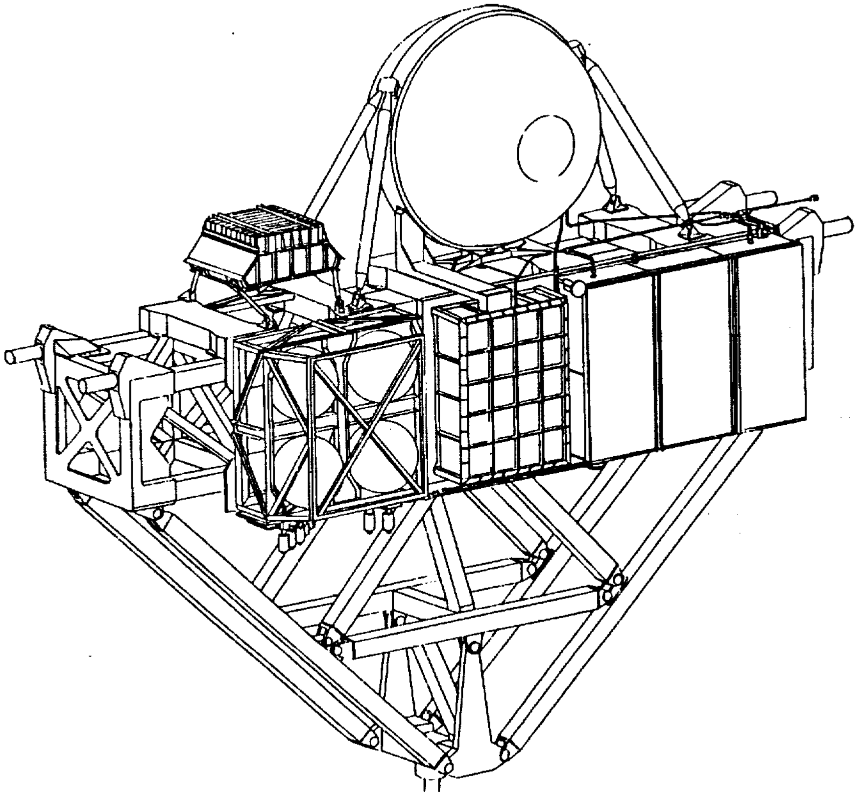

Figure 1-1, CONE General Arrangement

1.3.1 Experiment Subsystem

The experiment subsystem consists of a spherical LN_2 supply dewar, cold valve box, warm valve box, a tank pressurization system, and instrumentation.

The supply tank has a capacity of 0.479 m^3 (16.9 ft^3) and is the principal experiment tank on CONE. It is a vacuum-jacketed dewar with an inconel pressure vessel supported from the aluminum vacuum shell and girth ring by fiberglass-epoxy support struts. A passive thermodynamic vent system and heater strips are attached to the pressure vessel wall for cooling and heating during tests, and the vacuum annulus contains two inches of multiple-layer insulation (MLI).

The cold valve box houses valves and components which are continuously exposed to liquid nitrogen from the supply tank. A vacuum-jacketed piping run connects the cold valve box to the supply tank, and all lines leaving the cold valve box for other locations are thermally isolated by a section of epoxy-fiberglass tubing.

The warm valve box contains other valves and fluid components which may be exposed to liquid nitrogen during the mission but are not "cold" at all times. There are three vent paths to space which exit the warm valve box: (1) a 105 kPa (15 psia) back pressure path for overboard liquid dumping and final tank venting, (2) a 14 kPa (2 psia) back pressure path for all TVS vent flows, and (3) an open path for tank evacuation during pressurant bottle recharge. Numerous temperature and pressure sensors and turbine flow meters are also contained in the warm valve box.

All liquid outflow operations require pressurizing the supply tank with gaseous nitrogen. The pressurization system consists of four stainless-steel bottles at a storage pressure of 20.7 MPa (3,000 psia). All four bottles are manifolded together but are isolated by check valves in the event of a leak. One of the bottles is equipped with additional plumbing for the pressurant bottle recharge experiment. Pressure is reduced from the supply bottles to either 138, 172, or 207 kPa (20, 25, or 30 psia) and then routed to the supply tank. Redundant turbine flow meters monitor and integrate the pressurant flow rate to provide total pressurant used.

Instrumentation consists of temperature, pressure, flow rate, acceleration, and liquid/vapor detection. Over 200 sensors are installed at various locations in the CONE; their type, number, location, and accuracy are described in section 3.

The experiment control processor is part of the command and data handling subsystem and serves three primary functions for the experiment subsystem: software monitoring and experiment control, telemetry gathering, storing, and sending, and sensor signal conditioning.

1.3.2 Structural Subsystem

The CONE structure provides the mechanical interface between the individual payload elements and HH-M carrier. CONE consists of a number of independent modules mounted directly to the HH-M structure. Mechanical support is provided tailored to each modules' requirements. The supply tank and mass simulator possess similar strut and keel-fitting arrangements providing kinematic isolation. The cold and warm valve boxes share a flexure-mounted plate spanning two bays of the HH-M truss structure. A pressurant module contains the four GN_2 pressurant tanks and associated plumbing. Finally, the avionics module is mounted to a standard interface plate identical to that used by the HH-M avionics.

1.3.3 Thermal Control Subsystem

CONE may be exposed to wide-ranging thermal environments during on-orbit operations. Possible shuttle orientations range from bay-to-sun to bay-to-space, with associated "hot" and "cold" thermal conditions. Payload element temperature control must therefore mitigate the effects of this wide range of environments.

Passive thermal control was selected as the baseline approach, with payload elements controlled individually using Multiple Layer Insulation (MLI) and surface finishes. Analysis showed that heaters were only required for the pressurant tanks. All other elements exhibited satisfactory temperature control using passive means.

1.3.4 Avionics

The CONE avionics subsystem controls all payload functions. Command storage and interpretation, sensor data conditioning, telemetry formatting, data storage, and power distribution are all controlled by the experiment control processor (ECP). Signal conditioning and multiplexing electronics are housed in a common box with the ECP which weighs approximately 8 kg and requires less than 35 watts of operating power. Valve actuation, heater power, and mixer speed are commanded by the ECP through an interface to the valve driver unit (VDU), heater power buses, and mixer control electronics (MCE).

Full data recovery is provide by a data storage unit (DSU) and periodic telemetry downlink using the shuttle medium-rate Ku-band system. The baseline DSU is a conventional tape recorder, although the progress of solid-state memory devices may warrant a future in-depth trade. Real-time experiment and engineering telemetry is provided at a nominal 1 kbps, facilitating experiment and payload status monitoring.

The CONE electrical power distribution avionics provide all power conditioning, isolation, and distribution for the payload. Orbiter power provided by the HH-M is distributed by the distribution avionics to the various payload elements. Shuttle safety considerations are a significant subsystem driver, necessitating specific bus isolation and control approaches. Heater bus control requires both astronaut and ground commanding to ensure crew safety. Provision of experiment electrical power for the mixer driver, valve drivers, sensors, and experiment heaters are also key tasks.

Section 2

EXPERIMENT REQUIREMENTS

2.1 EXPERIMENT SET DEFINITION AND REQUIREMENTS

The CONE experiment set was developed at the NASA Lewis Research Center by assessing all low-gravity CFM requirements and determining the optimum combination of technical objectives which could be met with a single cryogen tank on a shuttle flight. Although some CFM technologies could not be evaluated in a single-tank, single-mission concept, many of the critical CFM issues for Space Station and the Space Transfer Vehicle (STV) will be addressed by CONE. The relationship of the CONE experiment set to the overall requirements for low-gravity cryogenic fluid management is depicted by the diagram in Figure 2-1. Note that including fluid transfer in subsequent CONE concepts will further enhance the development of space-based cryogenic fluid systems.

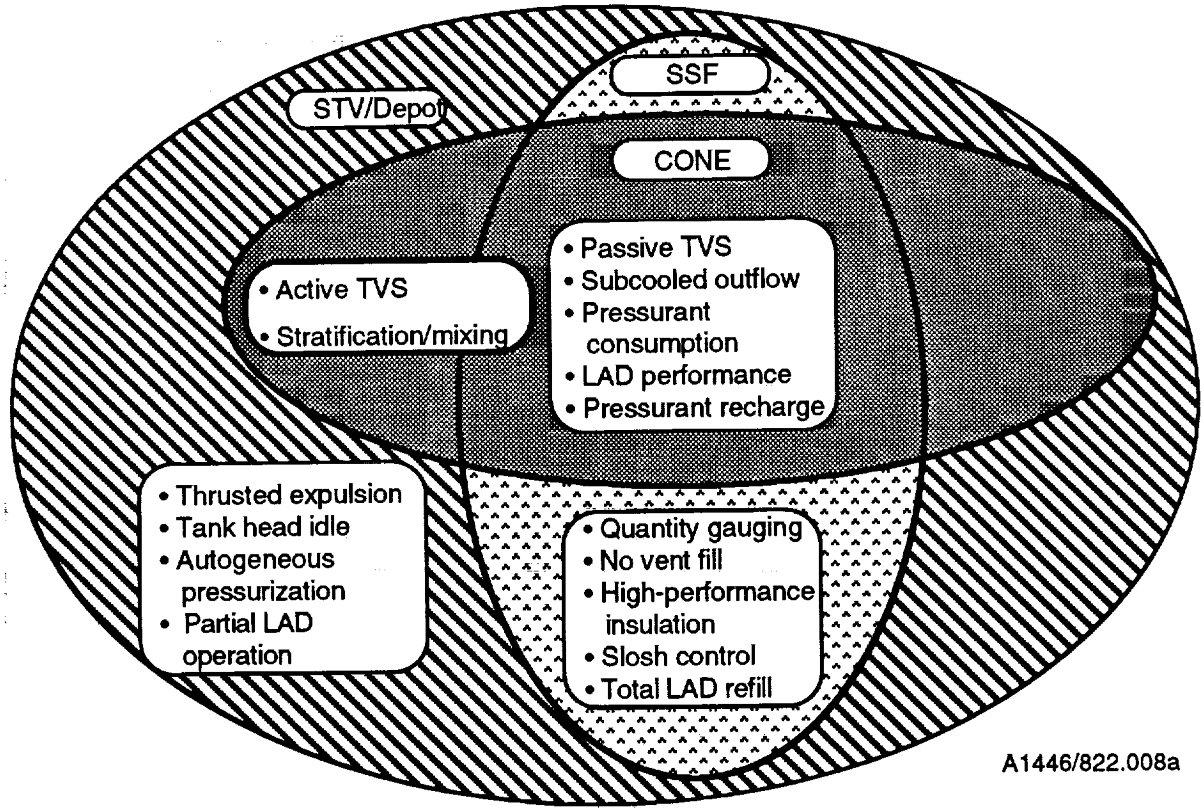

Fig. 2-1, CONE Addresses a Subset of STV/Depot and SSF Technology Requirements

Technologies slated for evaluation on CONE were classified as experiments or technology demonstrations. For experiments, a matrix with parametric tests at different levels of key variables will be conducted during the mission. For demonstrations, the flight hardware will be demonstrated at one or two operating points, but a full test matrix will not be completed. Technical objectives and end uses for each CONE experiment and demonstration are summarized in Table 2-1.

Name/Description	Technical Objectives	End User Or Application	Category D = Demo E = Expt
Active Thermodynamic Vent System (TVS)	Evaluate the effectiveness of a TVS heat exchanger coupled with a fluid mixer to control tank pressure	Large cryogen storage tanks--STV's, Depots	E
Mixing	Evaluate the ability of a fluid mixer to reduce the rate of pressure rise	Large cryogen storage tanks--STV's, Depots	E
Stratification	Measure degree of stratification and rate of pressure rise as a function of heat flux and fill level	All cryogen storage tanks with extended quiescent periods	E
Passive Thermodynamic Vent System	Demonstrate tank pressure control using a distributed passive TVS heat exchanger	Small to medium size storage tanks--life support, space-station resupply	D
Liquid Outflow from a Surface-Tension Liquid Acquisition Device (LAD)	Demonstrate vapor-free liquid outflow from a screen-channel device under low-gravity conditions	Liquid supply or transfer operations for life support, biological research, and orbital resupply	D
Liquid Expulsion Efficiency	Demonstrate high expulsion efficiency using a screen-channel LAD	Liquid supply or transfer operations for life support and orbital resupply	D
Pressurization	Determine low-gravity pressurant requirements and pressure collapse rates using a condensible pressurant gas	All tanks delivering liquid using a pressurization system	D
Subcooled Liquid Outflow	Evaluate effectiveness of a high-flow TVS coupled to a heat exchanger to subcool outflowing liquid	Cryogen resupply to warm or partially full storage vessels	D
Pressurant Bottle Recharge	Demonstrate resupply of a high-pressure gaseous pressurant bottle by injection of a metered quantity of liquid cryogen	All systems carrying high-pressure gas	D

Table 2-1, Objectives and End Uses for CONE Technologies

CONE will evaluate three primary technologies: the active thermodynamic vent system (ATVS), the passive thermodynamic vent system (PTVS), and liquid acquisition device (LAD) performance. Six supporting technologies will also be characterized, including stratification, mixing, pressurization, liquid subcooling, LAD expulsion efficiency, and pressurant bottle recharge.

The ATVS uses a Joule-Thomson (JT) expansion valve coupled to a fluid mixer and compact forced-flow heat exchanger to control tank pressure. The system is sized for intermittent operation so that when the tank pressure reaches the top of its allowable dead-band, the mixer will be activated and the JT valve opened to subcool the vent stream and heat exchanger. Heat from the tank fluid will be transferred to the two-phase vent fluid, vaporizing any remaining liquid in the vent stream and cooling the tank fluid to a lower saturation pressure. The effects of mixer speed, tank fill level, and duty cycle will be investigated during the mission. Mixing (with no venting) and stratification tests are related to the ATVS technology and will also be parametrically investigated during CONE.

In addition to the ATVS, a PTVS will be incorporated into the supply tank design. The PTVS is designed to intercept incoming heat and control tank pressure with no moving parts (except for the vent-system valve). Unlike the ATVS, the PTVS requires a distributed heat exchanger thermally coupled to the tank wall. Because parametric studies for a PTVS design require different tank sizes, vent systems, and very long operating times, the PTVS test is a technology demonstration.

The third major technology area to be demonstrated on CONE is a Liquid Acquisition Device (LAD) which collects and delivers vapor-free liquid nitrogen to an overboard dump vent. These screened-channel devices use surface tension to acquire liquid from within the tank and can be designed to leave liquid residuals of less than 2%. In addition to demonstrating vapor-free liquid acquisition and outflow, the demonstration will include low-gravity pressurization with gaseous nitrogen, subcooling of outflowing liquid with a JT expansion valve and forced-flow heat exchanger, and ultimate LAD expulsion efficiency when the CONE mission is completed. While the supply tank is pressurized and the transfer lines are chilled, a high-pressure gaseous pressurant bottle will be recharged using liquid cryogen. The recharge demonstration will fill the pressurant bottle approximately 20% full of liquid prior to sealing it off for re-pressurization.

The technical objectives for each CONE experiment provided top-level (level one) requirements for the system concept. Second and third level requirements were derived for CONE by including results of trade studies, mission constraints, shuttle operations, safety, and good engineering practice. Figure 2-2 is a block diagram of the requirements development process from conception through level three design requirements. The experiment concept and all of its detailed design features are directly related to the requirements generated by the process illustrated in Figure 2-2.

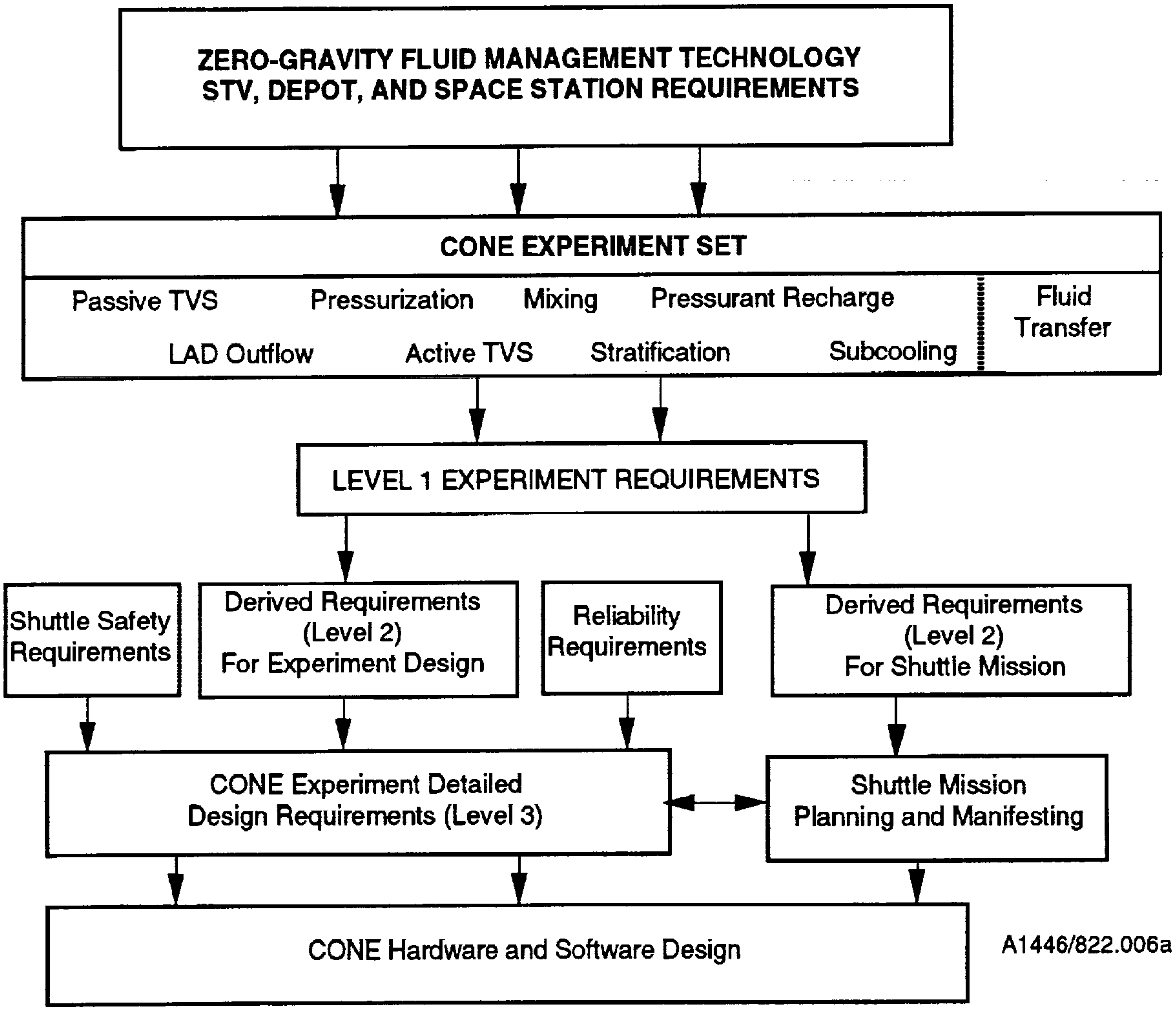

Figure 2-2, CONE Requirements Led to Development of the Experiment Design

A detailed description of all experiment requirements and the analysis which accompanies the experiments are given in the Payload Requirements Document (see CONE Payload Requirements Document, DRD-1, Revision 3.0, July, 1991). Level 1 and level 2 requirements for each experiment are also enumerated in the PRD, where level 1 requirements are "top" level requirements which frame the system concept and level 2 requirements are "derived" requirements which reflect basic design parameters and specifications.

2.1.1 Active TVS and Mixing

2.1.1.1 Level One Requirements

The active TVS experiment is designed to control or reduce pressure in the tank using a fluid mixer coupled to a forced-flow TVS heat exchanger. The ATVS experiment requires a multiple-speed mixer to deliver fluid as a liquid or 2-phase jet in mixing regions I and IV (see the PRD for a definition of mixing regions). The mixer should be capable of handling liquid, vapor, or a 2-phase mixture. The TVS heat exchanger should be sized at 3 times a full scale STV liquid oxygen background heat load (approximately 100 W). Fluid settling over the mixer at a Bond number in excess of 4 is required for 2 mixing tests to provide a known fluid orientation. The mixer jet to tank diameter ratio should be similar to STV applications.

2.1.1.2 Level Two Requirements

To accommodate the 2-phase requirement, the mixer inlet should be mounted to draw fluid directly from the tank, as opposed to drawing fluid from the LAD manifold. The TVS flowrate should be approximately 30 g/min (4.0 lb/hr), and the mixer flow range should be 2.8 to 14 L/min (0.1 to 0.5 cfm). The tank diameter to mixer jet diameter ratio should be between 25:1 and 75:1. Unless an extremely compact mixer/heat-exchanger assembly can be constructed, the mixer should be mounted outside of the supply tank to maintain geometric similarity with full-scale systems. The mixer inlet should be oriented so that a fluid settling maneuver will position liquid over the mixer inlet. For a 0.48 m^3 (16.9 ft^3) spherical supply tank, fluid settling requires 18 to 45 μg for 30 minutes.

2.1.2 Stratification Requirements

2.1.2.1 Level One Requirements

Stratification tests apply heat to the supply tank surface and observe the rate of pressure rise and temperature stratification within the liquid. Two levels of uniformly distributed heat flux are required above the background heat flux. The fluid and near-wall temperatures should be well-characterized during testing, and two tests should be run with minimum g-level disturbances.

2.1.2.2 Level Two Requirements

Tank wall heaters should be sized to provide heat flux levels of 6.3 and 12.6 W/m^2 (2.0 and 4.0 Btu/hr-ft^2) distributed uniformly around the tank. Temperature probes which can accurately measure differential temperatures in the liquid should be placed at several key locations inside the tank to monitor liquid and vapor stratification. Two periods of 5 to 6 hours in gravity-gradient attitude are required to minimize g-level disturbances.

2.1.3 Liquid Outflow and Expulsion Efficiency Requirements

2.1.3.1 Level One Requirements

The liquid outflow tests require a surface-tension driven liquid acquisition device capable of delivering vapor-free liquid from the supply tank in a low-gravity environment. Outflow rates should be scaled to STV and space station applications, and one expulsion should be conducted with liquid positioned away from the LAD manifold. The expulsion efficiency should be characterized after the device breaks down and can no longer deliver liquid.

2.1.3.2 Level Two Requirements

A total communication screened-channel design is required for CONE. The design must be robust enough to survive launch loads without breakdown and should provide residuals of less than 5 percent of tank volume. The LAD and supporting subsystems should be capable of delivering 0.75 to 2.27 kg/min (100 to

300 lb/hr) of vapor free liquid, and the device should not break down if exposed to warm GN_2 pressurant. The tank should be oriented so that fluid settling maneuvers will position the liquid away from the LAD manifold. Heaters sized to vaporize a 5 percent liquid residual are required to characterize the final expulsion efficiency of the LAD. Vapor detection capability is required in the liquid outflow system to adequately characterize the point at which the screens break down.

2.1.4 Passive TVS Requirements

2.1.4.1 Level One Requirements

The passive TVS should be designed to control (maintain) tank pressure without venting liquid overboard using a distributed heat exchanger coupled to a TVS. Background heat flux should be representative of STV and space station applications. Since these systems can experience long transients (2 to 6 hours), test time should be adequate to verify successful operation. The system should be characterized at 2 fill levels. In order to separate g-level effects, one quiescent period of shuttle operations is required during the mission.

2.1.4.2 Level Two Requirements

The background heat flux should be less than 1.6 W/m^2 (0.5 $Btu/hr\text{-}ft^2$), and the TVS flowrate should be sized for twice the background heat leak to overcome transient effects in a timely manner. Based on a concept trade study, the heat exchanger should be external and mounted to the pressure vessel wall. One 12-hour block of testing with no OMS or PRCS firings is required to remove the effects of large g-level disturbances.

2.1.5 Pressurization Requirements

2.1.5.1 Level One Requirements

The pressurization system should supply gaseous nitrogen for LN_2 expulsion tests. GN_2 should be delivered to the supply tank with minimal disruption of the liquid-vapor interface, and the inlet enthalpy and consumption of pressurant gas should be well characterized.

2.1.5.2 Level Two Requirements

To avoid large thermal transients during pressurant delivery, the pressurant gas should be stored in at least 3 identical bottles with a total storage volume of 0.11 m^3 (3.9 ft^3). The GN_2 should be maintained above 255 K (460 R), and the system should be sized based on complete collapse (thermal equilibrium). Two receiver tank expulsions should be included in the GN_2 quantity to allow for future growth of CONE. GN_2 should be delivered at 138 and 207 kPa (20 and 30 psia) through a diffuser with a large velocity reduction.

2.1.6 Pressurant Bottle Recharge Requirements

2.1.6.1 Level One Requirements

Pressurant bottle recharge should safely demonstrate refill of a high-pressure gas bottle with liquid nitrogen to within 10 percent of its normal operating pressure. The bottle should be stabilized at 300 K within 24 hours after recharge. Existing, qualified hardware should be used if possible.

2.1.6.2 Level Two Requirements

An isolated stainless-steel pressurant bottle equipped with a spray nozzle at the inlet is required for recharging. Tank-wall heaters rated at 30 W are required to vaporize liquid cryogen and rewarm the gas to normal operating conditions within 24 hours. Flow metering and shut-off valves capable of regulating LN_2 delivery to within 0.45 kg (1 lb) are required to avoid overcharging the bottle. To accommodate the charge-hold-vent cooldown concept, a low-pressure vent (less than 14 kPa) is required.

2.1.7 Subcooling Requirements

2.1.7.1 Level One Requirements

Subcooling requires a compact, forced-flow heat exchanger coupled to a TVS. The nominal design point for the system should be subcooling 2.27 kg/min (300 lb/hr) of LN_2 by 2.8 K (5 R). The high-flow liquid and TVS streams should be drawn from the LAD manifold to avoid vapor ingestion.

2.1.7.2 Level Two Requirements

The TVS and LN_2 pressure drops should be less than 14 kPa (2 psia), and the TVS flow rate should be 70 g/min (9.2 lb/hr). The heat exchanger should be thermally isolated and should have precooling capability.

2.2 INTEGRATED EXPERIMENT SET REQUIREMENTS

Many requirements for the CONE mission had to be determined from a combined (integrated) experiment set in which all tests were listed in chronological order. This section describes requirements which were derived from the integrated experiment set and not determined by any one experiment or demonstration.

2.2.1 Venting Requirements

The CONE experiment set was analyzed to determine all venting requirements for the mission and the results are summarized in Table 2-2. Each TVS was sized according to the required thermal load for pressure control or subcooling; the mass flow rate through each TVS was calculated thermodynamically. Liquid outflow rates were determined based on scaling to space station life support replenishment. Pressurant bottle recharge and transfer-line cooldown venting rates were estimates based on preliminary analysis. The CONE venting rates determined flowmeter sizing and overall system pressure drop.

Type of Vent	Experiment	Backpressure		Mass Flowrate		Duration (hr)
		(kPa)	(psia)	(g/min)	(lb/hr)	
Low-P Regulated	ATVS	14	2.0	30	4.02	0.5 - 7.0
Low-P Regulated	PTVS	14	2.0	3.0	0.4	4 - 24
Low-P Regulated	Subcooler/LAD	14	2.0	70	9.2	0.5 - 3.0
LN2 Flow	LAD Outflow	103	15.0	756-2270	100-300	0.5 - 3.0
Space Vacuum	PB Recharge	0	0	15-150	2-20	<0.5
LN2 Flow	Transfer line cooling	103	15.0	30-60	4-8	<1.0

Table 2-2, Summary of CONE Venting Requirements

2.2.2 Instrumentation

The measurement requirements summary in Table 2-3 represents the most stringent requirements for CONE. A detailed table of measurement requirements and locations for each experiment can be found in the PRD.

Measurement	No. of Sensors	Range	Required Accuracy
Cryo temperature	76	61 - 222 K	± 0.3 K
Env temperature	23	222 - 333 K	± 0.6 K
Cryo gradients	18	61 - 89 K	± 0.04 K/cm
Pressure - absolute	12	0 - 345 kPa	± 1.4 kPa
Pressure - GN_2	4	0 - 20.7 MPa	± 0.3 MPa
Mass flowrate			
Liquid	2	0.23 - 2.3 kg/min	± 2%
Vapor	6	3.0 - 76 g/min	± 2%
Vapor detection	35	100% vapor or 100% liquid	< 5 sec response
Acceleration	1 (3-axis)	10^{-6} to 10^{-3}g Bandwidth TBD	± 10% over any decade

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Table 2-3, Experiment Measurement Requirements

Three different temperature measurement requirements were identified for the experiment subsystem. The controlling accuracy requirements were determined by error analysis of the pressure control experiments. Temperature gradients during stratification will be small and therefore, a sensitive differential measurement is required.

Most pressure measurements must be accurate to 3.4 kPa (0.5 psia). Repeated measurements on the same gauge for delta-P determination require a greater accuracy of 1.4 kPa (0.2 psia).

Liquid/vapor detection is used as a criterion for experiment control, and therefore, its accuracy requirement is expressed as time for detection based on allowable liquid or vapor mass losses in the flow lines.

Acceleration measurement requirements are driven by Bond number accuracy requirements during induced-g maneuvers and by the need to characterize the shuttle gravitational environment. To obtain a Bond number accuracy better than 10%, the g-level measurement must be accurate to 1-2 micro-g.

For each experiment, all relevant sensors must be monitored at appropriate measurement frequencies which are determined by the rates of change of the processes taking place. For example, during stratification testing, a sensor sweep every 60 seconds will adequately characterize the test, but during mixing, a sweep is required every second. Because CONE is a limited duration experiment, it is simpler to sweep all sensors at the 1 Hz rate rather than incorporate multiple sweep logic in the control computer.

The required experiment data rate was determined by multiplying the number of sensors by the number of bits per sensor (8 or 12 depending on the measurement) and adding a 20% contingency for future growth. Assuming a 1 Hz sweep rate, the required CONE experiment data rate is 2548 bps.

Several key top-level requirements were identified for the flight computer system which must collect data from all the sensors during experiments. Specifically, the computer must scan the sensor set once per second and be sized to handle 2548 bps of experiment data, it must provide basic monitoring and control capability, it must interpret and issue commands from the ground, and it must gather telemetry for processing and downlink. Details of the flight computer system can be found in Section 5.4.1.3.

2.2.3 Mission Model

All experiments, demonstrations, and other fluid management operations were integrated into a spreadsheet model called CONEPRIM. CONEPRIM was developed using Quattro Pro 2.0 and currently occupies 125 kbytes of disk space. It is a time-sequenced mathematical description of the CONE experiment mission profile. Inputs include the key parameters for the experiments such as heat flux, fluid outflow and vent rates, test sequence, and other data such as fluid properties, tank size, and test duration. Output is available as a complete operations table or in graphical form. Each entry in the model corresponds to a specific operation or experiment and is assigned a duration time and numerous other characteristics. The model tracks pressure, fill level, heat input, and mass vented or dumped. CONEPRIM was used extensively in mission scheduling and to determine overall fluid and time requirements for each experiment.

2.2.3.1 Consumable Requirements

2.2.3.1.1 Power Requirements

In order to properly establish the experiment subsystem power requirements, the mission model CONEPRIM was modified to create a new spreadsheet (CNPOWER). A detailed power consumption profile was created by assigning the appropriate power consumption values to heaters, normally closed valves, and the fluid mixer, and incorporating power levels into the mission timeline.

The CONE power profile is shown in Figure 2-3. The average power required is 91 watts, and the peak power of 140 watts occurs during a liquid outflow test. These power requirements include the power "floor" of the electronics which is always on. The maximum allowable power for HH-M payloads is 500 W, so CONE operates with a substantial power margin throughout the mission. Details of the power "floor" are given in Section 5.4.2.

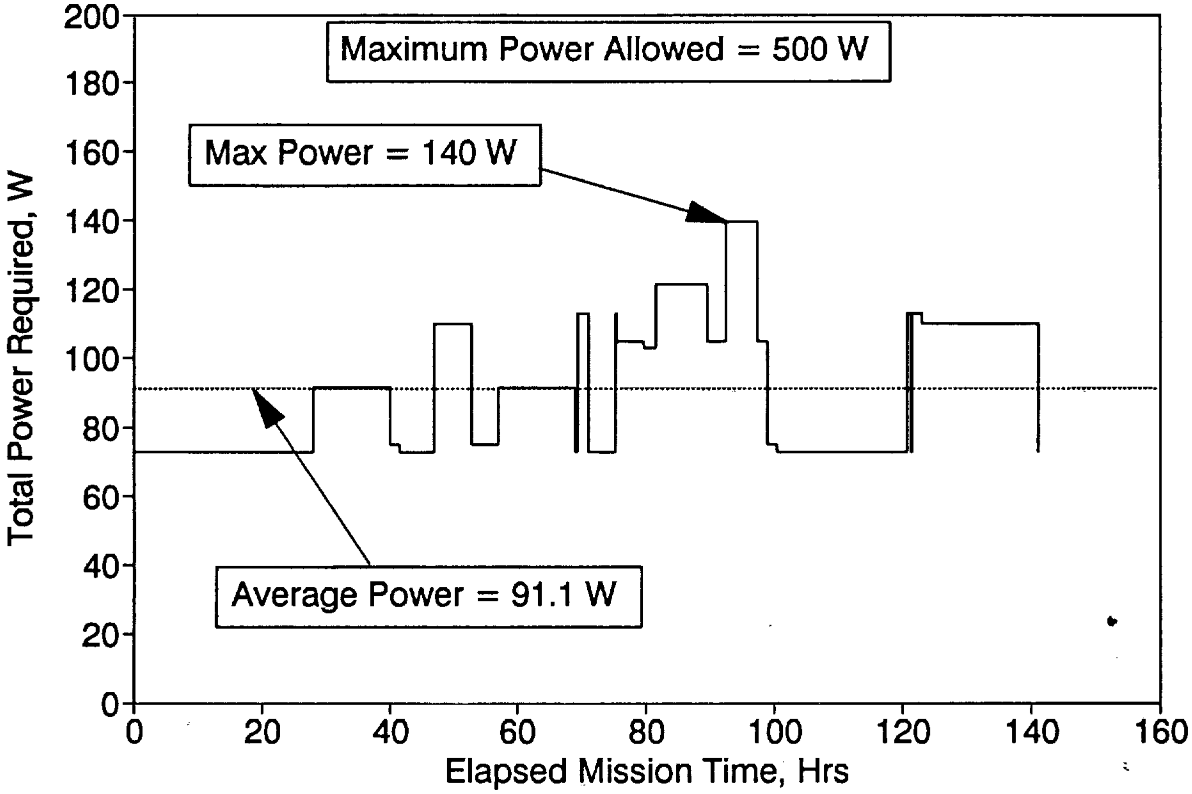

Figure 2-3, CONE Power Requirements

2.2.3.1.2 Liquid Nitrogen Requirements

CONEPRIM tracks and records the usage of LN_2 for different experiments. Most of the liquid nitrogen in the supply tank (approximately 70%) will be dumped overboard during liquid outflow tests. The remainder of the LN_2 is required for other venting experiments. The pie chart in Figure 2-4 provides a breakdown of the quantities of liquid nitrogen required for each of the venting experiments, and the accompanying table shows the quantities required for liquid outflow and the margins available for re-allocation (if necessary). Note that there is a substantial LN_2 margin available so that future incorporation of a transfer experiment is not limited by LN_2 capacity.

	Required (kg)	**Allocated (kg)**	**Margin**
LAD Outflow	181	282	55%
Other Experiments (See Pie Chart)	74	74	0%
Total LN2	255	356	39%

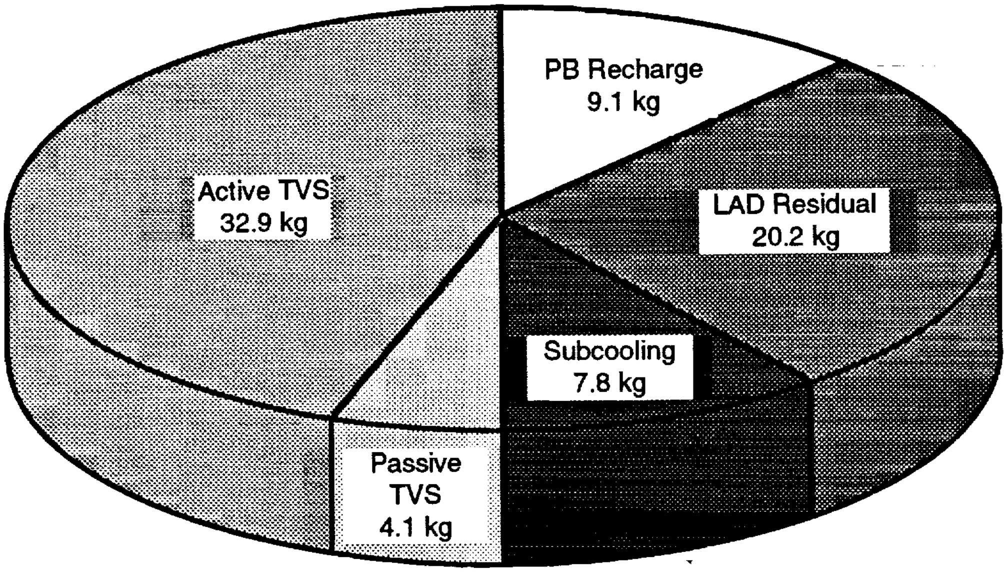

Figure 2-4, CONE Liquid Nitrogen Requirements and Allocation

2.2.3.1.3 Gaseous Nitrogen Pressurant Requirements

Requirements for GN_2 pressurant are listed in Table 2-4. Pressurant consumption for supply-tank pressurization and outflow was calculated assuming complete thermal equilibrium (collapse) which represents the maximum quantity possible. The receiver tank allowance was also calculated assuming complete thermal equilibrium. The margins indicated in Table 2-4 may be needed for experiments if (1) operating pressures change from their current levels (pressurizing to 173 kPa (25 psia) with a full tank requires more GN_2 than pressurizing to 138 kPa (20 psia)), and/or (2) the pressurant bottle recharge experiment does not produce pressurant gas in time for use with the final outflow series.

Expulsion #	Pressure, kPa		LN_2 Outflow (kg)	Initial Fill Level	GN_2 Required (kg)
	Initial	Final			
1	103	138	75.2	86%	5.8
2	138	172	63.9	64%	4.1
3	103	172	75.2	44%	5.4
4	172	207	67.1	25%	1.9
Total GN_2 required, supply tank					17.2
Receiver tank allowance					5.1
Total GN_2 required					22.3
Total GN_2 available					30.3
Margin					36%

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Table 2-4, Gaseous Nitrogen Pressurant Requirements

2.2.3.2 STS Operational Requirements

CONE requires several maneuvers and attitude adjustments to provide the desired gravitational fields for some experiments. All liquid outflow tests will be coordinated with the astronauts to insure that the bay doors are open and the shuttle is in an acceptable attitude. An induced g-field is required for two mixing tests and one outflow test, and the shuttle will provide the g-field by spinning at a slow rotation rate around the pitch or yaw axes. Two stratification tests will be conducted in a minimum disturbance attitude (gravity gradient) for approximately 6 hours. During a passive TVS test near the mission end, it is desirable to avoid large thruster firings from the OMS or PRCS systems for a period of twelve hours. These shuttle requirements are summarized in Table 2-5 along with the mission time at which the event is currently scheduled to begin.

Mission Day	Mission Time (hr)	Event	Duration (hr)	Experiment
3	47	Gravity-gradient orientation	6	Stratification
3	54	Shuttle spin	0.5	Mixing
4	69,75	LN_2 venting	3.0	LAD
5	92	Gravity-gradient orientation	5	Stratification
5	98	Shuttle spin	0.5	Mixing
5	100	No OMS or PRCS firings	12	Passive TVS
6	121	Shuttle spin and LN_2 venting	0.5 3.2	LAD

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Table 2-5, STS Operations Required to Support CONE

Section 3

EXPERIMENT SUBSYSTEM DESIGN

The experiment subsystem was designed to perform the CONE experiment set in a standard 7-day shuttle mission. The prevailing design philosophy encouraged simplicity, flight heritage, and minimum cost without sacrificing experiment capability or reliability. Figures 3-1 and 3-2 illustrate the baseline CONE configuration.

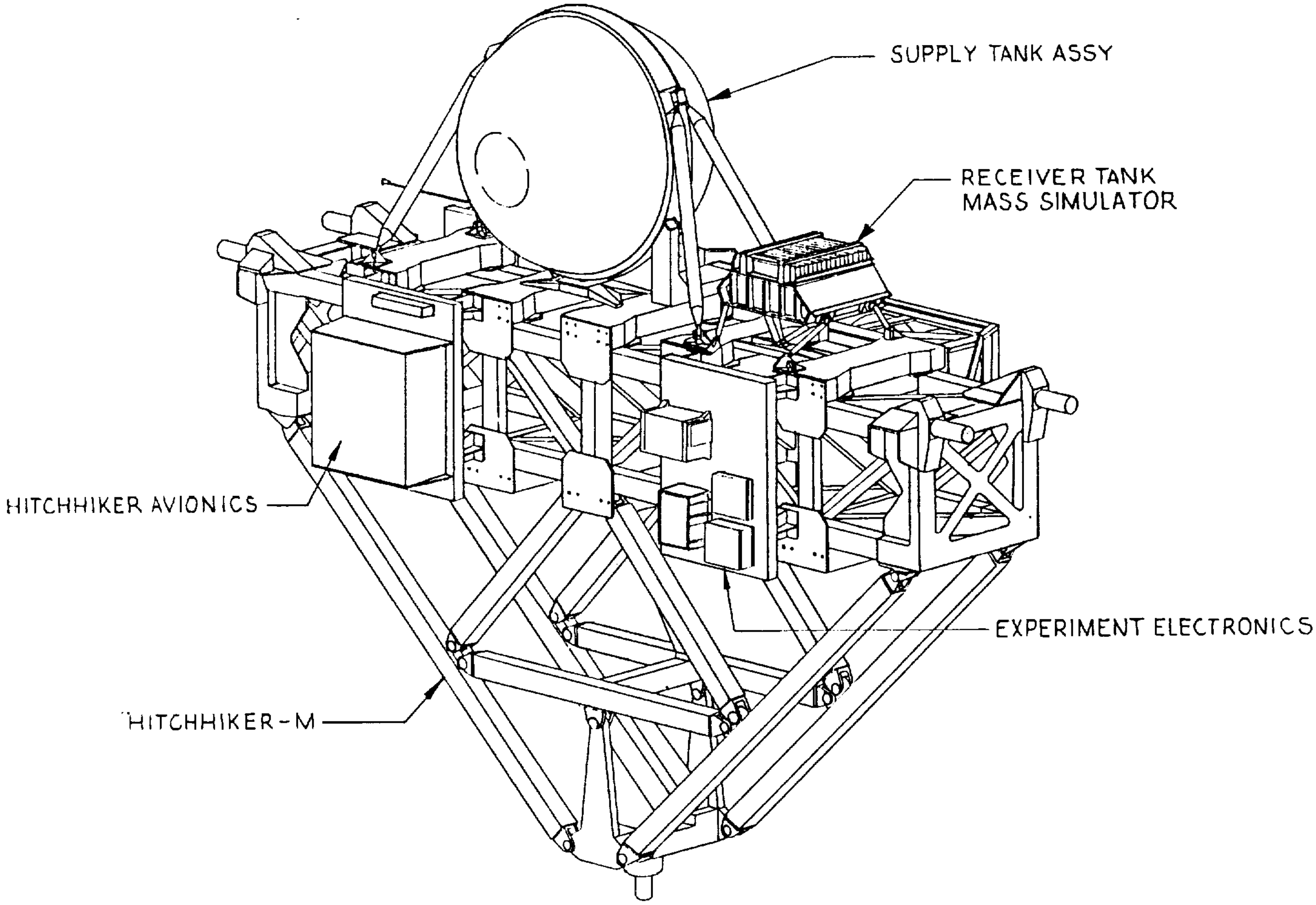


Figure 3-1, CONE Baseline Configuration (Avionics Face)

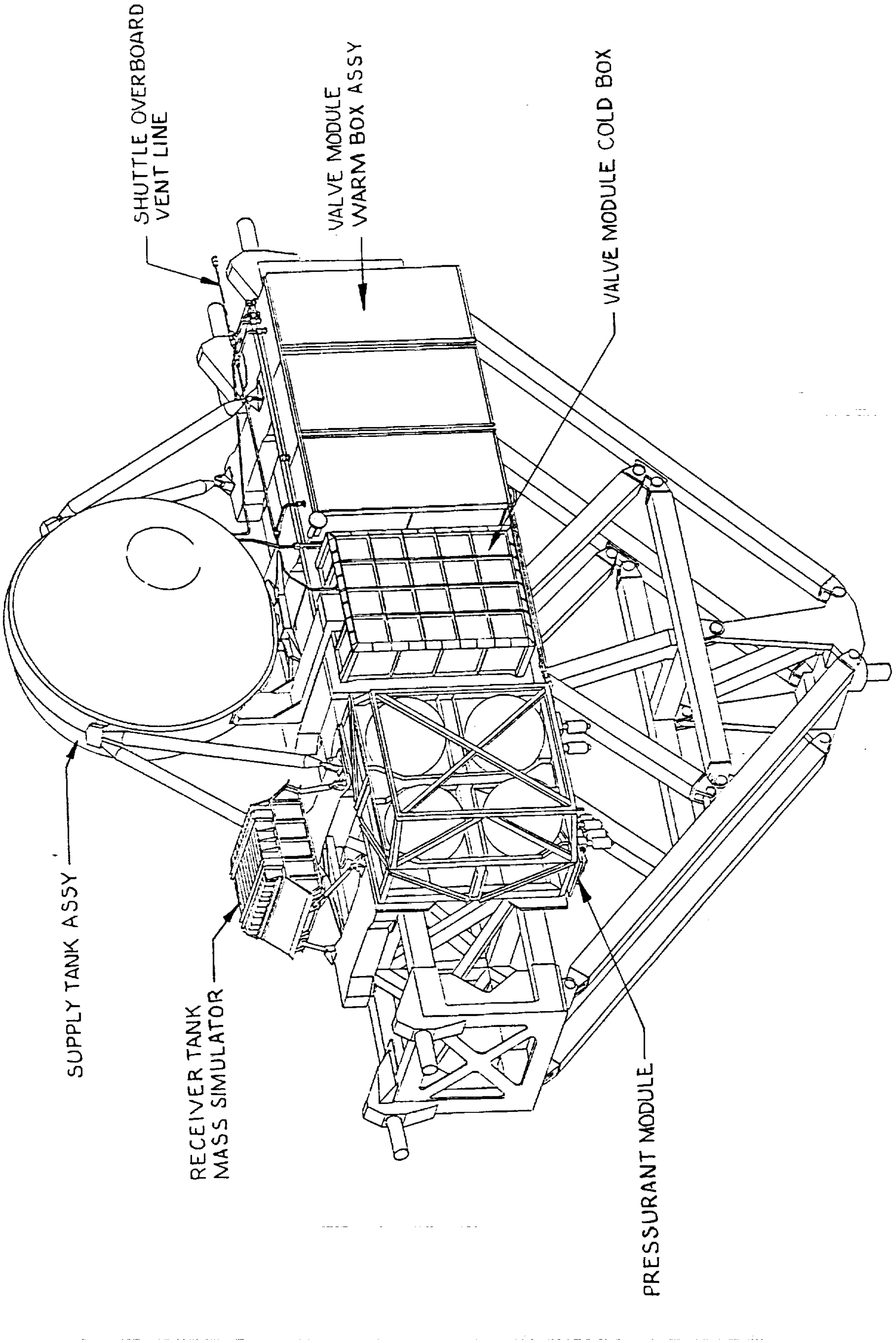


Figure 3-2, CONE Baseline Configuration (Fluid Components Face)

3.1 EXPERIMENT SUBSYSTEM CONFIGURATION

The CONE experiment subsystem consists of seven major components: a 0.48 m^3 (16.9 ft^3) supply tank, a pressurant module containing four (4) 3.2 x 10^{-2} m^3 (1.1 ft^3) metallic bottles, a "cold" valve box, a "warm" valve box, a set of interconnecting fluid lines, a receiver tank mass simulator, and required instrumentation. Figure 3-3 is a block diagram depicting how the major experiment-subsystem components (excluding instrumentation) interface with one another.

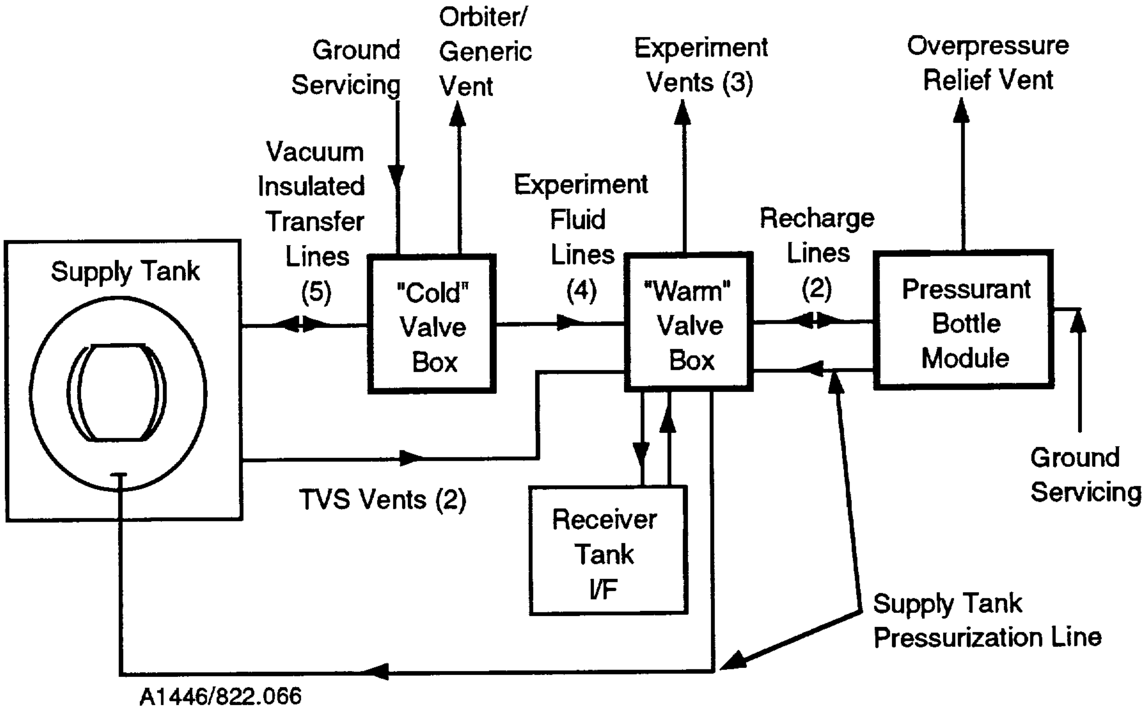


Figure 3-3, Block Diagram of CONE Fluid Components

3.2 LN_2 DISTRIBUTION SUBSYSTEM

The LN_2 distribution subsystem was designed to perform the CONE experiment set according to the requirements developed in section 2. Figure 3-4 is an end-to-end fluid schematic and Figure 3-5 is a layout drawing of the fluid distribution subsystem. The major LN_2 distribution subsystem components are the "cold" valve box, the "warm" valve box and the interconnecting fluid transfer lines, and each valve box contains many smaller fluid components. The pressurant module and supply tank are described in sections 3.3 and 3.4.

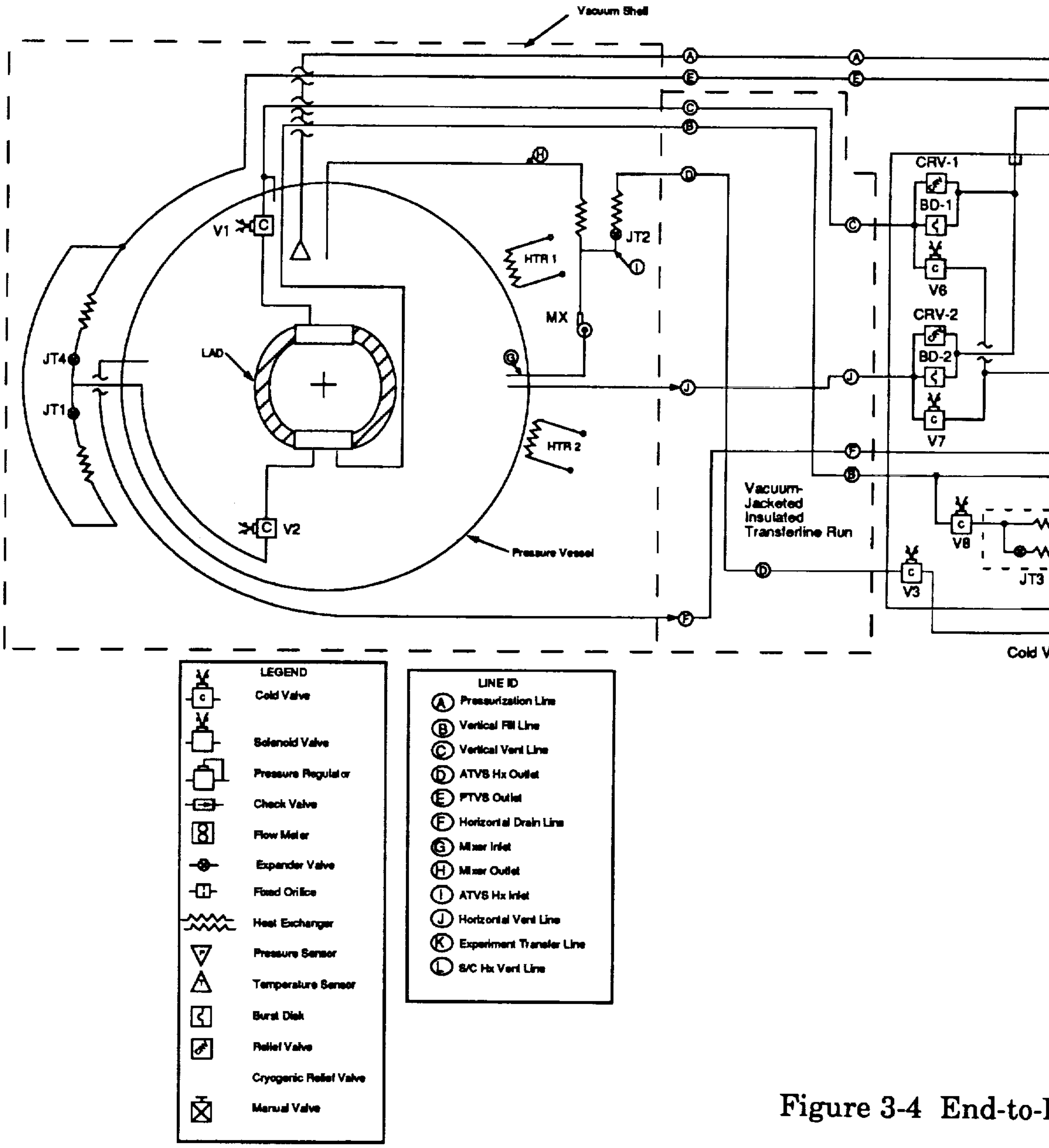
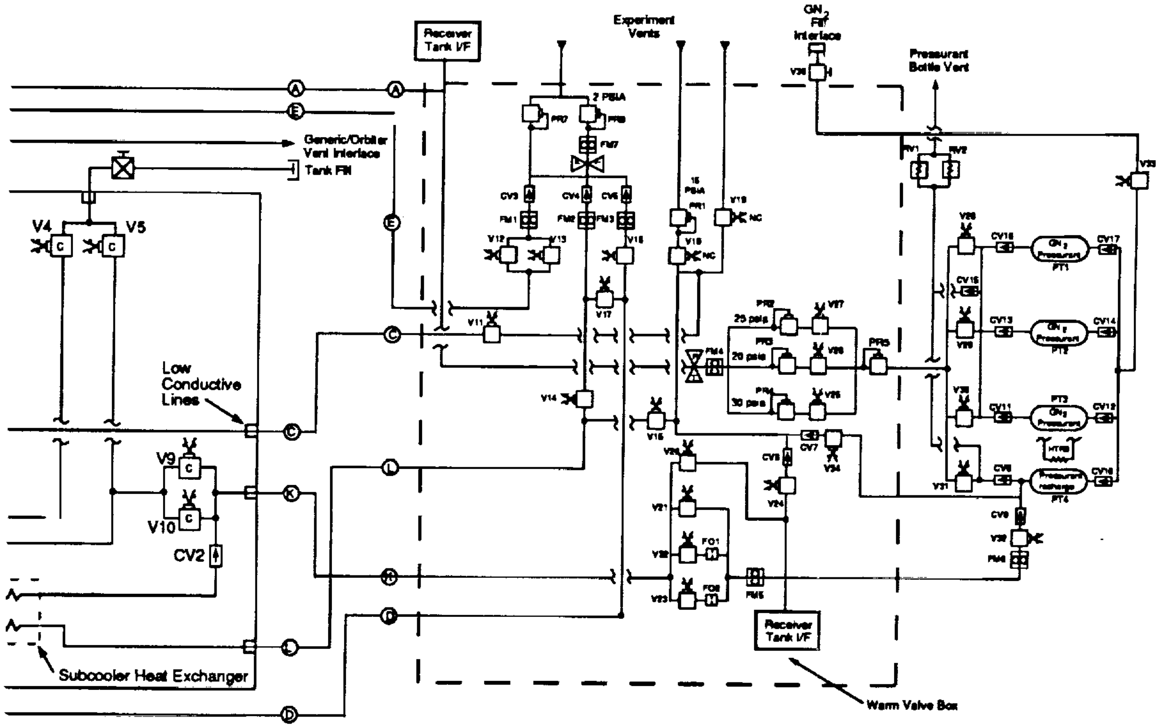


Figure 3-4 End-to-

FOLDOUT FRAME 2.



lve Box Schematic

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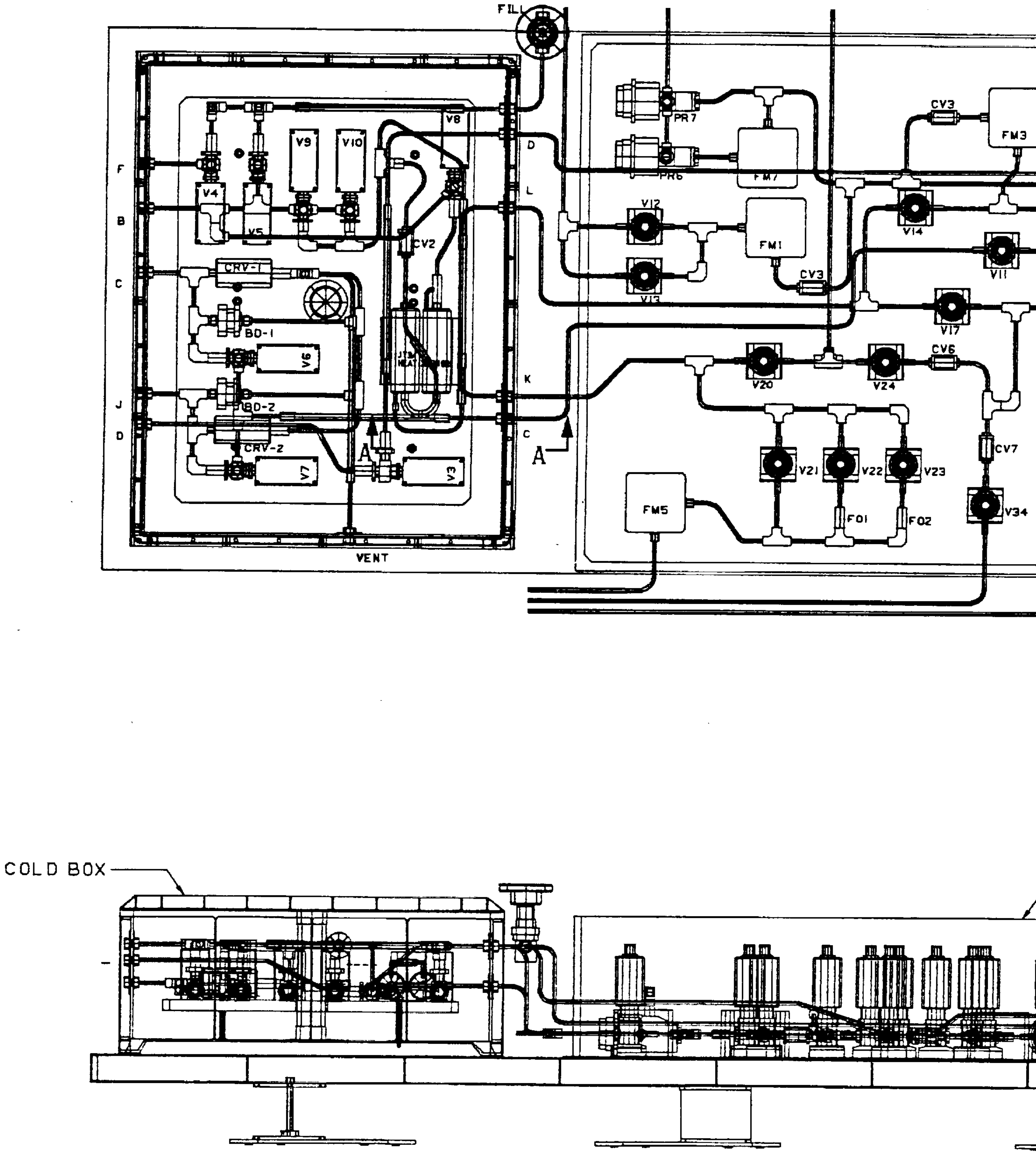
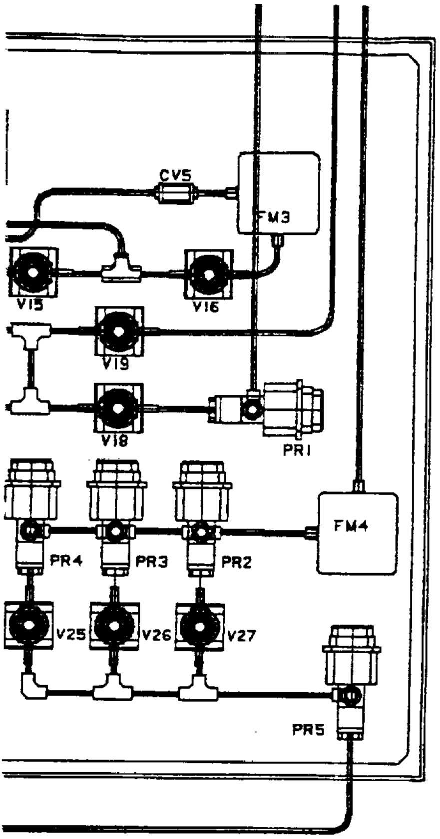
End CONE Fluid Schematic

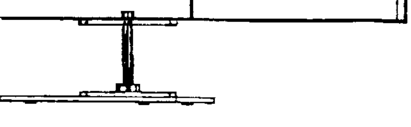
FOLDOUT FRAME

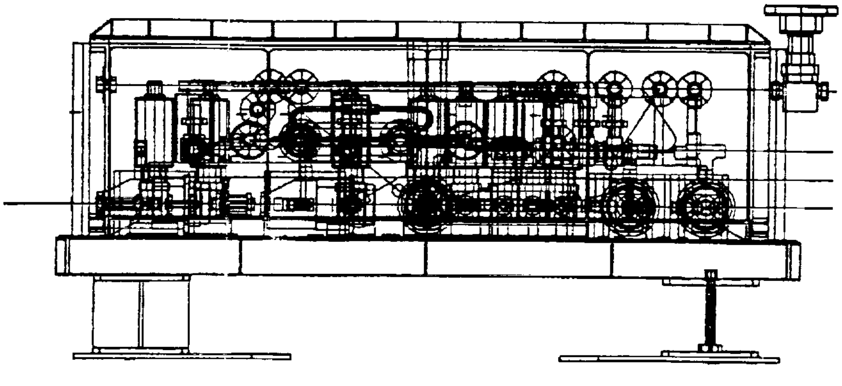
Figure 3-5 CONE LN_2 Distribution Subsystem Layout



2.


CV5
FM3
V15
V16
V19
V18
PR1
FM4
PR4
PR3
PR2
V25
V26
V27
PR5


WARM BOX



Component failures in the distribution subsystem which could jeopardize the entire experiment were eliminated by adding redundancy, but the subsystem is not completely single-fault tolerant. Consequently, some component failures could cause experiment data to be degraded, but not lost completely. CONE is two-fault tolerant for all credible failures which impact shuttle safety.

This report summarizes the system level design for CONE and does not include design details for all components. To indicate the level of design detail developed during the Ball CONE study, the discussion of the the "cold" valve box includes more detailed design information than the other components.

3.2.1 "Cold" Valve Box (CVB)

The CVB is a vacuum-jacketed, multi-layer insulated manifold containing eighteen fluid components (either enclosed or attached) which are continuously exposed to LN_2 temperatures. The CVB functions as an extension of the supply tank. It accommodates required "cold" components necessary for the supply tank which can not be included in the volume of either the supply tank pressure vessel or the vacuum shell. Figure 3-6 is a schematic of the CVB.

The CVB has a volume of 0.19 m^3 (6.71 ft^3) and is constructed from aluminum plate. An exploded view of the CVB structure in Figure 3-7 shows the top and bottom plates, the four side plates, the component mounting plate and the thermal/structural isolator posts. All plates are machined to remove excess weight. The bottom and side plates are welded together to provide a leak tight environment. All penetrations into the CVB come through the side plates. The top plate is bolted into place and the vacuum seal is maintained by dual Viton O-rings.

All fluid components are structurally mounted to a 73 cm x 53 cm x 1.11 cm (29 inch x 21 inch x 7/16 inch) aluminum support plate within the CVB. The mounting plate is isolated from the external environment by a 5.1 cm (2 inch) MLI blanket completely surrounding the plate. This MLI blanket contains 55 layers of double-aluminized mylar with Rayon fiber net spacers.

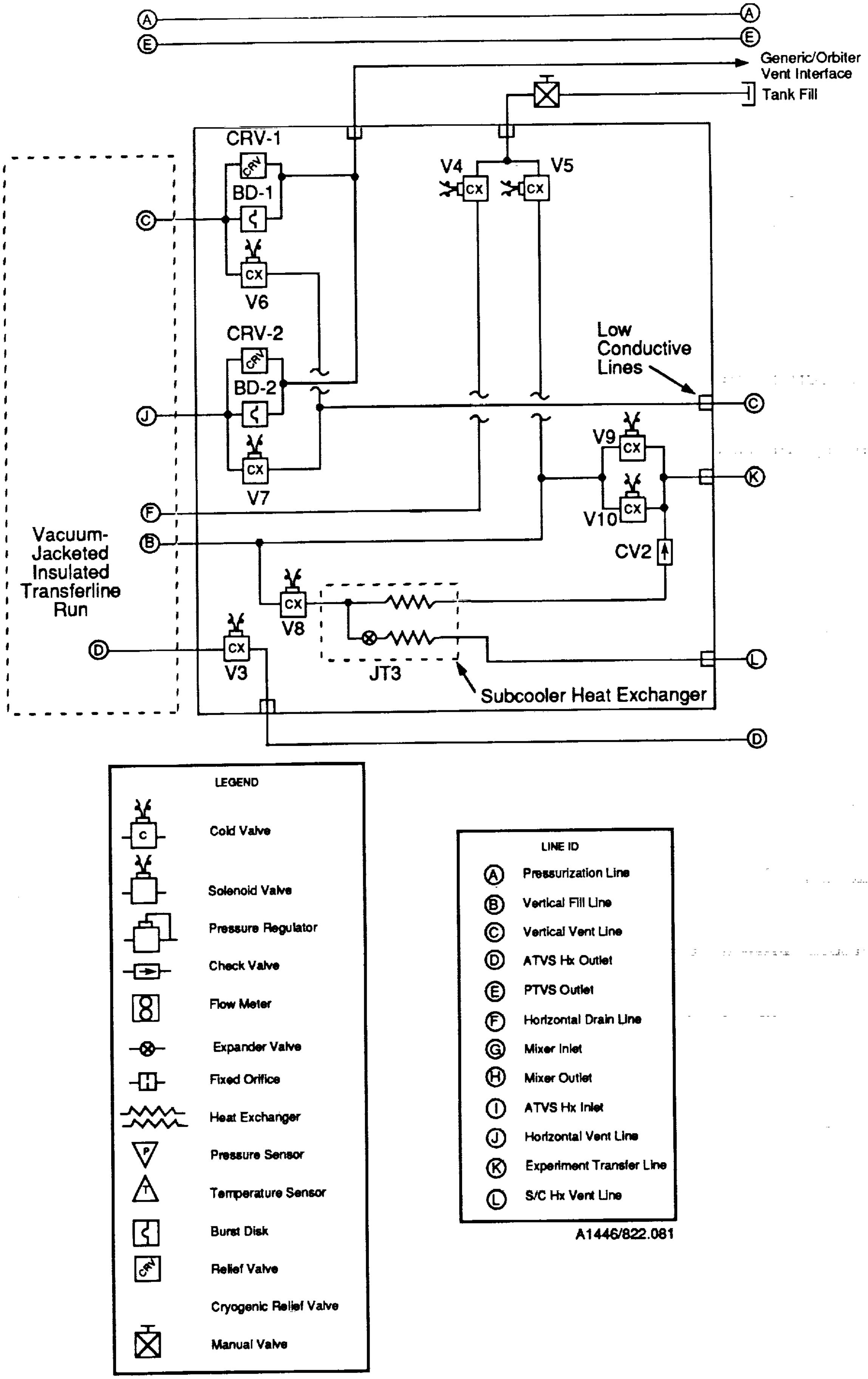


Figure 3-6, Cold Valve Box Schematic

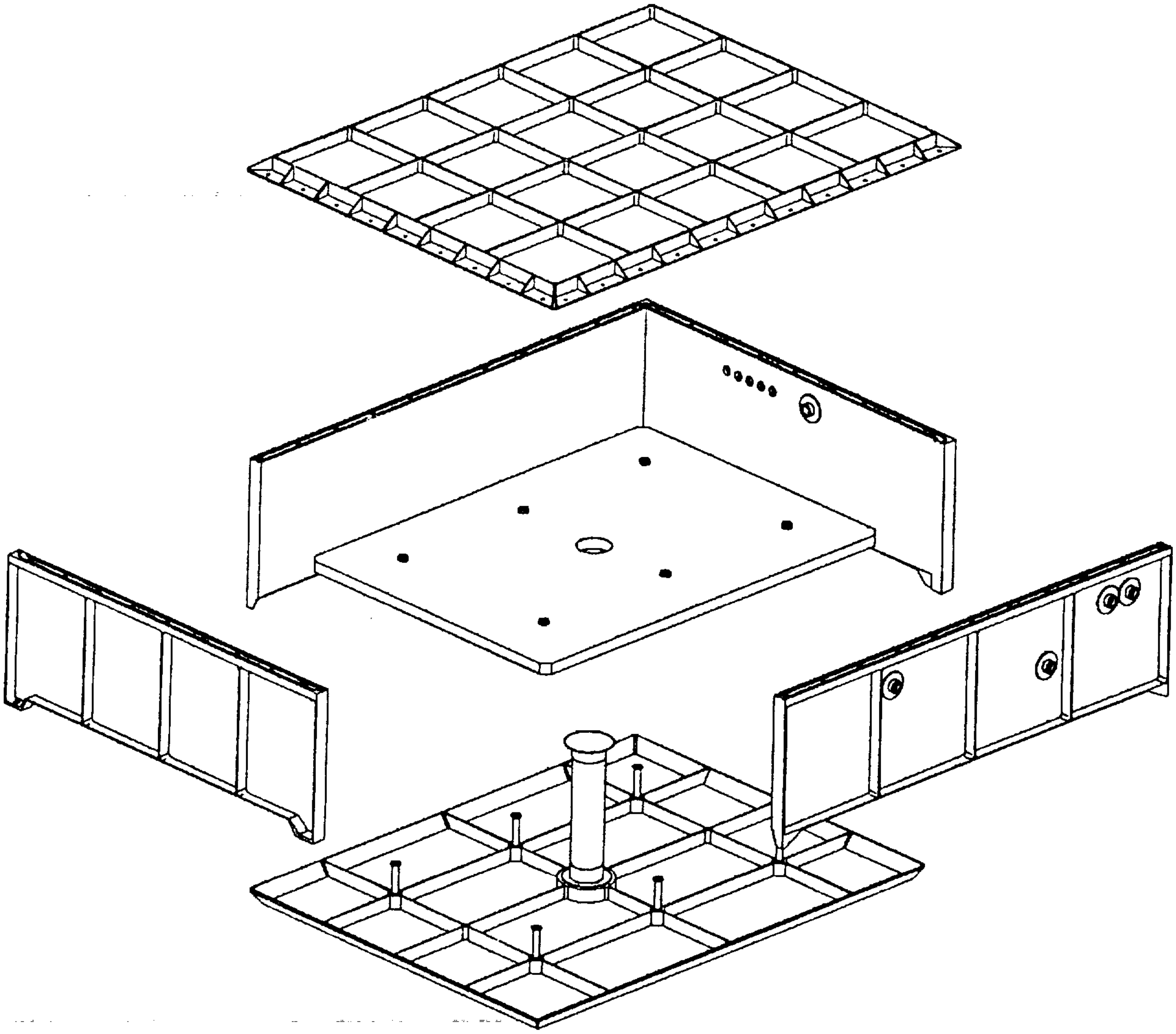


Figure 3-7, Exploded View of Cold Valve Box Structure

A combination port (not pictured) provides vacuum pump-down and pressure relief for the CVB in the unlikely event of an internal nitrogen leak.

Six thin-walled G-10 tubes (posts) attached to the component mounting plate provide thermal isolation and structural support. To maintain structural integrity and to prevent vacuum-induced buckling of the top and/or bottom plates, a large diameter G-10 support tube is located in the center of the CVB. The support tube is isolated from the component mounting plate for thermal considerations. Figure 3-8 illustrates the thermal isolation of the mounting plate.

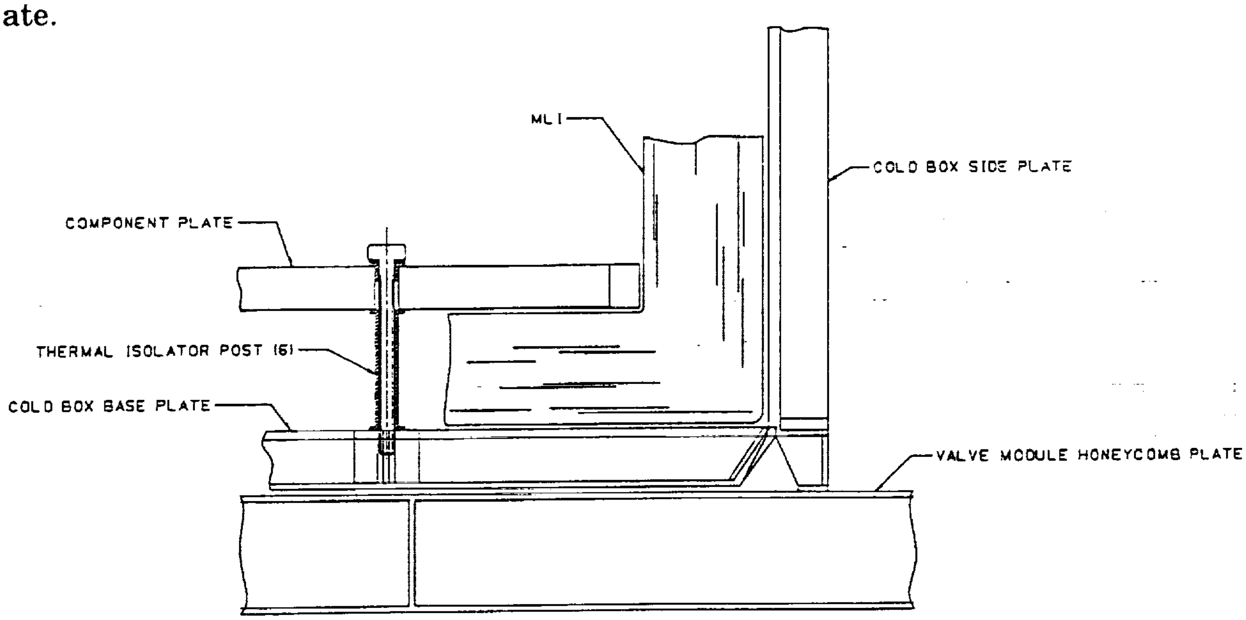


Figure 3-8, Thermal Isolation of CVB Component Plate

There are a total of eleven fluid penetrations into the CVB; five from the supply tank, four to the "warm" valve box (one of which is not shown in Figure 3-7), a line which interfaces with the generic orbiter vent interface, and the ground fill line. Nine of the fluid lines handle LN_2 and are 1.3 cm x 0.071 cm wall (1/2 inch x 0.028 inch wall) stainless steel (SS). The remaining two (downstream sections from JT-3 and V3, as seen in Figure 3-6) are GN_2 lines and are 0.64 cm x 0.051 cm wall (1/4 inch x 0.02 inch wall) SS. Low-conductivity G-10 line sections penetrate the CVB to minimize the heat leak into the CVB. These low-conductivity sections are a minimum of 0.3 m (1 ft.) in length, and have 0.13 cm (0.05 inches) wall thickness. Once inside the CVB the G-10 sections are bonded to the internal fluid lines.

The components mounted in the CVB are itemized in Table 3-1. These include the supply tank fill valve (V5), horizontal drain valve (V4), both the horizontal and vertical vent valves (V7 and V6, respectively), a redundant set of liquid outflow valves (V9 and V10), the vertical contingency vent manifold (CRV-1 and BD-1), the horizontal contingency vent manifold (CRV-2 and BD-2), the active TVS heat exchanger outlet valve (V3), subcooler heat exchanger (includes V8, JT3, and CV2), the manual fill close valve, and the fill bayonet.

3.2.2 "Warm Valve Box (WVB)

The WVB is an aluminum support structure which contains thirty-nine different fluid components. A list of these components and a flow schematic are shown in Table 3-1 and Figure 3-9.

COMPONENT*		SIZE		LOCATION				
TYPE	NUMBER	1.3 cm (1/2 in)	0.65 cm (1/4 in)	PV/VS	COLD VALVE BOX	GN2 MODULE	WARM BOX	TOTAL
Cryogenic Relief Valves	CRV1 - CRV2	2	0	0	2	0	0	2
Cold Valves	V1 -V10	10	0	2	8	0	0	10
Solenoid Valves	V11 - V34	8	16	0	0	6	18	24
Manual Valves	V35 - V36	1	1	0	1	0	1	2
J-T Expander Valves	JT1 - JT4	0	4	3	1	0	0	4
Check Valves	CV1 - CV16	2	14	0	1	10	5	16
Burst Disks, Cold	BD1 - BD2	2	0	0	2	0	0	2
Fixed Orifices	FO1 - FO2	2	0	0	0	0	2	2
Pressurant Tanks	PT1 - PT4	-	-	0	0	4	0	4
Flowmeters	FM1 - FM7	-	-	0	0	1	6	7
Pressure Regulator	PR1 - PR7	-	-	0	0	0	7	7
Relief Valves	RV1 - RV2	0	2	0	0	2	0	2
Mixer	MX	-	-	1	0	0	0	1
Heat Exchangers	HX	3	0	1	2	0	0	3
Cryogenic Bayonets	CB1	1	0	0	1	0	0	1
			TOTAL	7	18	23	39	87

Liquid/Fill Lines	1.3 cm (1/2 in)
Gas Lines	0.65 cm (1/4 in)
Tank Vent Lines	1.3 cm (1/2 in)
Mixer inlet/outlet	1.9 cm (3/4 in)

* All components previously flight-qualified

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Table 3-1, CONE Fluid Component Sizes and Locations

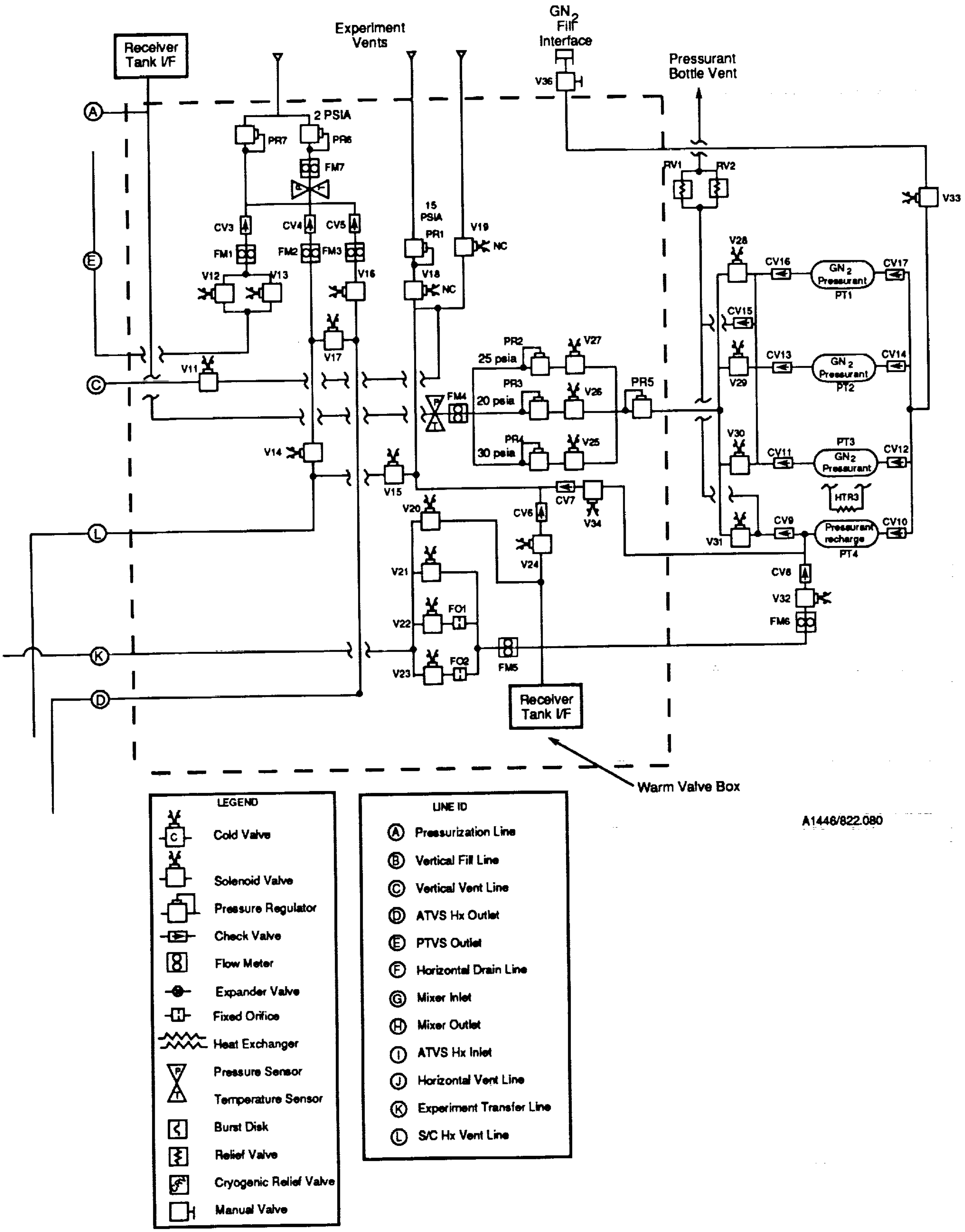

Figure 3-9, Warm Valve Box Fluid Schematic

The WVB is constructed by screwing a series of aluminum panels to a welded aluminum skeleton, providing simple access by removal of the appropriate panel. The overall volume of the WVB is 0.39 m^3 (13.81 ft^3). Both the WVB and the CVB are mounted onto a honeycomb plate which is attached to the side panels of the HH-M. Figure 3-10 illustrates this mounting scheme. All fluid lines penetrate the side panels, and all components mount to the bottom plate.

3.2.3 Interconnecting Fluid Lines and Functions

A set of five (5) vacuum-jacketed LN_2 lines connect the supply tank to the CVB. Four of these lines are 1.3 cm (1/2 inch) x 0.071 cm wall (0.028 inch) and one is 0.64 cm (1/4 inch) x 0.051 cm wall (0.02 inch). These lines follow a vacuum-jacketed line run which contains 20 layers of double aluminized mylar and rayon net. The remaining fluid lines are uninsulated and provide supply tank pressurization, the flow paths to the WVB, and experiment/contingency vent paths.

To comply with shuttle safety requirements, CONE must provide normal and contingency vent paths for horizontal and vertical orientations. Two identical manifolds containing an isolation valve, cryogenic relief valve, and a burst disc provide redundant tank overpressurization protection. In the unlikely event of a leak from the pressure vessel into the vacuum space of the supply tank, the redundant pump-out ports used for vacuum acquisition contain relief mechanisms. Line overpressurization will be avoided by software interlocks and operational procedure.

Only two valves are non-latching normally-closed solenoid type; V18 and V19 located in the WVB. All others are either motor-driven "cold" valves (identical to those used in the SHOOT program) or are latching solenoid valves. To operate any valve in the system, all other critical valves are polled as to current correct position, before the selected valve is powered up. Flow control for LN_2 outflows is accomplished by using fixed orifices on separate parallel paths. A discussion of flow metering is included in section 3.8.

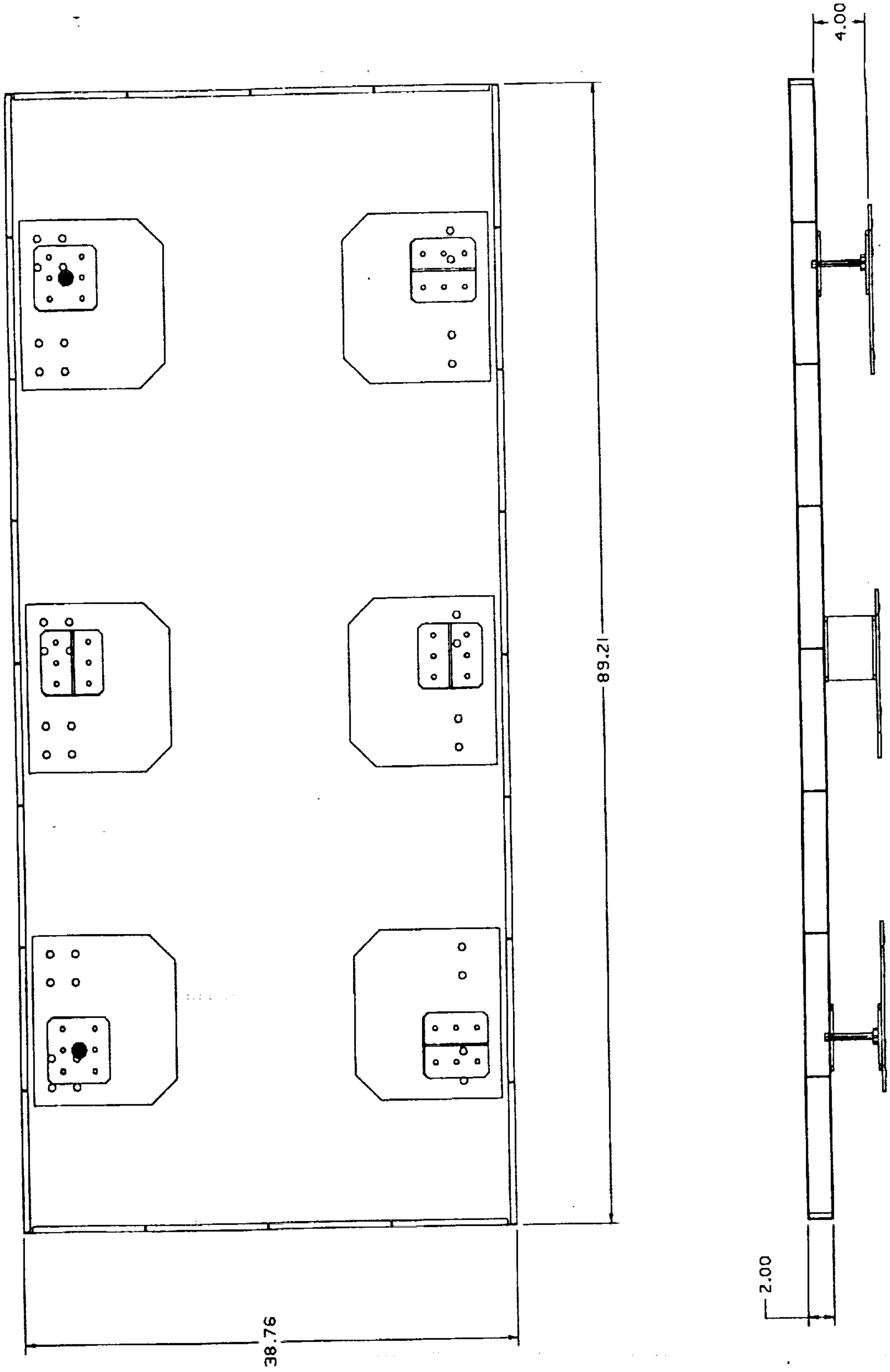

Figure 3-10, Valve Box Honeycomb Mounting Plate

There are three CONE vent paths to space for normal orbital operations, and one vent path for both ground and contingency orbiter operations. The ground and contingency vent is through the CVB. The orbital operation vents are: (1) a 103 kPa (15 psia) back pressure vent for line chill down and continuous liquid outflow, (2) a 13.8 kPa (2 psia) back pressure vent for TVS vent flows, and (3) an open (0 kPa) vent for pressurant bottle and transfer line evacuation. For ground operations a ground support vent line gathers and directs vent gas to a safe location. For flight operations, this line is connected to the generic orbiter vent which allows the supply tank to safely vent outside the payload bay during all contingency operations.

Pressure-drop analysis determined the required vent line size for ground and contingency operations, and the results are summarized in Table 3-2. The vent line diameter was driven by the potential loss of guard vacuum surrounding the pressure vessel. Pressure losses indicated that a 1.3 cm (1/2 inch) vent line is more than adequate.

OPERATION	Q (WATTS)	VENT RATE		FACTOR OF SAFETY	DERIVED VENT DIAMETER
		KG/S	(LB/S)		
Standby	4.7	2.36×10^{-5}	5.20×10^{-5}	—	—
Inadvertent Tank Heaters	40	2.01×10^{-4}	4.43×10^{-4}	—	—
Loss-of-Vacuum	322.3 *	1.62 x 10-3	3.57 x 10-3	10	0.40 in.

* Scaled from loss-of-vacuum test, report #BR16425, March 20, 1987

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Table 3-2, CONE Supply Tank Vent Sizing

Pressure losses were also calculated for selected CONE operations based on estimated flow rates and fluid path length. The results of these calculations are given in Table 3-3. No attempt was made to size the fixed orifices (FO1 and FO2) since it is anticipated that these will be modified when a cryogenic transfer experiment is added to CONE. The liquid-outflow pressure-drop analysis results assumed that the maximum tank pressure of 207 kPa (30 psi) produced the maximum pressure drop.

Operation	Flow Rate		Initial Fluid Pressure		Pressure Drop	
	(kg/hr)	(lb/hr)	(kPa)	(psi)	(kPa)	(psi)
LAD Outflow	136.1	300	207	30	9.31	1.35
Subcooling Flow	131.9	290.8	207	30	8.76	1.27
Passive TVS	0.1	0.2	138	20	<15.9	<2.3
Active TVS	1.8	4.02	138	20	4.3	0.62
Subcooling HX (2-phase flow)	4.2	9.2	103	15	7.1	1.03
Generic Vent	5.9	12.9	345	50	<0.7	<0.1

Table 3-3, Selected CONE Operational Pressure Drops

3.3 PRESSURIZATION SUBSYSTEM

The pressurization subsystem provides warm nitrogen gas for supply-tank pressurization. Gaseous nitrogen (GN_2) is stored in four 0.032 m^3 (1.13 ft^3) bottles at a pressure of 20.7 MPa (3000 psia). All four bottles are manifolded together in the pressurant bottle module through a series of check and solenoid valves which allow for single or multiple bottle use. The schematic of the pressurization subsystem is integrated with the WVB and is shown in Figure 3-9. Figure 3-11 is a conceptual layout of the pressurant module.

The pressurant bottles are formed from 301 series stainless steel. This is a standard Arde, Inc. design for which similar bottles have been space qualified. The Arde design has a working pressure of 22.4 MPa (3250 psia), a safety factor of 2.2, and meets the leak-before-burst criteria. The bottles and most components are attached to an aluminum carrier via the mounting stubs (for the bottles) and brackets (for the fluid components). Figure 3-12 is an exploded view of the pressurant bottle carrier.

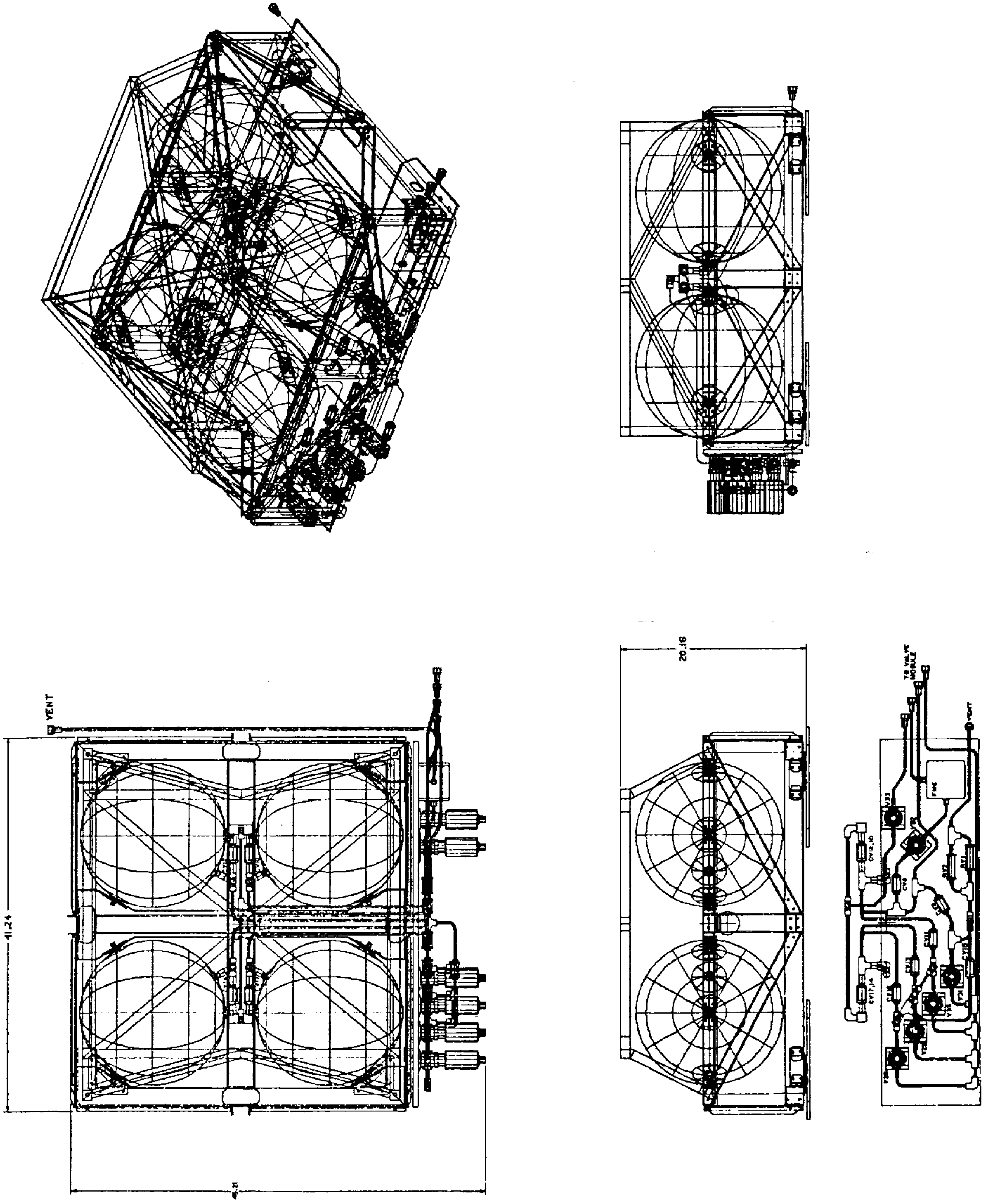


Figure 3-11, Layout of the Pressurant Module

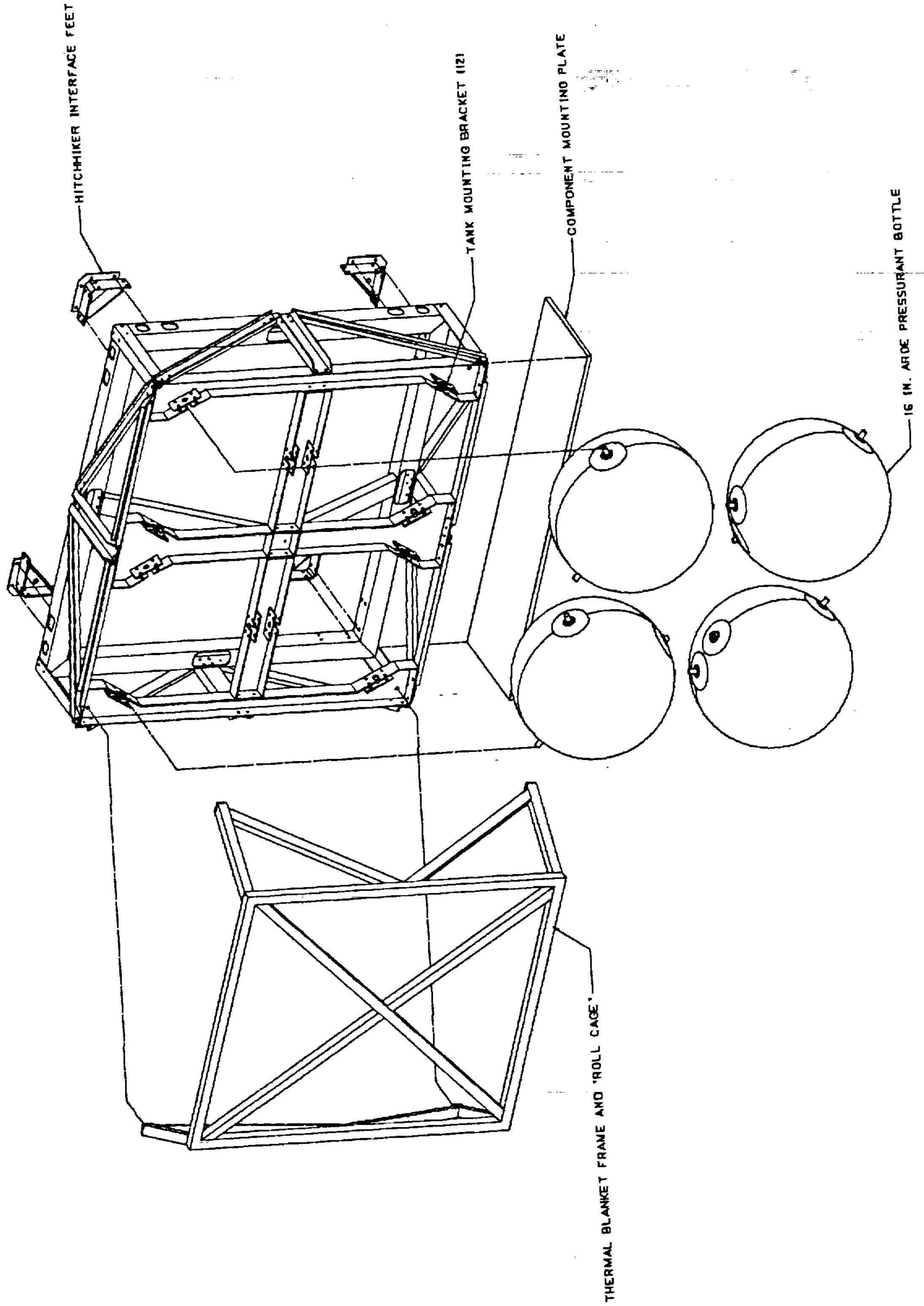


Figure 3-12, Exploded View of Pressurant Bottle Carrier

Pressure from the pressurant bottles is reduced to 1.55 MPa (225 psia) by a high pressure regulator (PR1). The pressure is then further reduced to either 138, 172, 207 kPa (20, 25, 30 psia) by regulators PR2, PR3, and PR4 before the line is routed to the supply tank. A mass flow meter (FM4) is in series with the pressure regulators to monitor and integrate the nitrogen flow rate to determine the total pressurant used. Temperature and pressure are monitored near the inlet to the diffuser so the thermodynamic state of the pressurant is known.

One bottle will be modified and used for the pressurant bottle recharge demonstration. These modifications include the addition of a spray nozzle, heater, and instrumentation necessary to monitor the condition of the bottle during the demonstration. A flow meter and high-pressure cryogenic isolation valve (FM6 and V32) have been included to connect this bottle with LN_2 from the supply tank. The emptying and cooldown venting of this bottle is accomplished by tying the pressurant module into the 0 kPa vent through V34.

3.4 SUPPLY TANK

The supply tank (Figure 3-13) was designed to hold sufficient liquid nitrogen for all the CONE experiments and demonstrations and to provide a test bed for pressure control experiments. It has a 0.48 m^3 (16.9 ft^3) Inconel 718 STA pressure vessel (PV) supported by fiberglass-epoxy struts, 55 layers of multi-layer insulation, and an aluminum girth ring and outer shell.

3.4.1 Supply Tank Trades

A trade study involving five different tank designs was completed to determine the appropriate size and tank configuration for the supply tank. Four existing designs from the Power Reactant Storage Assembly (PRSA) and Space Station Freedom Fluid SubCarrier (FSC) programs were compared with one unique CONE design. None of the existing tank designs were acceptable without modification, and therefore, the trade became a study of required modifications vs. a new design. The PRSA hydrogen tank was eliminated early in the trade study since its inadequate support system would necessitate a complete redesign.

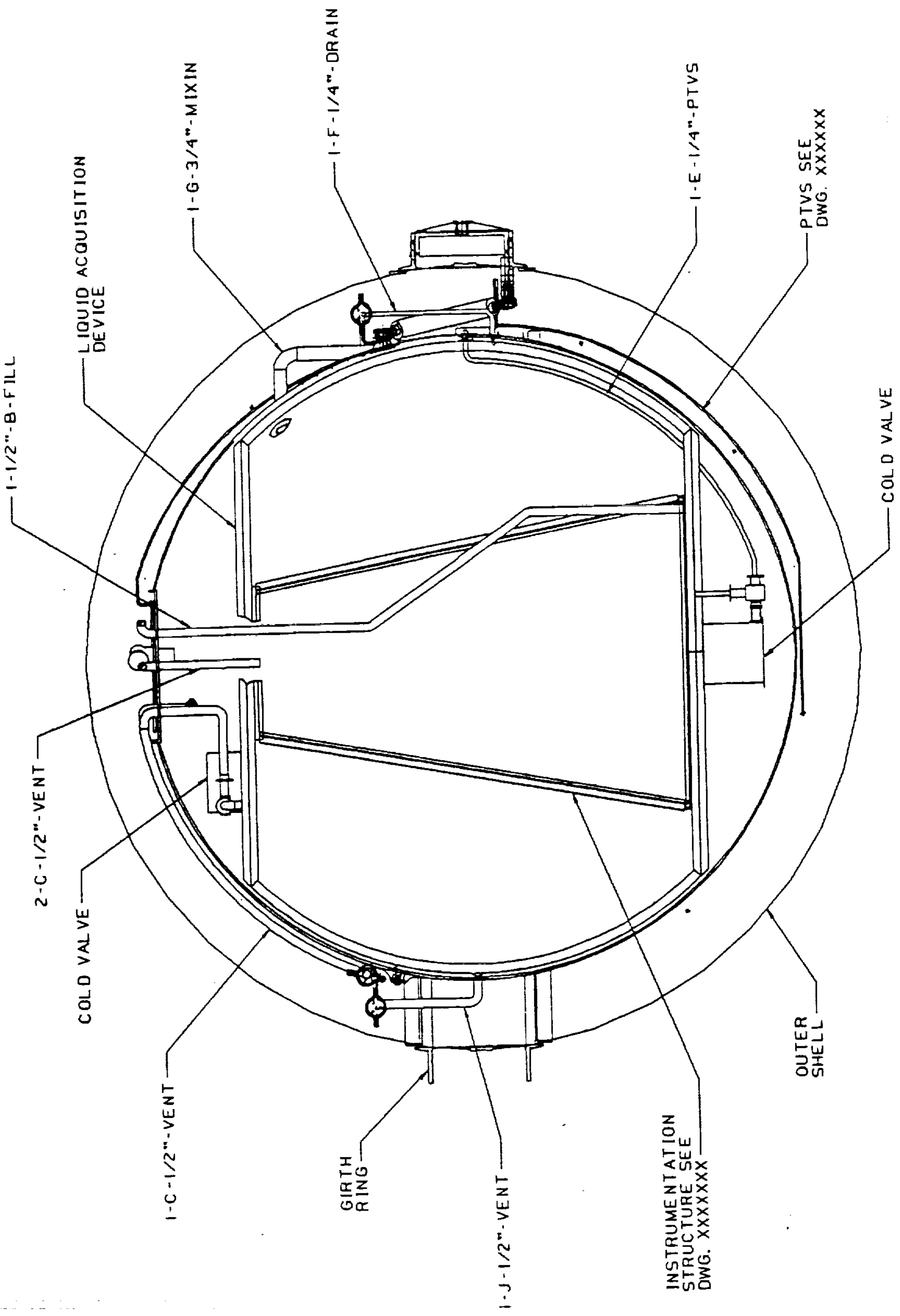


Figure 3-13, CONE Supply Tank

Based on the trade-study results in Table 3-4, the FSC nitrogen tank design was selected for the CONE supply tank.

Weighting Factor	**Feature**	**PRSA O2 with Modified PV**	**FSC N2 with Modified PV**	**FSC O2 with Modified PV**	**New Design**
8	Size	5 40	9 72	5 40	10 80
4	Mass	10 40	7 28	8 32	10 40
3	Number and ease of modifications	3 9	7 21	5 15	10 30
5	Thermal performance	3 15	7 35	8 40	10 50
2	Interior access	7 14	1 2	1 2	10 20
5	Robust design (high margins, allow post-flight mods/welds)	6 30	10 50	10 50	10 50
5	Low cost of qualification	5 25	5 25	5 25	5 25
9	Low total cost	4 36	8 72	8 72	2 18
7	Low development risk	8 56	6 42	6 42	2 14
		5.64	7.38	6.77	6.96

Best possible rating = 10

Raw score	5
Weighted score	25

Table 3-4, Evaluation of Supply Tank Candidates

Several scaling considerations and mission constraints were factored into choosing a tank of the right size. The major factors considered for tank sizing are illustrated in Figure 3-14, and show that the preferred range of tank sizes was from 0.34 m^3 (12 ft^3) to 0.51 m^3 (18 ft^3). Thermal performance considerations are not explicitly identified in Figure 3-14, but revolved around the allowable background heat leak to the supply tank and the appropriate pressure rise within the tank for passive and active thermodynamic vent system studies. A performance band of 1.58 W/m^2 (0.5 Btu/hr-ft^2) ± 20% was established as the desired thermal performance for the CONE supply tank.

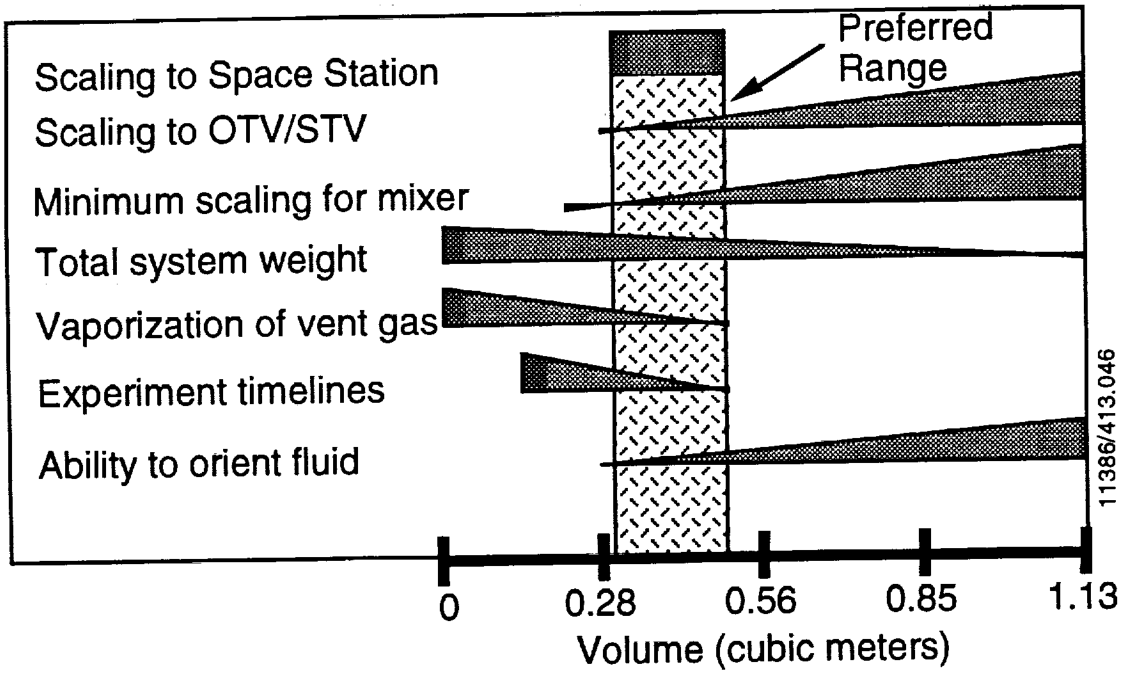


Figure 3-14, CONE Supply Tank Size Requirements

3.4.2 Current Baseline Design

The CONE supply tank is a 0.48 m^3 (16.9 ft^3) warm, 0.47 m^3 (16.6 ft^3) cold, LN_2 dewar having a spherical pressure vessel (PV) and outer shell (OS). Three mounting trunnions are spaced equally around the girth ring section of the OS, as shown in Figure 3-15. All penetrations into the OS are through the girth ring. The OS and girth ring material is 2219T6 aluminum, and the average OS thickness is 1.9 mm (0.074 inch).

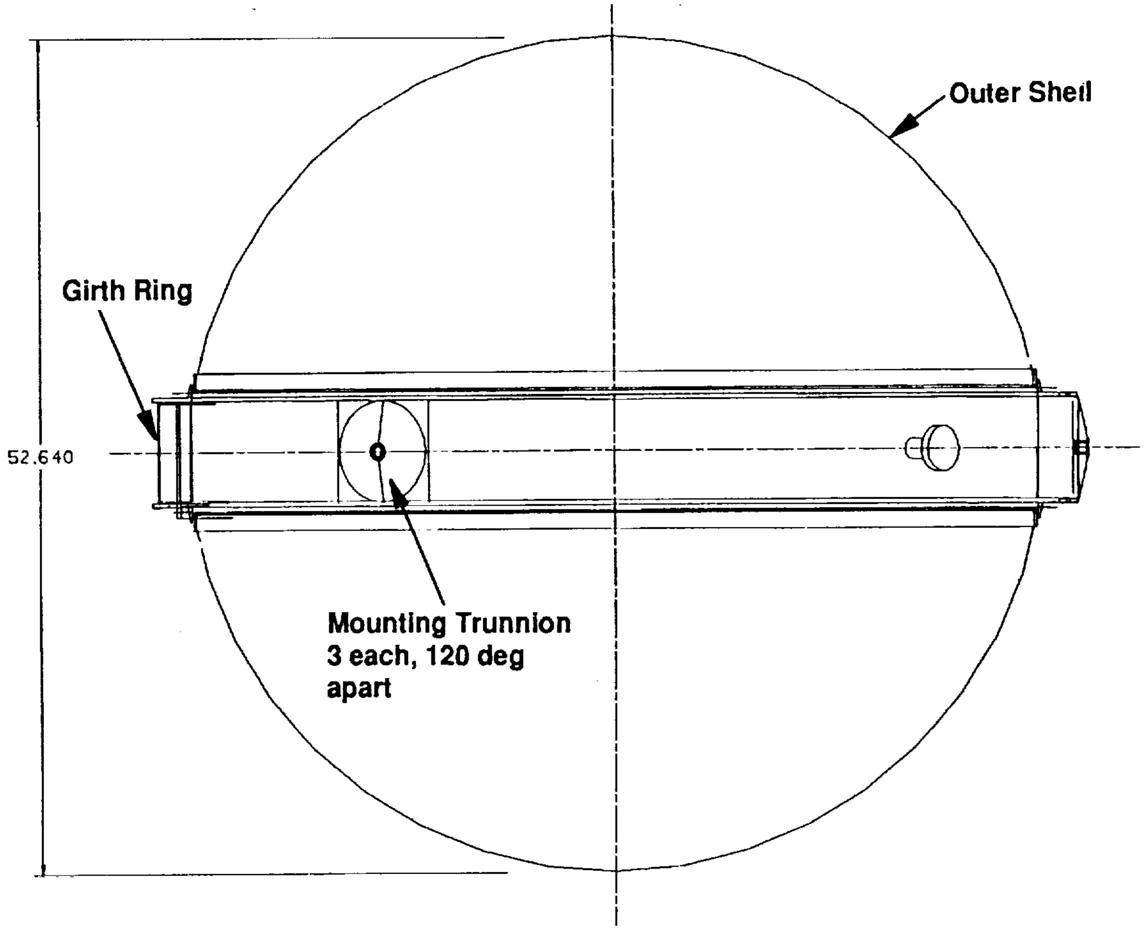


Figure 3-15, Outer View of CONE Supply Tank

The PV is made of Inconel 718 STA with an average wall thickness of 3.3 mm (1/8 inch). A thickened girth section is used for attachment of the support struts and components, PV line penetrations, and welding of the upper and lower domes. Figure 3-16 contains two cut-away views of the supply tank. Two cold valves, a liquid acquisition device (LAD), an instrument tree, and numerous fluid penetrations are located inside the PV. The supply tank has a dry mass of 209.1 kg (461 lbm) and a launch mass of 620 kg (1368 lbm).

1.

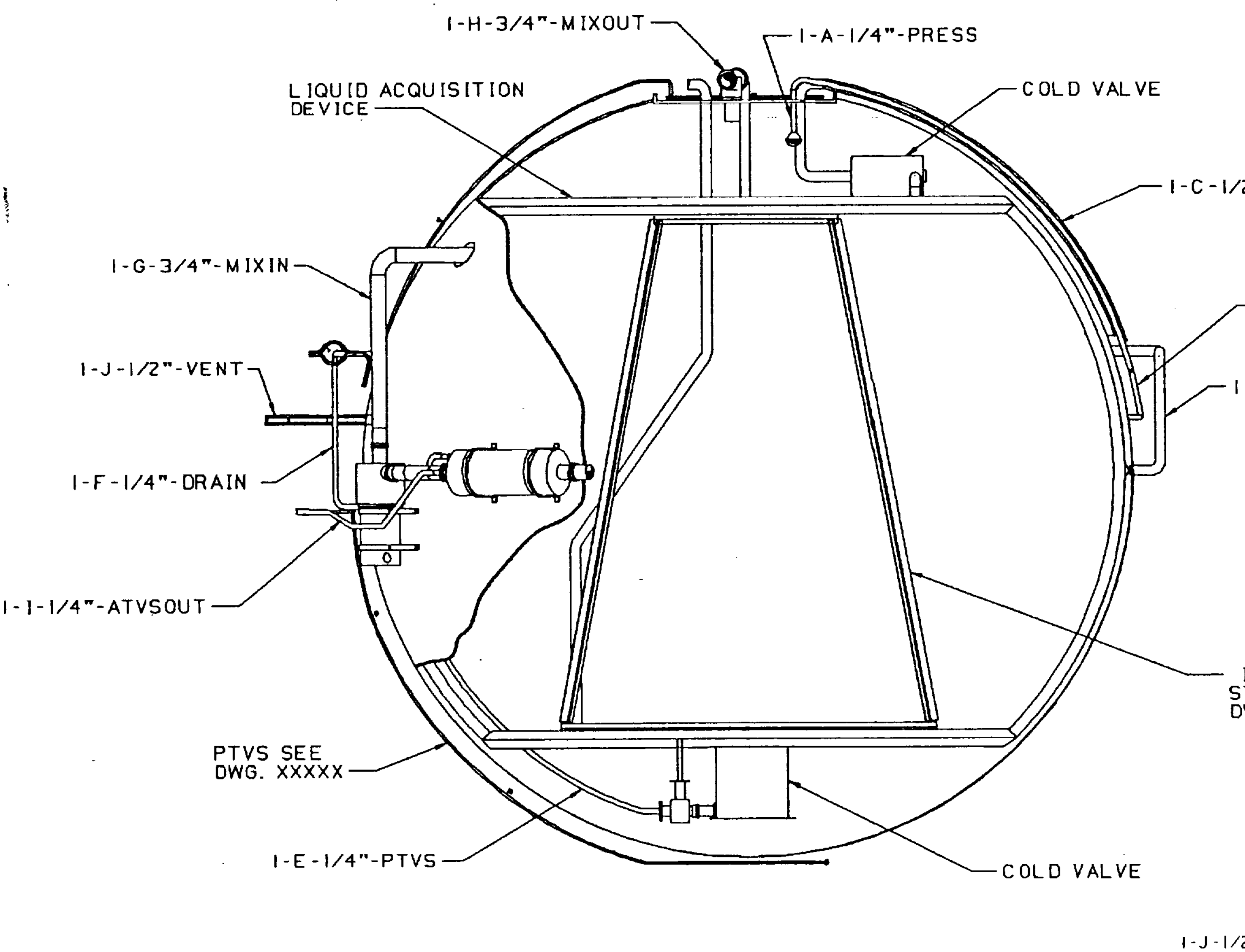
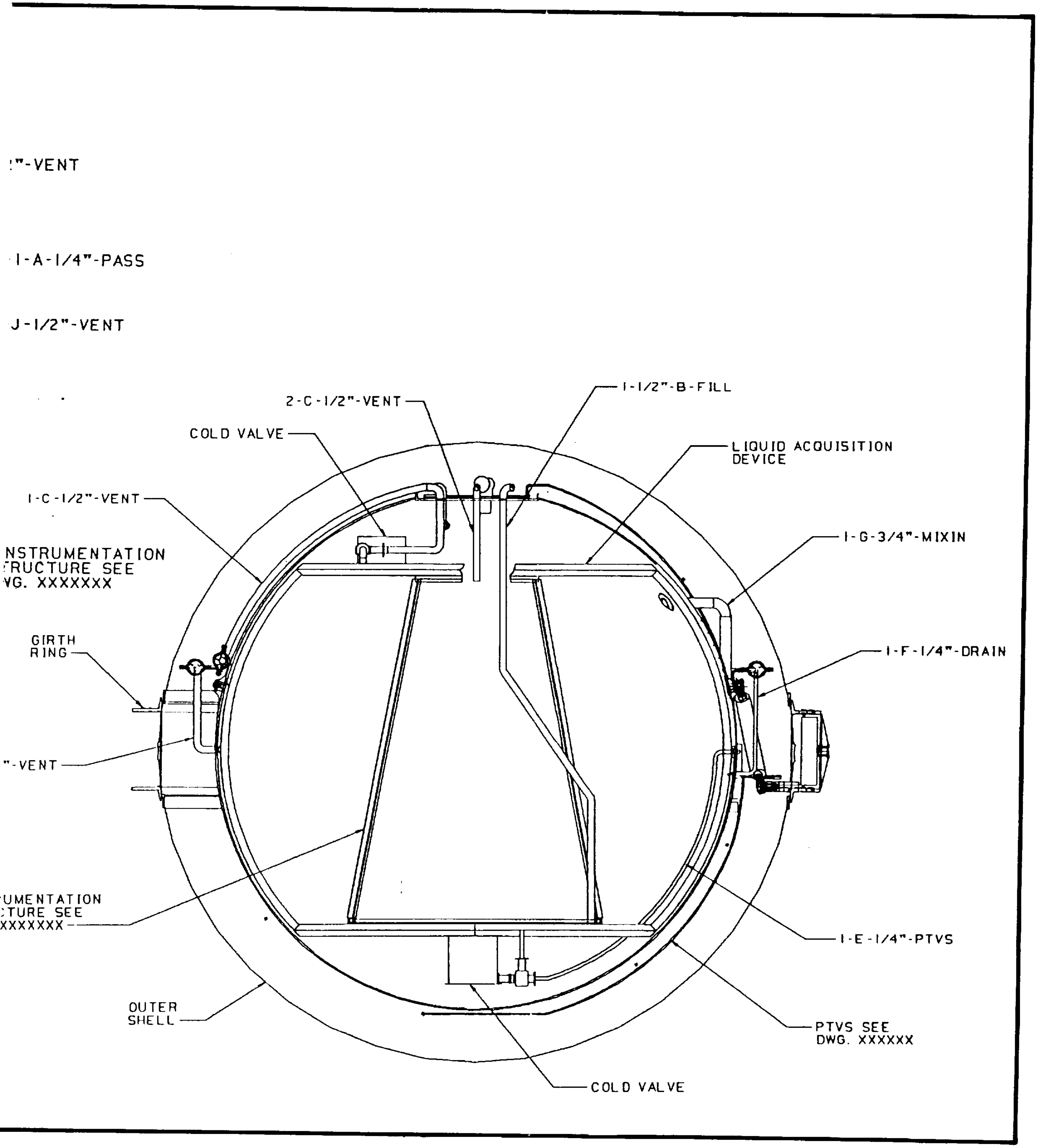


Figure 3-16. Supply Tank Cut-Away Views

2.

FOLDOUT FRAME



The PV is supported by six S-glass epoxy support struts. A 5.1 cm (2 inch) annular space surrounding the PV is filled with a 55-layer MLI blanket made of double-aluminized mylar with nylon net spacers. The mixer, ATVS heat exchanger, and the passive TVS are attached to the outside wall of the PV under the insulation blanket.

The overall thermal performance of the supply tank produces a boiloff rate of 0.5 percent/day. The maximum expected operating pressure (MEOP) is 345 kPa (50 psia), which translates to a ground-hold capability of greater than 300 hours to MEOP. Although the pressure vessel can tolerate pressures up to 6.2 MPa (900 psia), all relief mechanism settings are based on MEOP. Consequently, ground hold times are set by the passive relief components integrated into the overall CONE design.

Five of the fluid penetrations into the PV are routed to the upper dome through a neck assembly (see Figure 3-17). The remaining fluid penetrations are located in the lower PV dome at the thickened girth section and utilize bimetal joints for maintaining PV integrity. All plumbing leaving the supply tank is grouped within the annular space of the tank to facilitate assembly and integration. Figure 3-17 identifies the connection location for each group of lines, and the grouping is further illustrated in Figure 3-18.

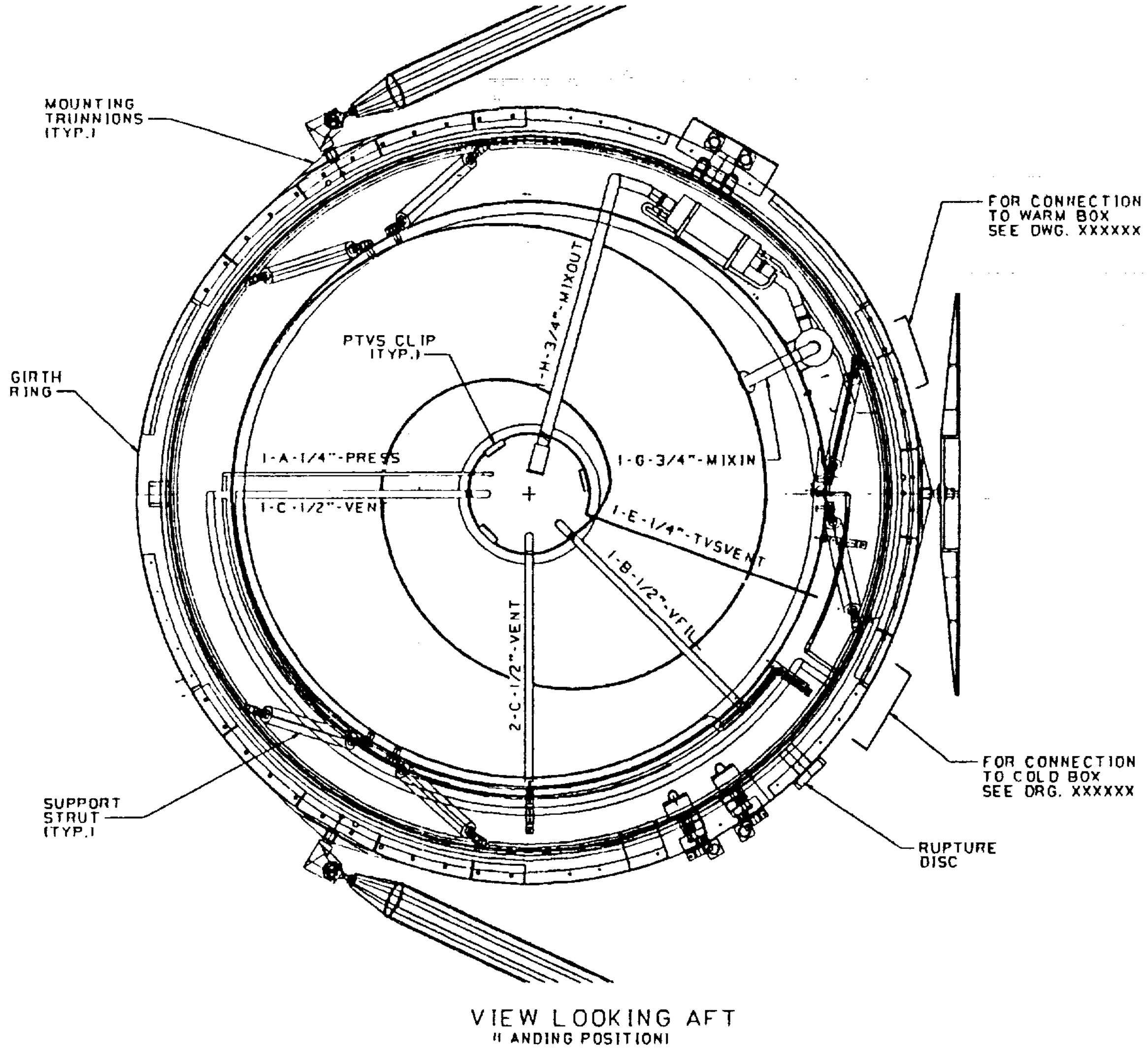


Figure 3-17. Upper Dome Cut-Away of Supply Tank

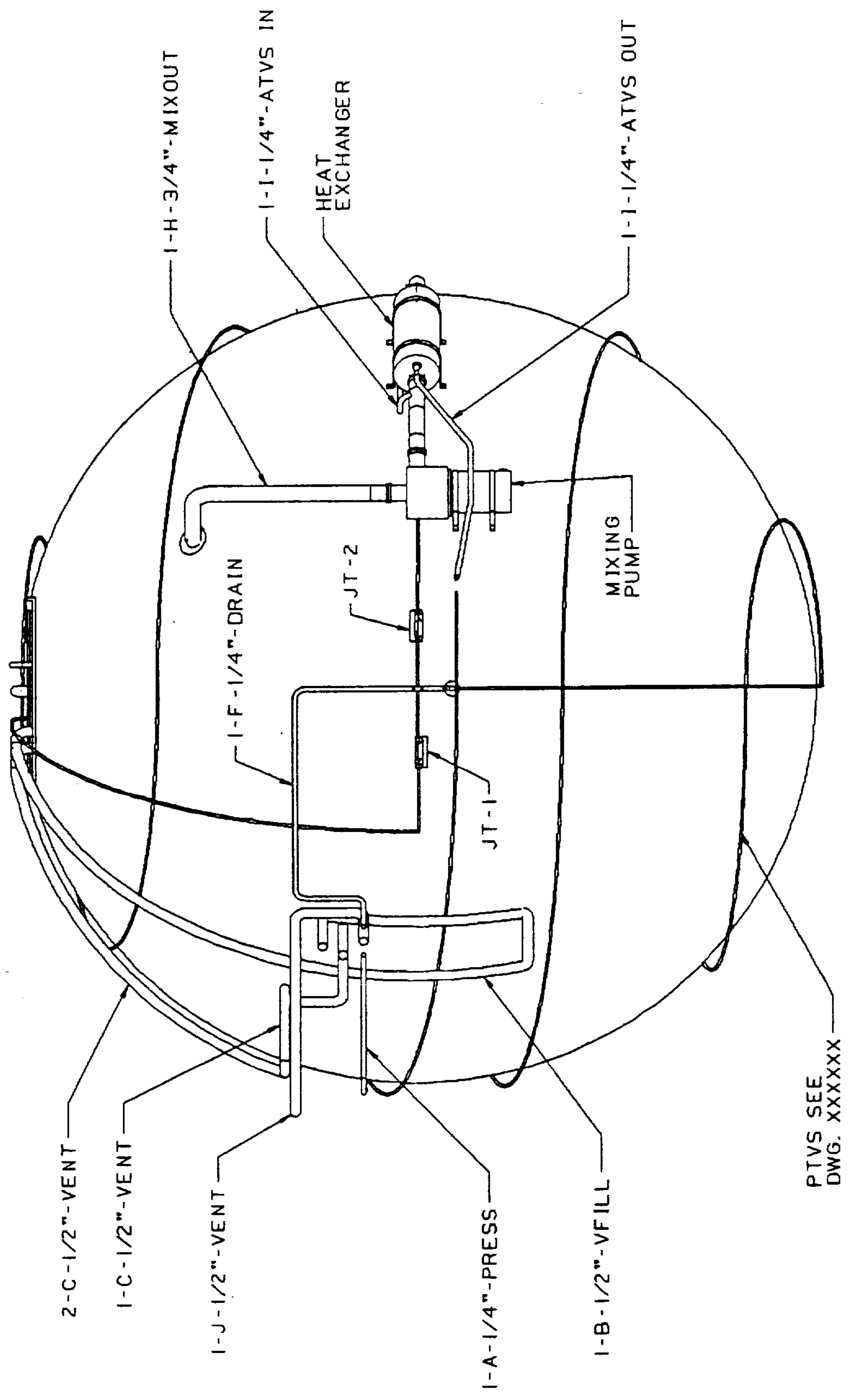


Figure 3-18. External Plumbing of CONE Pressure Vessel

3.4.3 Assembly and Access of the Supply Tank

Ball's extensive experience with the manufacture of cryogenic tanks was used as the data base for determining a production flow plan. The major subassemblies of the supply tank are (1) the upper and lower PV domes, (2) the liquid acquisition device, (3) the instrumentation tree, (4) the PV neck assembly, (5) the OS girth ring and half shells, and (6) the insulation blanket. Figure 3-19 illustrates how the production flow plan would be implemented, including numerous parallel subassembly activities.

Early in the CONE project, a trade study evaluated access methods into the supply tank to replace components for future flights. Access into the PV can be achieved by four different methods depending on how the PV is assembled: (1) bonding joints, (2) mechanical sealing, (3) welded joints, or (4) completely replacing the PV with a new unit. A detailed analysis showed that using a replaceable PV was the least expensive and most time efficient method. This technique allows for rework to begin even prior to complete disassembly of the supply tank. Once access is gained into the PV, the operating components are placed into the new PV domes, the failed components are replaced, and the PV reassembled. Evaluation of the access methods is summarized in Table 3-5.

Access Technique	Advantages	Disadvantages	Status
Bonded Joints	No welding Moderate access	Heavy damage to PV upon removal Complex application procedure	Eliminated
Mechanical Sealing	No welding Almost totally reusable Easiest to gain access	Labor intensive No good cold seals for large-dia. tanks	Eliminated
Welded Joints	Structurally soundest Leakproof Easy to verify	Most difficult to gain access Shielding reqd. for internal components	Optional
Replaceable PV	Same as welded joints Parallel effort Lowest cost	Same as welded joints	Baselined

Table 3-5, Access Techniques for the Supply Tank PV

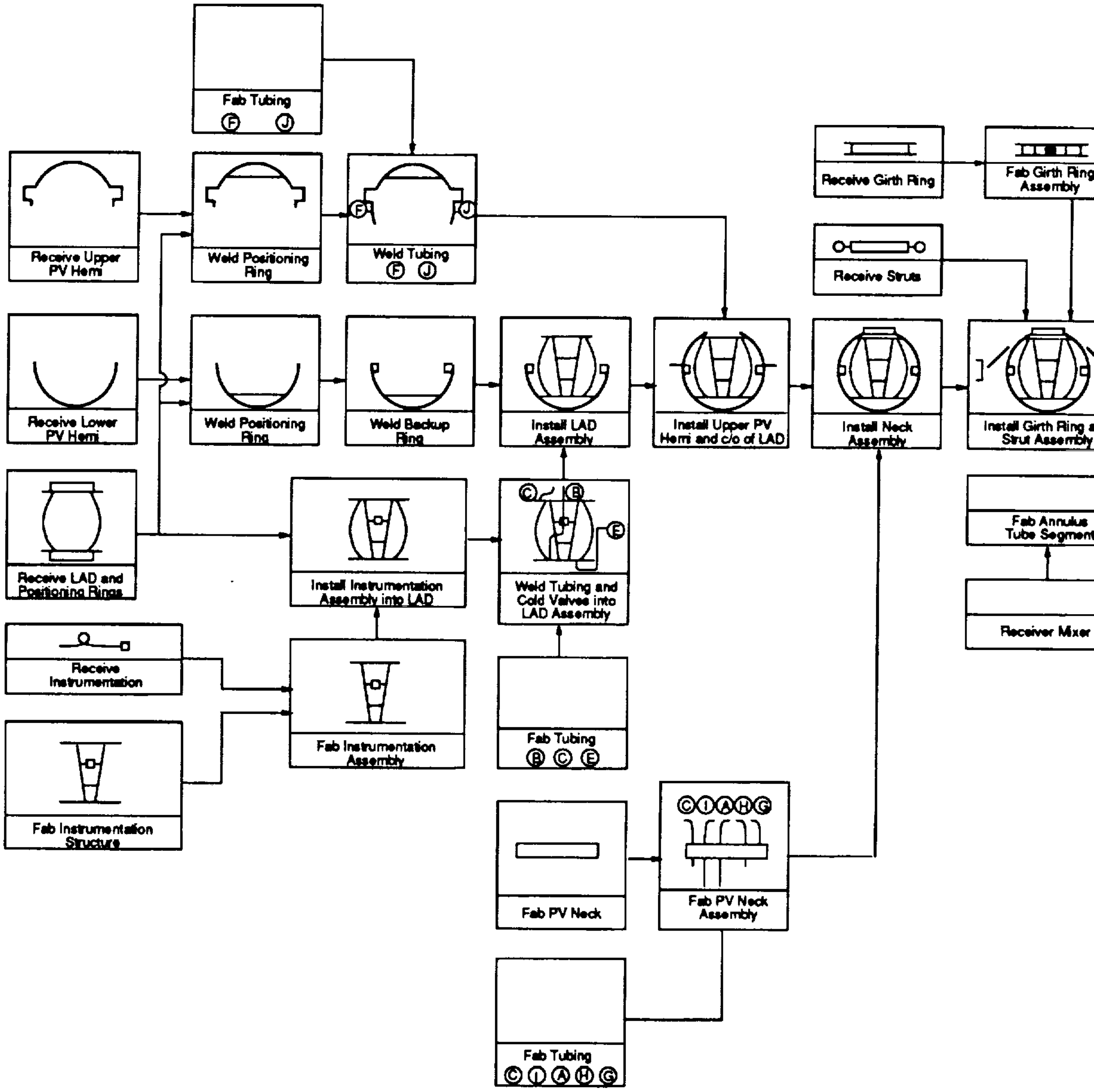
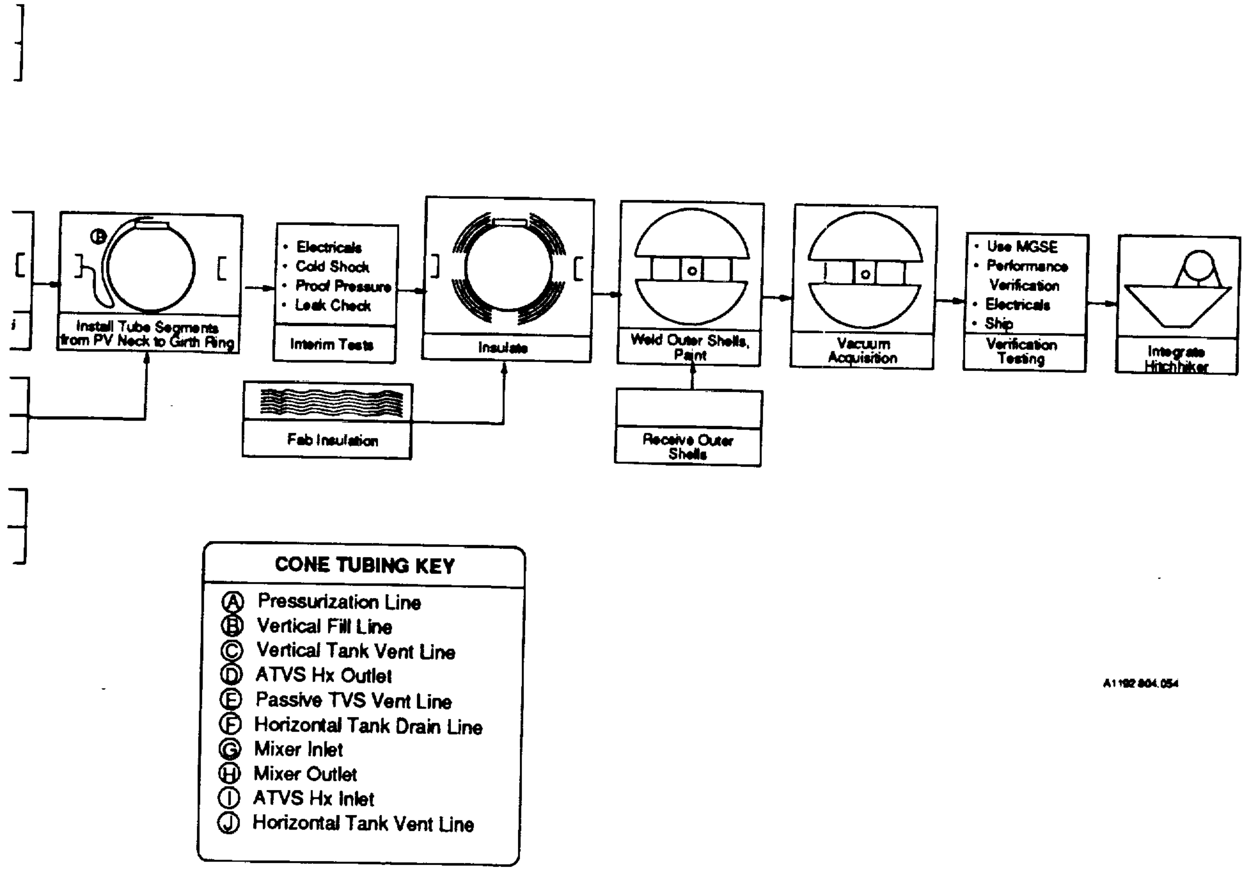


Figure 3-19. CONE Supply Tank Production Flow Plan

1

2.


B
Install Tube Segments from PV Neck to Girth Ring
• Electricals
• Cold Shock
• Proof Pressure
• Leak Check
Interim Tests
Insulate
Fab Insulation
Weld Outer Shells, Paint
Receive Outer Shells
Vacuum Acquisition
• Use MGSE
• Performance Verification
• Electricals
• Ship
Verification Testing
Integrate Hitchhiker
CONE TUBING KEY
Ⓐ Pressurization Line
Ⓑ Vertical Fill Line
Ⓒ Vertical Tank Vent Line
Ⓓ ATVS Hx Outlet
Ⓔ Passive TVS Vent Line
Ⓕ Horizontal Tank Drain Line
Ⓖ Mixer Inlet
Ⓗ Mixer Outlet
Ⓘ ATVS Hx Inlet
Ⓙ Horizontal Tank Vent Line
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3.4.4 Supply Tank Design Analysis

3.4.4.1 Thermal Analysis

The nominal thermal design point for the supply tank was 1.58 W/m^2 (0.5 $Btu/hr\text{-}ft^2$), and therefore, an economical thermal design which met the background heat flux requirement was developed based on standard thermal management methods. Thermal analysis for the supply tank is summarized in Table 3-6.

ELEMENT		Q, Watts
TANK		
MLI 55 Layers		1.20
Wiring 0.25 mm	36 - Cu	0.56
(30 AWG)	174 - Manganin	0.12
Plumbing	0.71 mm (0.028 in) wall	1.17
Supports		0.43
Subtotal		**3.48**
VALVE BOX		
MLI 55 Layers		0.41
Wiring 0.25 mm	14 - Cu	0.26
Plumbing	9 G10 tubes	0.19
Supports	6 G10 supports	0.23
Subtotal		**1.09**
Total		**4.57**
Total Budget		**4.70**
Total Delta		**0.13**

Table 3-6, Detailed Supply Tank Heat Leak Summary

Integrated thermal conductivities of 300 series stainless steel, G-10 fiberglass, and manganin wire were used to calculate conduction heat transfer rates. Heat transfer through the MLI was calculated using a predictive method based on correlations developed in the 1960's and verified on the Apollo and PRSA programs. Assumptions for calculating heat leaks were:

1. Warm and cold boundary temperatures were 300 K and 76 K.
2. All plumbing lines were 6.35 mm or 12.7 mm (0.25 or 0.5 inch) diameter with a wall thickness of 0.71 mm (0.028 inches).
3. Manganin wires of 0.25 mm (30 AWG) were used for all instrumentation except 18 thermocouples which were 0.25 mm copper wire.
4. The plumbing lines and instrumentation wiring had a thermal length of 1/4 of the pressure vessel circumference.
5. Each of the plumbing lines leaving the cold valve box was thermally isolated by a 30.5-cm (12-inch) section of G-10 fiberglass tubing.

The MLI blanket thickness and corresponding heat leak were determined from an optimization curve which accounted for performance degradation at very high layer densities. Since the vacuum space varies in size from 5 cm to 10 cm (2 to 4 inches), the design density of 55 layers in 5 cm represented the optimum MLI performance which could be expected without going to a thicker blanket.

The values in Table 3-6 are probably conservative because they assume that all heat which reaches the cold valve box will be directly transmitted to the supply tank. The cold valve box temperature will be slightly higher than the liquid nitrogen temperature inside the supply tank, but there is no path with large enough temperature gradients for all the heat which enters the valve box to flow into the supply tank. These estimates will be refined in the future when a more detailed model is built.

Supply-tank ground-hold time was estimated from the total background heat leak of 4.7 W using a thermodynamic model. Tank pressure vs. time is plotted in Figure 3-20 for the well-mixed (homogeneous) and stratified (2 times homogeneous) models. Since the stratified model is a conservative estimate of pressure rise, ground-hold times in excess of 10 days will be obtained with the CONE supply tank.

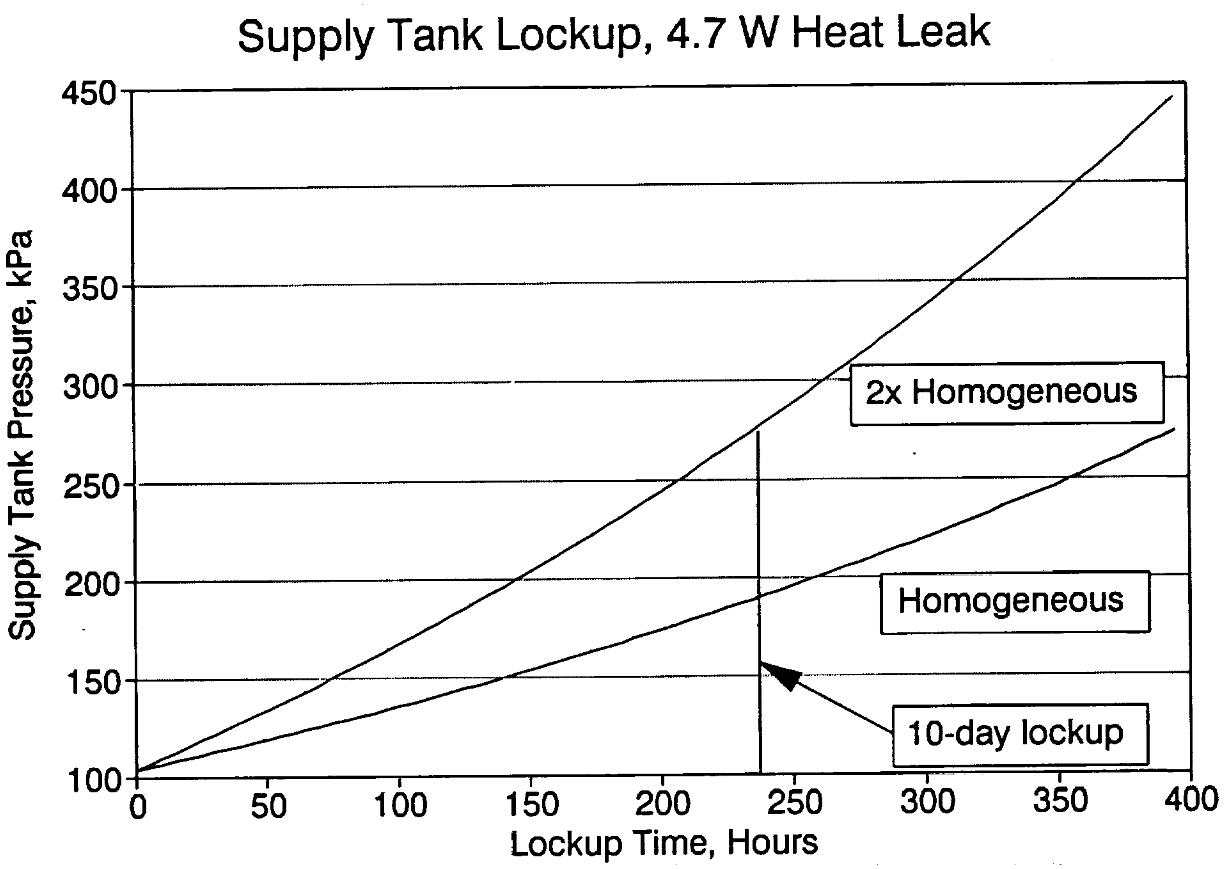

Figure 3-20, Supply Tank Ground Hold is Greater Than 10 Days.

3.4.4.2 Structural Analysis

The NASA Goddard Space Flight Center (GSFC) document HHG-730-1503-05, Hitchhiker Shuttle Payload of Opportunity Carrier Customer Accommodations and Requirements Specifications, was used as a guide in deriving structural performance requirements for the CONE supply tank (Table 3-7).

The structural analysis of the supply tank used COSMOC/M (Version 1.52) for dynamic and stress analysis, NASA/FLAGRO for fracture mechanics analysis, and hand analysis methods. The fracture analysis indicated that the supply tank meets the "leak-before-burst" criteria for the PV membrane and weld joint, with a weld $K_{IL} \geq 44.8$ ksi $(in^{0.5})$ when adjusting for thickness. The critical value for crack propagation $K_C = 53.7$ ksi $(in^{0.5})$.

- Factors of Safety:
  - With Test Verification: Ultimate FS = 1.4
  - Without Test Verification: Yield FS = 2.0, Ultimate FS = 2.6
  - Pressure vessels, lines, fittings, etc., per NSTS 1700.7B
- Materials:
  - Select for high resistance to stress corrosion cracking per MSFC-SPEC-522
  - Obtain properties from MIL-HDBK-5D
- Preliminary load factors:
  - Include the following components: (a) Steady State, (b) Low-frequency transient, (c) High-frequency vibroacoustic
  - Accelerations act through payload CG
  - Simultaneous and all combinations of sign
  - Preliminary load factor table:

Translation (g's)			Rotation (r/sec^2)		
$\bar{x}$	$\bar{y}$	$\bar{z}$	θ_x	θ_y	θ_z
± 11	± 11	± 11	± 85	± 85	± 85

- Final load factor determined by coupled loads analysis
- Fundamental frequency > 35 Hz hard-mounted to equipment-carrier interface

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Table 3-7, CONE Structural Design Requirements

Predicted resonant frequencies for the supply tank are given in Table 3-8. All frequencies except modes 1 and 2 exceed the 35 Hz requirement. Adjustment of the A/L from 0.42 to a slightly higher value will stiffen the primary structure and raise the corresponding frequencies above 35 Hz, however time and funds did not allow for this effort under the current contract. Table 3-9 summarizes the margins of safety for the major structural components of the supply tank.

Mode	A/L = 0.42 Primary Structure FN, Hz	A/L = 0.42 Secondary Structure FN, Hz	Remarks
1	31.3	40.8	X Translation
2	31.3	40.8	Y Translation
3	41.6	63.5	Z Translation
4	99.7	146.1	Rotation about X
5	99.7	146.1	Rotation about Y
6	142.5	186.2	Rotation about Z

Θ and Z constrained at trunnion locations

Table 3-8, Supply Tank Predicted Resonant Frequencies

Component	Material	Critical Load Case	Minimum Margin of Safety
• Pressure vessel			
– Parent material	Inconel 718	Liftoff 1,3	0.8 (ultimate) Bending and tension
– Weld joint	Inconel 718 EB (post-weld age)	Liftoff 1,3	3.4 (ultimate) Bending and tension
• Support struts	Filament wound composite (A/L = 0.42 cm)	Liftoff 1,3	0.53 (ultimate) Buckling
• Girth ring	2219-TL Aluminum	Liftoff 1,3	0.14 (yield) Bending, tension, and shear
• Outer shell	2219-TL Aluminum	Ground transport and storage	0.12 (ultimate) Buckling
• LAD	304L	Liftoff 1,3 with preload	7.15 (ultimate) Bending, tension, and shear

612 kg (1,350 lbs) supported weight

Table 3-9, Margin of Safety Summary Table

3.5 RECEIVER TANK INTERFACES

To gain the most pertinent information from a cryogenic fluid management (CFM) flight experiment, fluid transfer should be included. The baselined CONE design does not include a transfer experiment. To allow for future expansion as a CFM test bed, receiver-tank interfaces have been identified to minimize the design impact of adding a transfer experiment.

Several interfaces have been identified which would ease the integration of the transfer experiment into the baselined CONE design without exceeding the constraints of the HH-M carrier. These interfaces are defined as structural mounting points, a liquid transfer connection, and a pressurization connection.

The structural interfaces are required to mount the receiver tank within the CONE envelope. A receiver tank mass simulator (RTMS) was added into the baselined CONE design to minimize the impact of geometric, packaging, and verification requirements . Adding the RTMS produced a design which can readily add a receiver tank without a complete redesign. Figure 3-21 shows the location and orientation of the RTMS.

The RTMS represents a 0.18 m^3 (6.3 ft^3) cryogenic tank. It occupies a cross-sectional area of 0.35 m^2 (3.76 ft^2) and a HH-M length of 67.3 cm (26.5 in). The mass estimate of 171.5 kg (378.0 lb) was developed assuming that the receiver tank would be filled with LN_2 and would include a vacuum jacket and all required fluid components.

Figure 3-21 is a conceptual design of the RTMS. Mounting at five points on the HH-M allows several tank geometries to be considered for the receiver tank. The bulk of the mass is provided by a series of steel plates suspended in such a manner as to place the RTMS CG at the anticipated receiver-tank location.

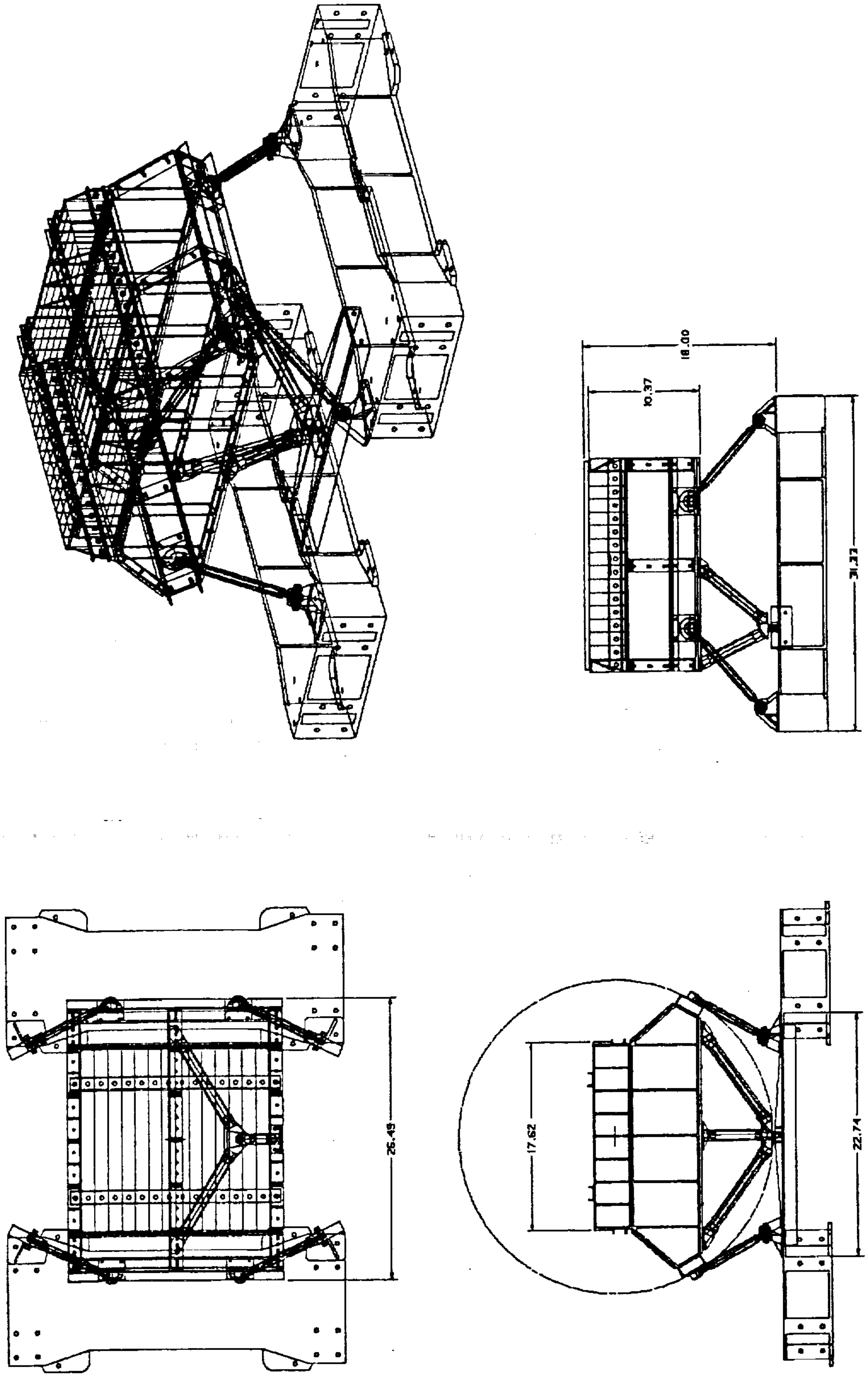


Figure 3-21, RTMS Design

3.6 LAD DESIGN AND ANALYSIS

3.6.1 LAD Design

The liquid acquisition device (LAD) is designed to guarantee vapor-free liquid discharge from the supply tank. The LAD is required to support the liquid outflow and expulsion efficiency tasks. Table 3-10 is a LAD design requirements summary.

Category	Requirement	Comments
Experiment objectives and priorities	>98% expulsion efficiency	Foremost LAD development objective. Other objectives impractical with Shuttle/CONE limitations
Experiment selection	Final expulsion under background acceleration	With single tank draining and CONE limitations, priority goes to uncertain liquid location
Parameter selection	Brief, highest achievable adverse acceleration	Brief adverse accelerations useful at highest level available
Parameter selection	Highest available outflow rate	Preferred to demonstrate expulsion with stresses representative of operational scenario
Measurements	Quantify residuals and LAD breakdown	Minimal new instrumentation required
Ground checkout and servicing	Checkout: Tank assembly-level flow tests Servicing: LAD and open flow paths full of liquid; high tank fill level (>95%)	Essential for reliability
Flight operations	LAD fill sustained through launch. Restart outflow with 80% empty tank	No screen exposed during launch. Complementary to LAD demonstration

Table 3-10, LAD Design Requirements Summary

A four-channeled, stainless steel, continuous curvature LAD was chosen for CONE. The channel screen surface through which bulk fluid is acquired is adjacent to the PV wall and is supported by a perforated plate (60% porosity). The 200 X 1400 stainless twilled double dutch weave (TDDW) screen is stitch welded into a triangular stainless-steel channel, with a base (screen side) of 3.2 cm (1.25 inch) and a height of 1.9 cm (0.75 inch). The LAD is axially aligned in a horizontally mounted tank within the orbiter payload bay to accommodate ground and flight fill/drain operations. The LAD is assembled in parallel to the supply tank and is integrated into the tank just prior to welding the PV together. The LAD is positioned and mounted via a positioning ring which also functions as a compression/shrink fit. Figure 3-22 summarizes the LAD design.

3.6.2 LAD Analysis

The objective of the liquid outflow and expulsion efficiency testing is to (1) demonstrate the ability of the LAD to supply vapor-free liquid and (2) determine its ability to expel the vast majority of liquid from a source supply.

The ability of the screen channels to function as liquid acquisition devices is based on their ability to remain filled (liquid retention) even when not completely submerged in the bulk fluid of the tank. Upon channel exposure to the ullage, a liquid-vapor interface is established at the screen due to surface tension. This interface has the capability to resist the passage of vapor into the channel (i.e., withstand a pressure drop from the ullage to the inside of the channel). The pressure capability of the interface is defined by the bubble point (denoted as a pressure drop), which is characterized by the liquid surface tension and the screen pore size. When the pressure difference across the LAD exceeds the bubble point, the liquid-vapor interface "breaks down" allowing vapor to pass into the LAD which will terminate vapor-free liquid flow.

The LAD screen is designed to not break down over the range of liquid outflow. It would have been desirable to apply an adverse stress g-load ($\geq 10^{-3}$ g's) during a high outflow and try to break down the LAD towards the end of the mission, but due to operational constraints of the STS and screen sizing necessary to minimize risk to the overall LAD testing this will not be possible.

FOLDOUT FRAME

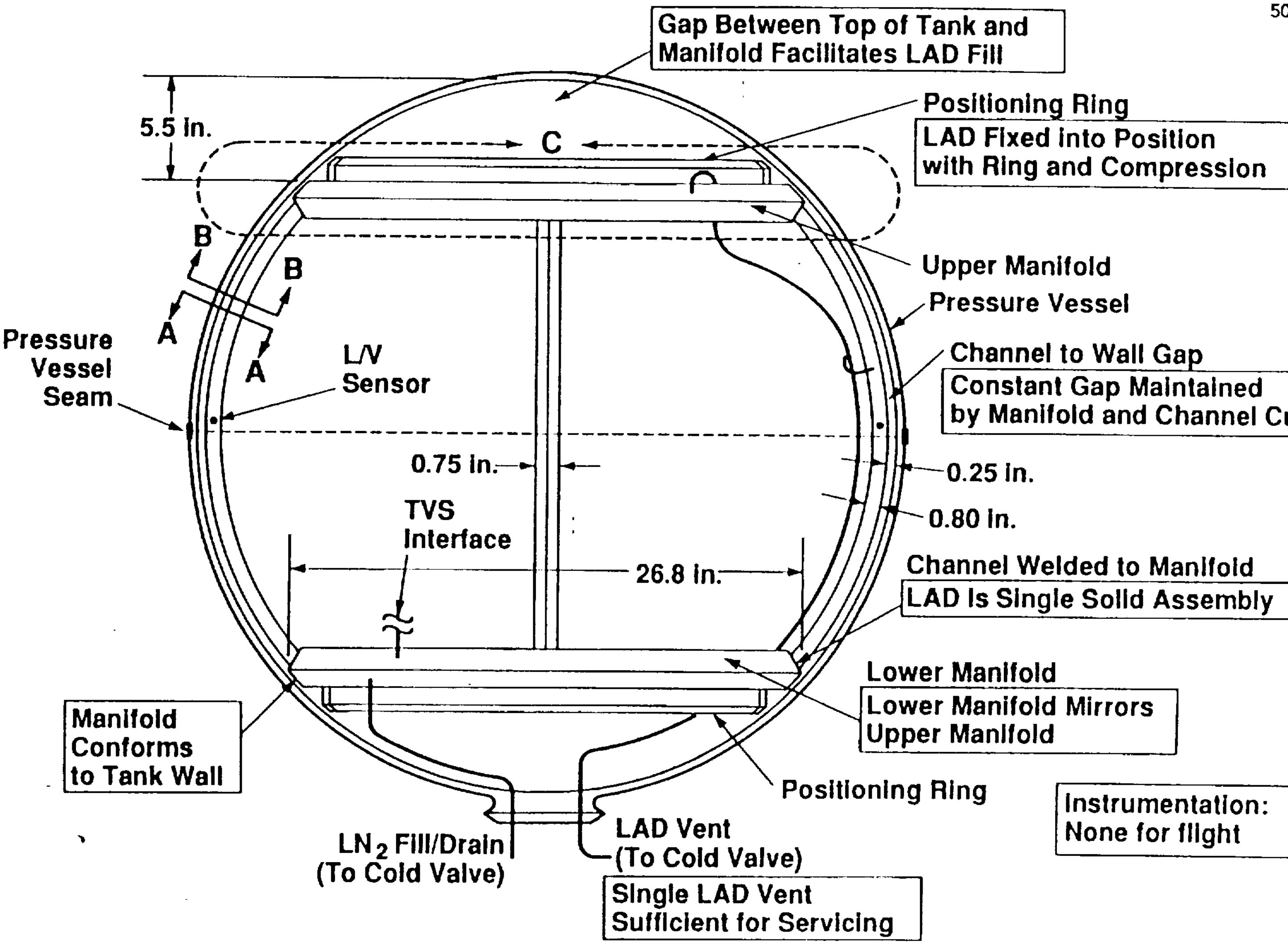
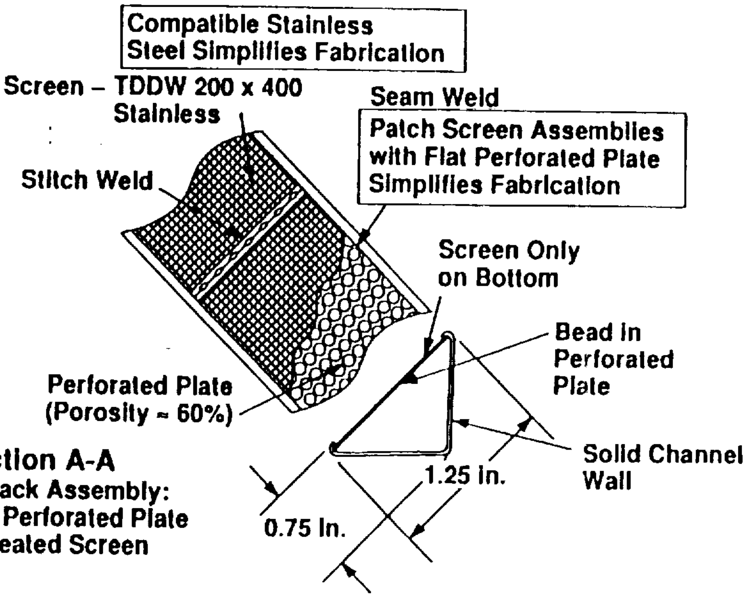


Figure 3-22. Summary of CONE LAD Design

2.

512 T10CJ



Section A-A

Screen Pack Assembly: Showing Perforated Plate and Unpleated Screen

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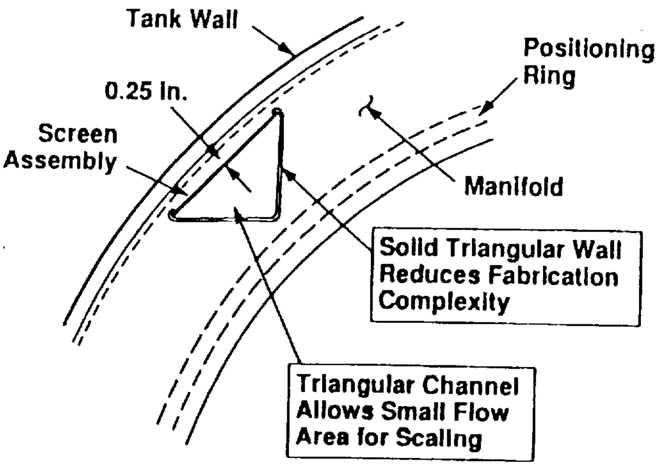
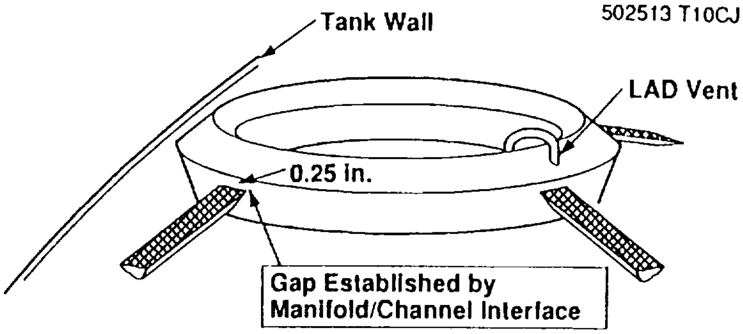


Section B-B

Compression Fit Support Scheme: Showing Conformed Manifold Establishing Wall Gap (After Compression) Between Tank Wall and LAD Screen

502513 T10CJ



Rotated View at C

Upper Manifold Assembly: Conforms to Tank Wall and LAD Vent

3.7 TVS Design and Analysis

There are three TVS systems installed on CONE: the active and passive pressure control systems, and the liquid subcooler. Of these three, the subcooler and active TVS require forced-flow heat exchangers with similar (but not identical) operating characteristics. Consequently, a common design which could be used for both the active TVS and subcooler would be desirable. The passive system is thermally connected to the supply tank at numerous points and requires a unique design, since there is no induced flow on the warm side of the heat exchanger.

In each TVS system, fluid from the LAD manifold or directly from the supply tank is fed into a Joule-Thomson valve where it experiences a pressure reduction from its entering condition to a lower pressure in the range of 14 to 34 kPa (2 to 5 psia). As the fluid expands across the valve, it cools and some liquid vaporizes to produce a 2-phase mixture. The liquid remaining in this mixture provides the source of cooling for heat exchange with the warm fluid (either tank fluid or outflowing liquid). All TVS systems were sized based on 100% saturated liquid entering the JT valve at either 103 kPa (15 psia) for the active and passive systems or 138 kPa (20 psia) for the subcooler. The TVS flow rates are controlled by opening and closing valves downstream of the JT; no attempt to vary the size of the expansion orifice was made.

3.7.1 Active TVS and Subcooler Designs

Requirements for the ATVS and subcooler TVS's are summarized in Table 3-11.

System	TVS Mass Flow (g/min)	Thermal Capacity (W)	Warm Side Flow (kg/min)
ATVS	30.4	94	11.1
Subcooler	69.6	222	2.27

Table 3-11, Requirements Summary for ATVS and Subcooler TVS

In addition to these design requirements, other requirements for the CONE forced-flow heat exchangers were:

1. Compact size to fit in vacuum annulus (active TVS).
2. Low pressure drop (<<7 kPa (1 psi) for liquid side, <20 kPa (3 psi) for 2-phase side).
3. Use existing designs and parts (no unusual development required).
4. Common design for active TVS and subcooler.

Four forced-flow compact heat exchangers were evaluated for use on CONE in the active TVS and subcooler. The four concepts were a concentric square-tube coil based on a Centaur design, the helical finned tube, a Giauque-Hampson coiled tube, and a perforated plate. Although all of the designs will operate properly in zero-gravity and all had acceptable pressure drops, the helical finned tube design could be packaged in the most convenient shape and size. The helical finned tube heat exchanger had several inherent advantages compared to other designs. The wall of the inner tube (which contains the 2-phase cold flow) is completely surrounded by the warm stream which maximizes heat transfer area. The warm liquid stream flows in a relatively large annular area (which reduces pressure drop) but has a very large surface area available for heat transfer from the fins.

The design of helical finned tube heat exchangers was reported by Croft and Tebby in Cryogenics, June, 1970 (Reference 3.1). Their design equations assumed gases on both sides of the exchanger and their equations were based on a unit length of heat exchanger. Although this basis was useful for exchanger sizing, it masked the heat transfer coefficient values and made direct comparison with other concepts more difficult. All of the design equations and the pressure drop equation for the liquid side flow were incorporated into a Quattro Pro spreadsheet. Calculations for both the active TVS and subcooler systems were performed by the spreadsheet, and the subcooler required approximately twice the heat exchanger length of the active TVS system. Consequently, the subcooler will be made by connecting two smaller heat exchangers in series. Pressure drop on the liquid side of the heat exchangers is less than 1.4 kPa (0.2 psi).

The CONE heat exchanger concept is shown in Figure 3-23 along with the original drawing from Croft and Tebby. The exchanger is made from 6.3 mm (0.25 inch) copper tubing with a total fin height of 15.9 mm (0.625 inches). The fin spacing can range from 3 to 4 fins per cm (8 to 10 fins per inch). The copper tubing is wound on an annular spacing material and sealed using header plates. Construction of this type of heat exchanger is standard practice in many other industries and will pose no problems for CONE. The package is compact and its pressure drop at CONE operating conditions is almost negligible.

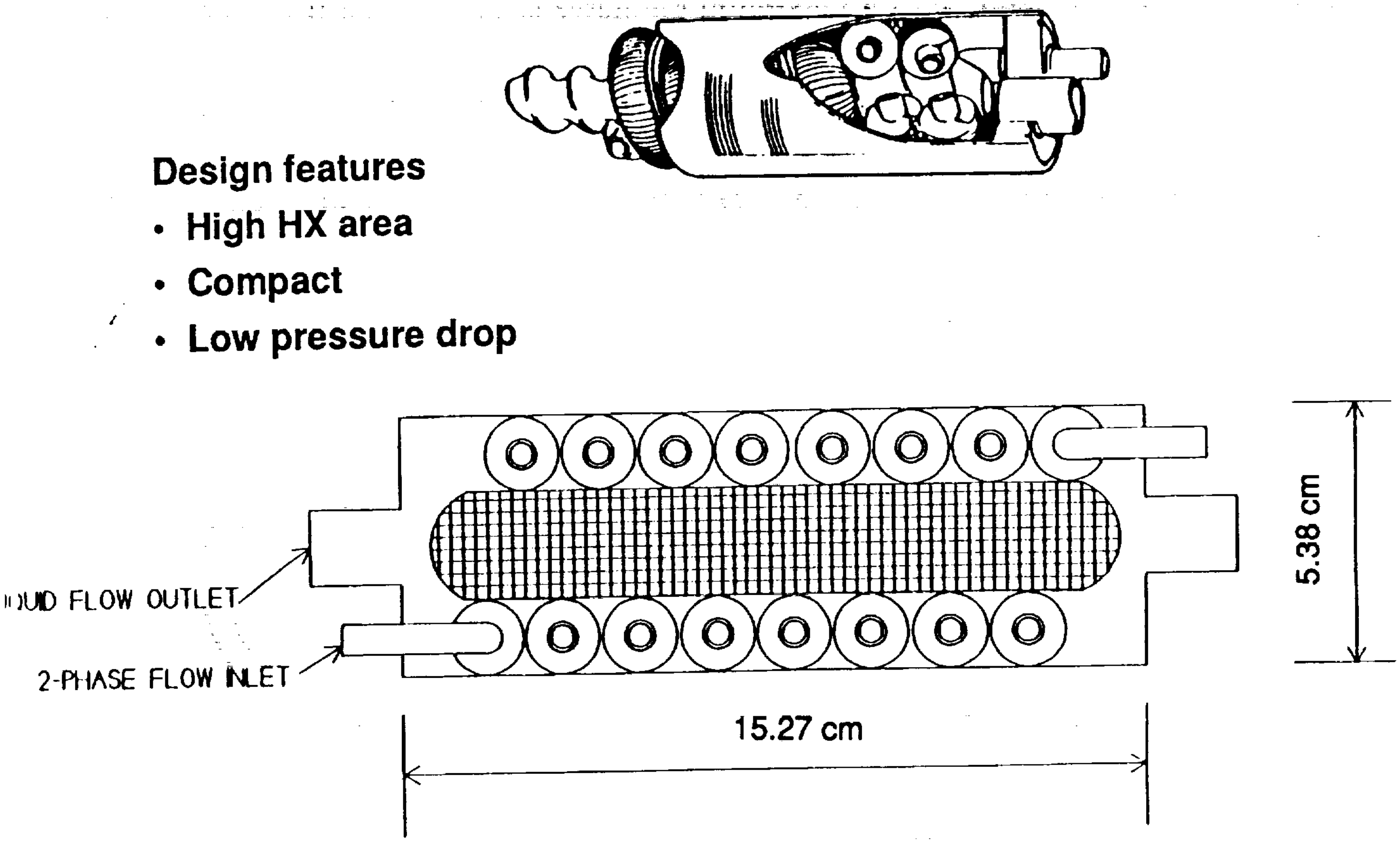
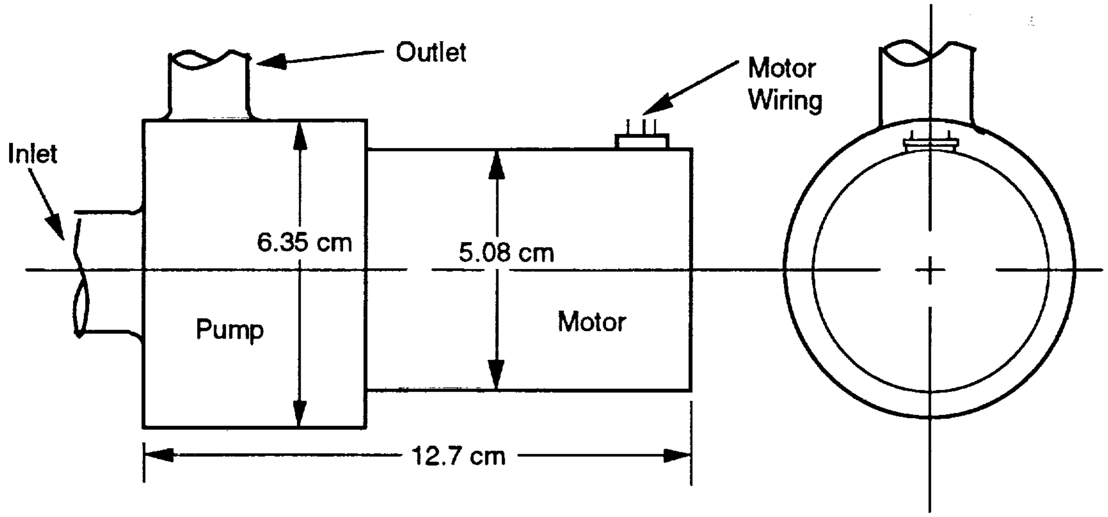


Figure 3-23, Active TVS and Subcooler Heat Exchanger Concept

3.7.2 Mixer Design

The CONE mixer design was developed with the help of a small firm specializing in customized pumping applications involving cryogenics. The mixing requirements are for liquid flows from 2.8 to 14 L/min (0.1 to 0.5 cfm) of LN_2 with the capability to handle liquid, gas, or a 2-phase mixture. The total head required is 0.91 m (3 ft), which is based on ground test requirements when the mixer must work against gravity. On orbit, the maximum head anticipated which the mixer must deliver is less than 0.15 m (0.5 ft). These requirements produced a specific speed in the range of normal centrifugal pumps, so a small centrifugal unit was baselined for CONE.

A diagram of the CONE mixer is shown in Figure 3-24. The impeller and housing are quite small, with a maximum diameter of 6.4 cm (2.5 in). The motor is a 3-phase AC with speed control provided by the Mixer Control Electronics (MCE). The unit is hermetically sealed and designed to run at liquid nitrogen conditions. Total power dissipation at maximum flowrate is less than 2 W. The actual layout of the pump and heat exchanger inside the vacuum annulus is shown in Figure 3-25.



Hermetically sealed, nitrogen cooled
Speed approximately 3050 RPM
Electric motor power ≈2 W at 50 percent efficiency
Impeller diameter ≈2.67 cm

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Figure 3-24, Active TVS Mixing Pump

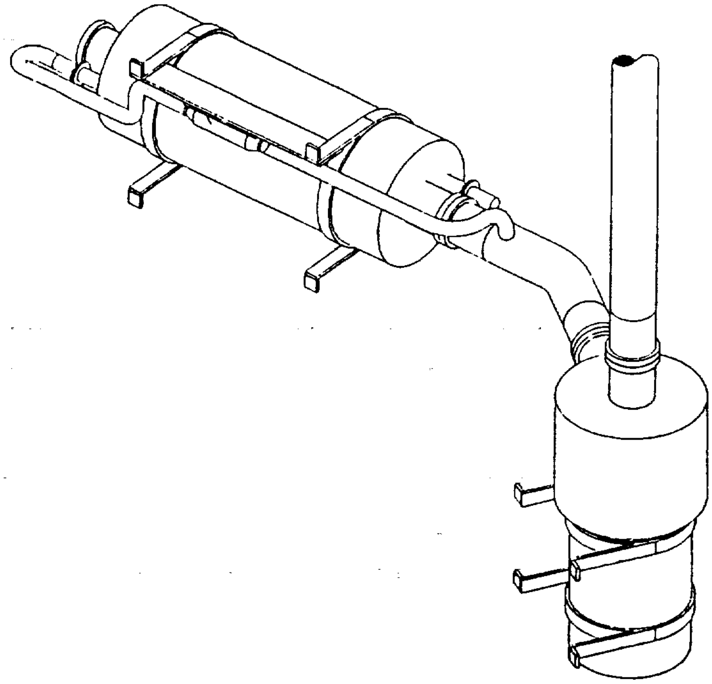

Figure 3-25, Active TVS Mixing Pump and Heat Exchanger Layout

3.7.3 Passive TVS Design

The design of the CONE PTVS began with a trade study to determine the best system for this application. The three candidates considered were:

1. TVS located on the inside of the PV wall and connected to the LAD, penetrations, or other internal supports to remove heat after it reaches the tank.
2. TVS located on the outside of the PV wall and connected to the penetrations and supports to intercept heat before it reaches the tank.
3. TVS located on a shield spaced just outside of the PV and connected to the penetrations and supports to intercept heat before it reaches the tank.

The results of the trade study indicated that option 2, an external wall-mounted heat exchanger was best for CONE. In this approach, the heat exchanger design and thermal contact system attempt to intercept all parasitic heat before it reaches the tank. This is accomplished by designing thermal contact clips which allow a certain amount of heat to flow from the tank to the TVS tube at each point of contact. A spreadsheet model was used to evaluate candidate clip designs and insure that transient effects would not render the system ineffective for testing on CONE.

The supply tank has two regions of high localized heat inputs, one at the top where most of the plumbing penetrations come through, and the other at the girth ring where the support struts attach and where all the wiring feedthroughs are located. There is also a distributed heat load from the MLI around the tank, but as Table 3-6 shows, this corresponds to only about 25% of the total heat input. To allow more heat to be absorbed at the high heat-input regions of the tank, several thermal clips were designed to connect the TVS tube to the tank wall or plumbing penetration.

The schematic and plumbing layouts for the PTVS are shown in Figure 3-26.

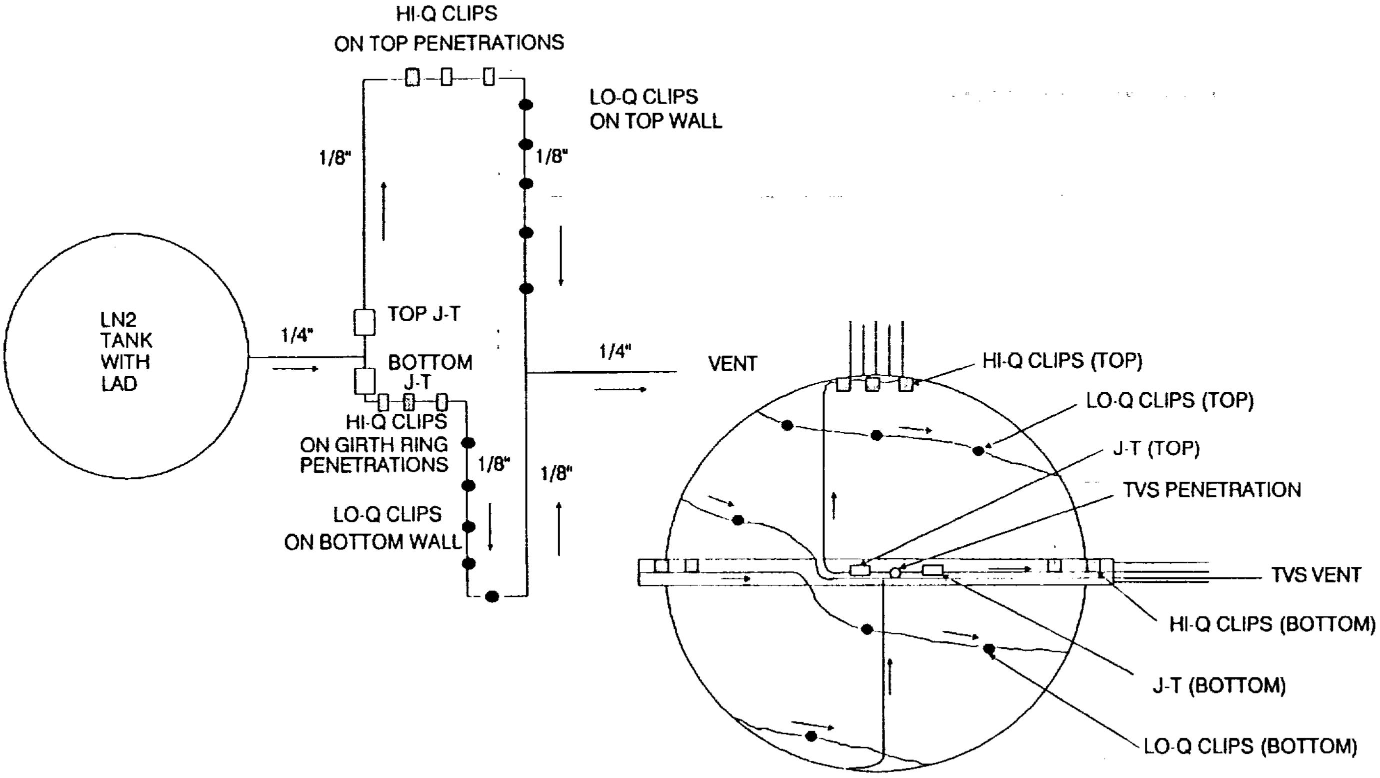

Figure 3-26, Schematic Layout of Passive TVS

The TVS flow schematic shows how the liquid leaves the tank and then is split into two lines for ease of assembly and to balance the thermal load with liquid coolant flow. The layout sketch shows how the PTVS might look when the lines and clips are in place. The top line leaves the girth ring and goes to the top of the tank to cool the plumbing penetrations and then returns to the girth ring by way of the spiral path around the upper tank hemisphere. The lower TVS line wraps around the girth ring to remove heat from wiring and support attach points and then spirals around the lower hemisphere to pick up heat from the MLI. The lower line then returns to the girth ring and joins the upper line prior to exiting the vacuum jacket. Hi-Q clips refer to the locations where high localized heat inputs must be absorbed, and the Lo-Q clips are designed to remove heat coming in from the MLI. Characteristics of each type of clip are given in Table 3-12. The copper straps are used when there is not enough physical space to mount a clip at a plumbing penetration. The region of influence is an indication of how large the "cold spot" on the tank wall is when the PTVS reaches steady state.

	High-Q Clip	**Copper Strap**	**Low-Q Clip**
Location	Close to J-T	Close to J-T	Near end of tube
Heat Flux per Clip	0.09 - 0.15 W	0.06 - 0.09 W	0.03 - 0.06 W
Region of Influence	30 - 38 cm	N/A	10 - 30 cm

Table 3-12, Summary of Clip Thermal Performance

The wide range of heat transfer coefficients that are possible for the 2-phase fluid in the TVS line and the variable conductance of the clip make the PTVS design challenging. The 2-phase fluid will initially wet the inside of the tube wall downstream of the JT, but the liquid will evaporate away during transient periods when large quantities of heat (compared with the size of the flow stream) are absorbed from surrounding structure. The first set of clips mounted on the TVS line will absorb large amounts of heat until the tube or wiring penetrations have cooled considerably, and then liquid will flow past these points to absorb heat from the Lo-Q clips mounted on the PV surface. The transient time is estimated at 3 to 6 hours.

3.8 INSTRUMENTATION

During the CONE study, the instrumentation concept was developed and then revised based on available transducers (preferably with flight heritage) which could meet the experiment requirements. Detailed requirements were compiled for each type of measurement, including response time, size, weight, excitation, and of course, range and accuracy. The required range and accuracy as well as the sensor chosen for each CONE measurement is given in Table 3-13.

Measurement	Range	Required Accuracy	Number Reqd.	Sensor Type	Part Number	Vendor
Temperature	61-100 K	0.1 K	76	Si Diode	DT-470-SD-13-4LS	Lakeshore
Temperature	61-330 K	0.6 K	23	Si Diode	DT-470-SD-13-4LS	Lakeshore
Delta-Temp	0-6 K	0.1 K	18	KP vs Au/Fe Thermopile	TBD	RdF
Pressure	0-345 kPa	1.4 kPa	12	Piezo Resistance	Series 400	Keller PSI
Pressure	0-21 MPa	0.3 MPa	4	Strain gauge	Model 2211 LT	Teledyne-Taber
GN Flow	0-76 g/min	1.5 g/min	4	Turbine	Model FT -10	EG&G/FTI
GN Flow	0-1.5 g/min	0.3 g/min	1	Turbine	Model FTO-5	EG&G/FTI
LN Flow	0-136 kg/hr	2.3 kg/hr	2	Turbine	Model FT 4-8	EG&G/FTI
Liquid-Vapor	Liq-Vap	5 sec response	35	Carbon Resistor	BB-221-5	Allen Bradley

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Table 3-13, CONE Sensor Selections

3.8.1 Temperature measurement.

Three types of temperature measurements will be required on CONE. Sensors inside the supply tank will measure temperatures over a fairly narrow range near the nitrogen saturation temperature. They must have a reasonably good accuracy of ±0.3 K (±0.5 R), minimal power dissipation, and a fast response time. Sensors located outside the tank on the plumbing or pressurant subsystems will measure temperatures over a wide range and will require an accuracy of ±0.6 K (±1.0 R). Finally, sensors inside the tank which will measure gradients must have reasonable accuracy over a very narrow range of 0.6 to 2.8 K (1 to 5 R) near liquid nitrogen temperatures.

Lakeshore silicon diodes were chosen for the first two measurement ranges because of their low power dissipation, wide range, fast response time, and high accuracy. A substantial amount of circuit development and error analysis can be carried over from COLD-SAT because of this selection. Differential thermocouples are under consideration for gradient measurements and are described later in this section.

3.8.2 Low-Pressure Sensors.

Until recently, pressure sensors designed for use at cryogenic temperatures were not available in ground or flight qualified forms. Keller PSI recently introduced a cryogenic pressure sensor based on a silicon piezo-resistance device. After seeing an actual demonstration where an operating absolute pressure transducer was dropped into a dewar of liquid nitrogen and remained stable during cooldown (except for the increase in pressure due to the head of liquid nitrogen), it was clear that these sensors were ideal for CONE. The design of the sensing element is robust (the original concept was used in military aircraft) and the power dissipation is less than 6 mW. Their small size makes them easy to mount inside the supply tank, in flow lines, or anywhere that pressure measurements are required.

3.8.3 High-Pressure Sensors.

High-pressure sensors rated to liquid nitrogen temperatures are required for the pressurant-bottle recharge test. Models rated down to 77 K (-320 F) are made by Teledyne Taber and will be used on CONE. These units are bonded strain gauges and are routinely used in military aircraft applications.

3.8.4 Liquid Flow Meters.

Three liquid flow meters were considered for CONE: a Micromotion direct mass-flow measurement unit, a Flow Technology turbine meter, and the Quantum Dynamics turbine meter. Based on comparisons of their features and results

C-2

from NASA's flow meter test program (see R. S. Baird, "Flowmeter Evaluation for On-Orbit Operations," NASA TM-100465, August, 1988), the Flow Technology meter appears to be the best developed meter for CONE. Development of small Venturi meters or additional testing of the Quantum Dynamics meter could change this assessment within the next year.

3.8.5 Vapor Flow Meters.

Three vapor flow meters were considered for CONE: a Micromotion direct mass-flow measurement unit, a Flow Technology turbine meter, and a FCI thermal velocimeter. Based on comparisons of their features and results from NASA's flow meter test program (op. cit.), the Flow Technology meter appears to be the best developed meter for CONE. Unlike liquid mass flow meters, there are no good alternates on the horizon which might emerge in the next year or two, but the turbines should prove adequate for measuring vent flows on CONE.

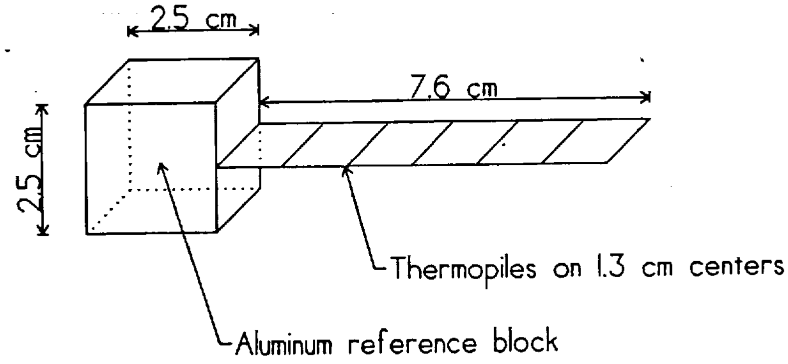
3.8.6 Liquid-Vapor Sensors.

Located in flow lines and inside the supply tank, these sensors should detect the presence of liquid or vapor. Most ground-based sensors use thermal dissipation rates and the characteristics of the sensors electrical response to determine liquid or vapor. Although NIST has recently tested some extremely small silicon sensors which were highly accurate and responded very rapidly, they are not yet commercially available and were therefore not considered for CONE. Standard Allen Bradley carbon resistors were chosen because they are inexpensive, robust, and readily available. Sensors inside the supply tank will not have forced flow to assist with stabilizing the local heat transfer field, and therefore, their on-orbit performance is unknown. Sensors mounted in the flow lines should not be substantially impacted by microgravity because of forced convection flow.

3.8.7 Differential Temperature Sensors

The measurement of small liquid and vapor temperature gradients inside a cryogen tank has been an experiment requirement since the beginning of the COLD-SAT program. Unfortunately, the standard approach of locating absolute temperature sensors at known spacing intervals leads to large errors in the measured delta-T. Based on a differential temperature measurement concept used in the NIST calorimeters, a differential thermopile probe concept was developed with RdF Corporation in New Hampshire. The probe has 6 foil-deposited thermopiles enclosed in a 0.2 mm (8 mil) Kapton "wing." The wing extends from a 2.5 cm (1 in) cube of aluminum which is used for a local temperature reference. Although the exact accuracy of the probe has not yet been determined, its sensitivity is better than 30 mK. The probe will be suitable for flight applications but may also find use in ground experiments.

Figure 3-27 is a conceptual drawing of the CONE gradient probe. There are six thermopile junction lines at 1.3 cm (0.5 in) spacings along the "wing" section. The aluminum cube serves as a reference point and is equipped with a diode thermometer to measure its absolute temperature. The foil thermopiles are deposited in a Kapton film using a proprietary RdF procedure, and all the thermocouple leads terminate inside the aluminum block. At the junction, all the leads connect to a 0.25 mm (30-gauge) copper ribbon cable which is ultimately routed outside the supply tank.



Mounting supports and wires not shown

Figure 3-27, Conceptual Diagram of CONE Gradient Probe

Using this type of construction, the only source of EMF across each lead pair arises from the differential temperature along the probe. Thermopiles are used to increase the sensitivity of the basic thermocouple junction. The response time of the probe is on the order of seconds because the Kapton film insulates the junctions from the fluid. Although this feature is desirable for CONE, other applications in mixing and fluid transfer might require faster responses.

The thermocouple vendor recommended KP vs. 0.07 Fe because it will work for liquid hydrogen and nitrogen applications. At 20 K, this thermocouple puts out 17 μV/K, and at 77 K it puts out almost 18 μV/K. These low sensitivities can be multiplied by 2 or 3 using a thermopile configuration. Since resolution of 1 μV is not difficult with off-the-shelf electronics, the primary error contribution will be stray EMF's introduced by other pseudo-junctions. The vacuum feedthroughs are copper wire coated with silver, and since the lead wires are all copper, the stray EMF's should be minimized. If the accuracy of the reading is on the order of 1 μV, then the probe accuracy will be better than 2%, which is a substantial improvement over the previous concept. Additional development and building of a prototype unit will be required for CONE.

3.8.8 Sensor Locations

Sensors are located throughout the CONE system in order to adequately characterize the experiments. All sensor locations are shown schematically in Figures 3-28, 3-29, and 3-30. Each sensor is numbered for reference. Temperature and liquid vapor sensors inside the supply tank are mounted to thin fiberglass struts which are supported from the LAD. The sensor distribution inside the supply tank is shown in Figure 3-31. Other sensors mounted on surfaces will be attached with thermal epoxy, and sensors in the flow lines will be installed using tees. Wiring is collected locally and bundled as the wires approach the electronics system.

3.8.9 Wiring Harnesses and Locations

The CONE wiring concept is shown in Figure 3-32, along with a description of the connectors required at each location. The number of wires exiting each are of the experiment subsystem is listed in Table 3-14. CONE requires a total of 612 wires to support the experiment subsystem, not including wiring for non-cryogenic housekeeping. The connector designation for each wire bundle is also given in Table 3-14 for reference.

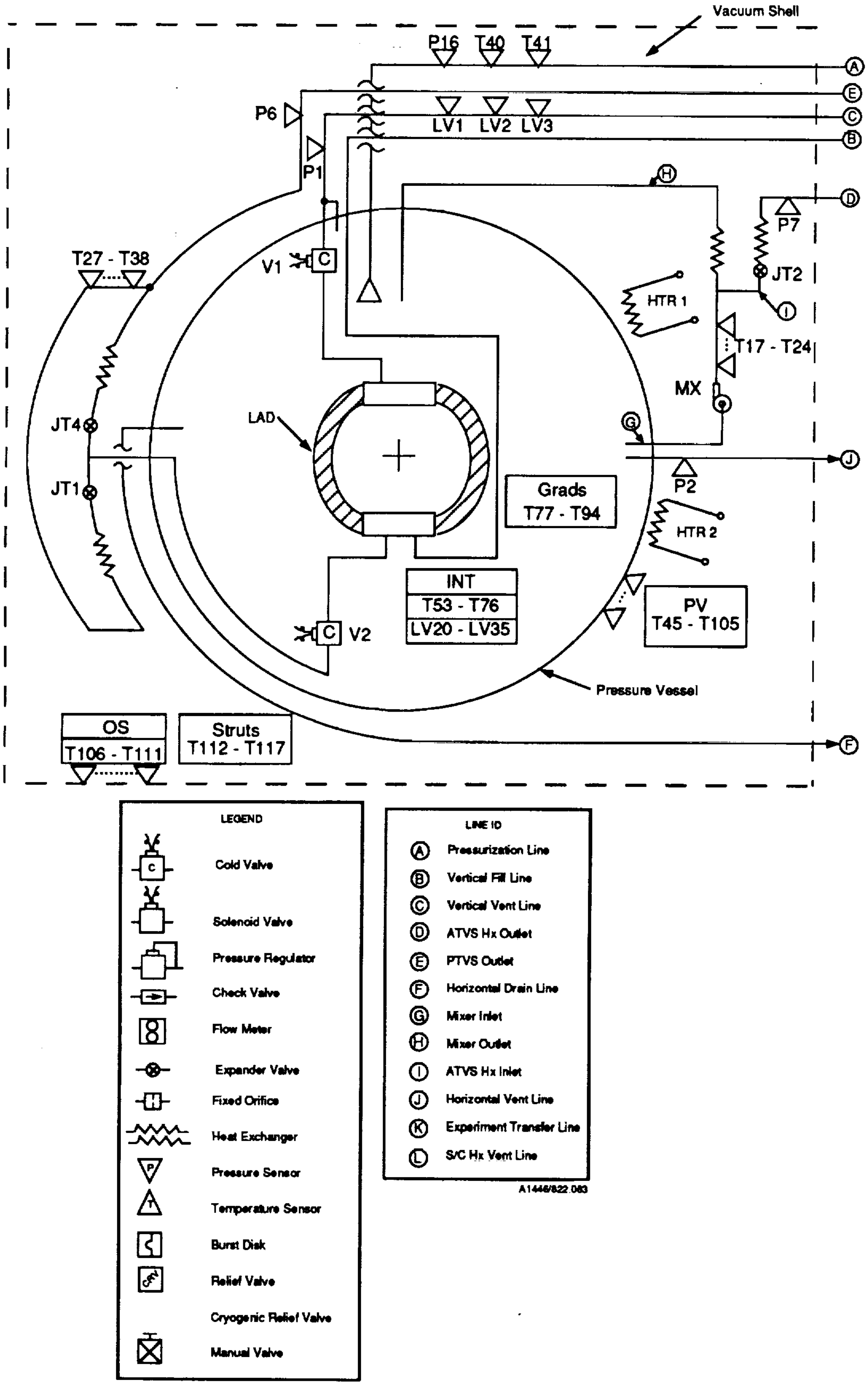


Figure 3-28, Supply Tank Instrumentation Schematic

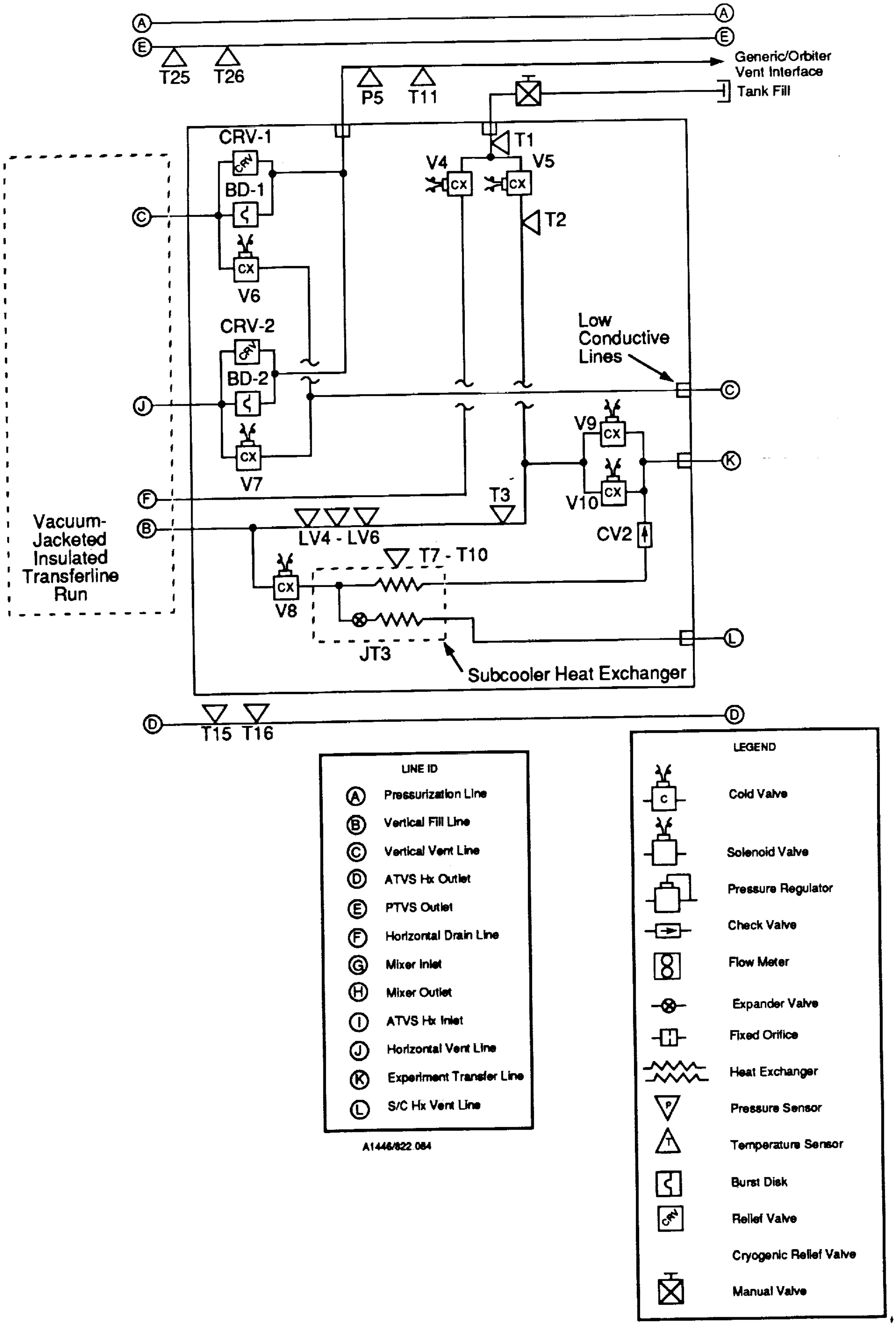


Figure 3-29, Cold Valve Box Instrumentation Schematic

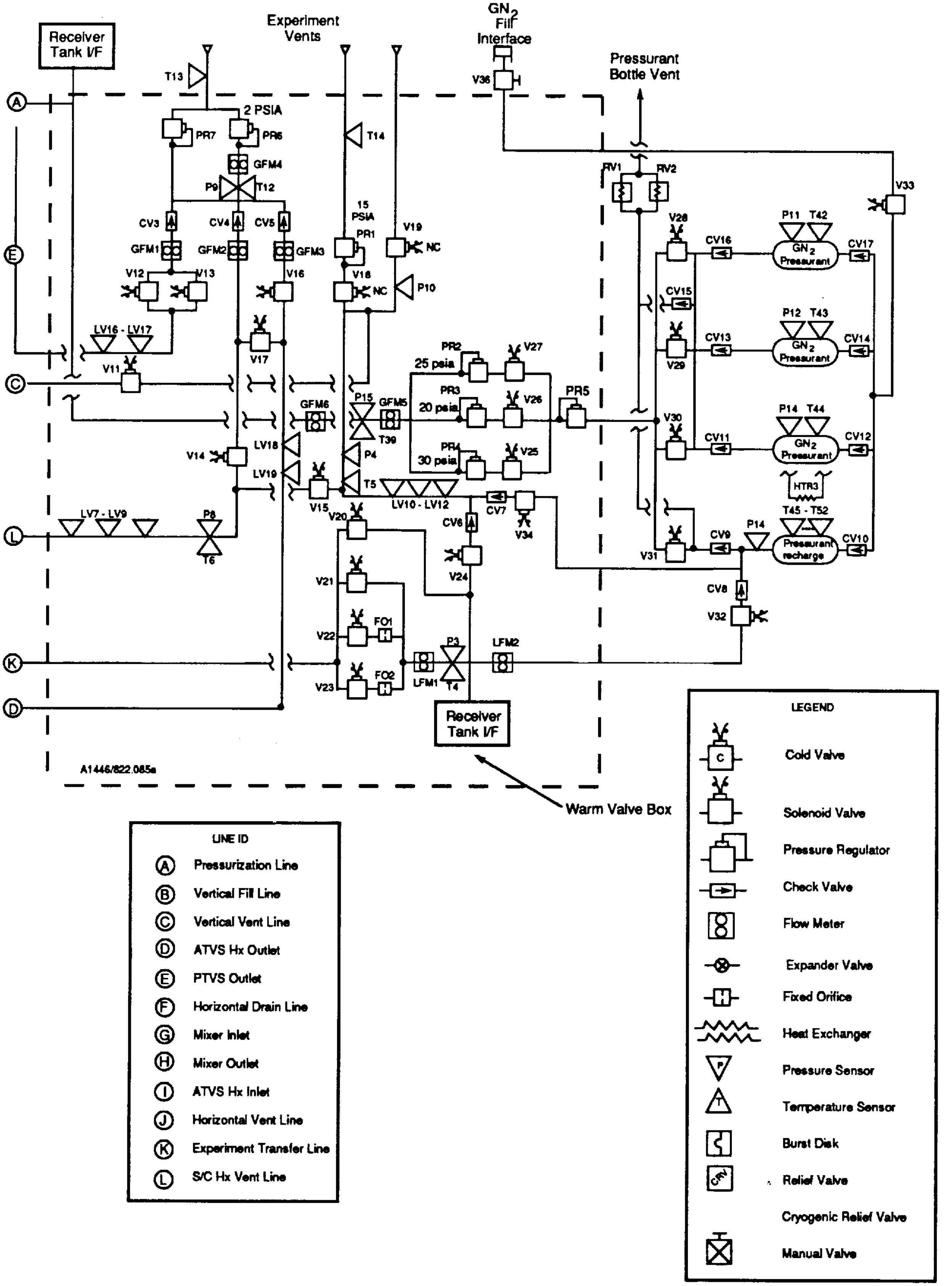


Figure 3-30, Warm Valve Box and Pressurant Module Instrumentation Schematic

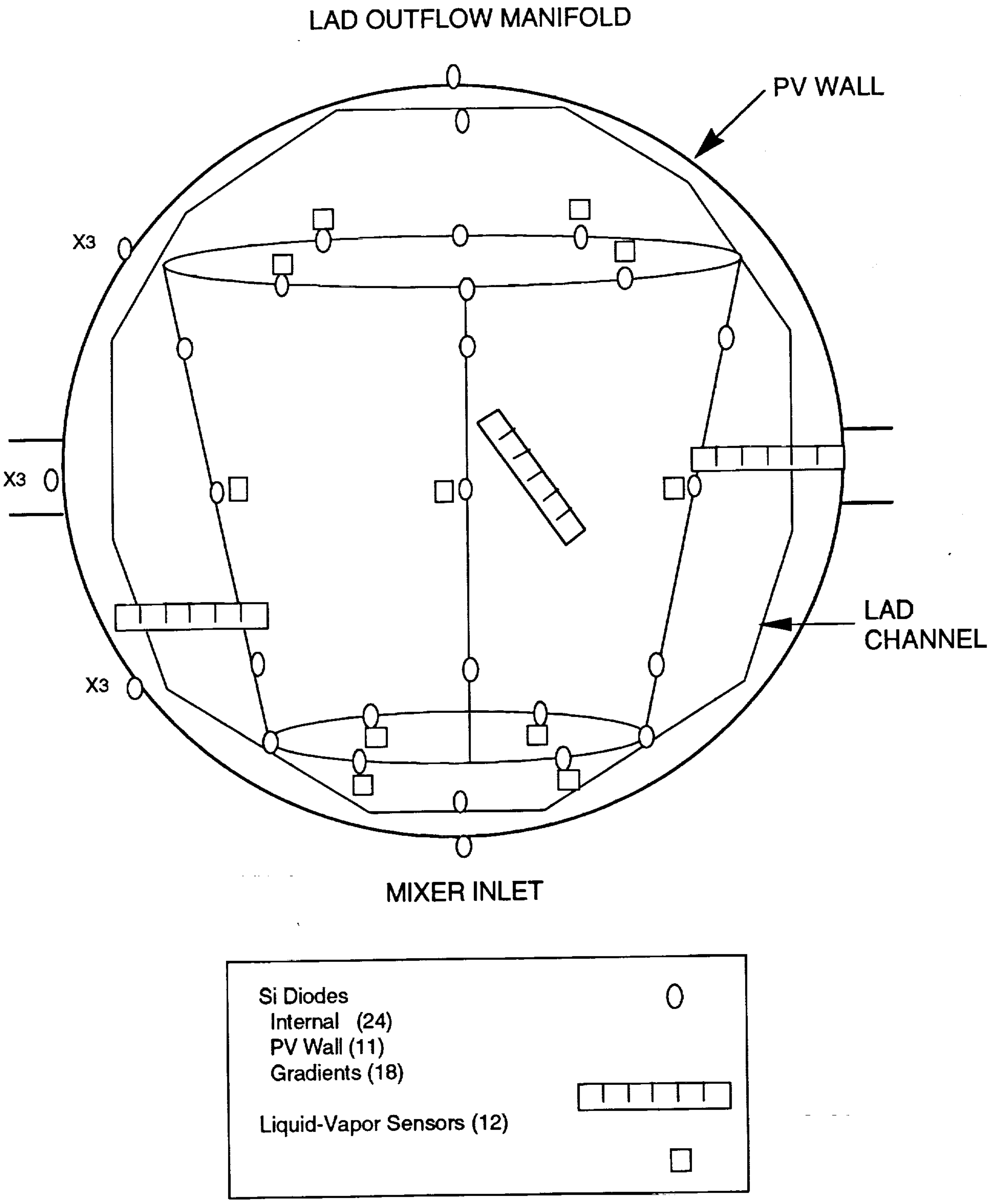
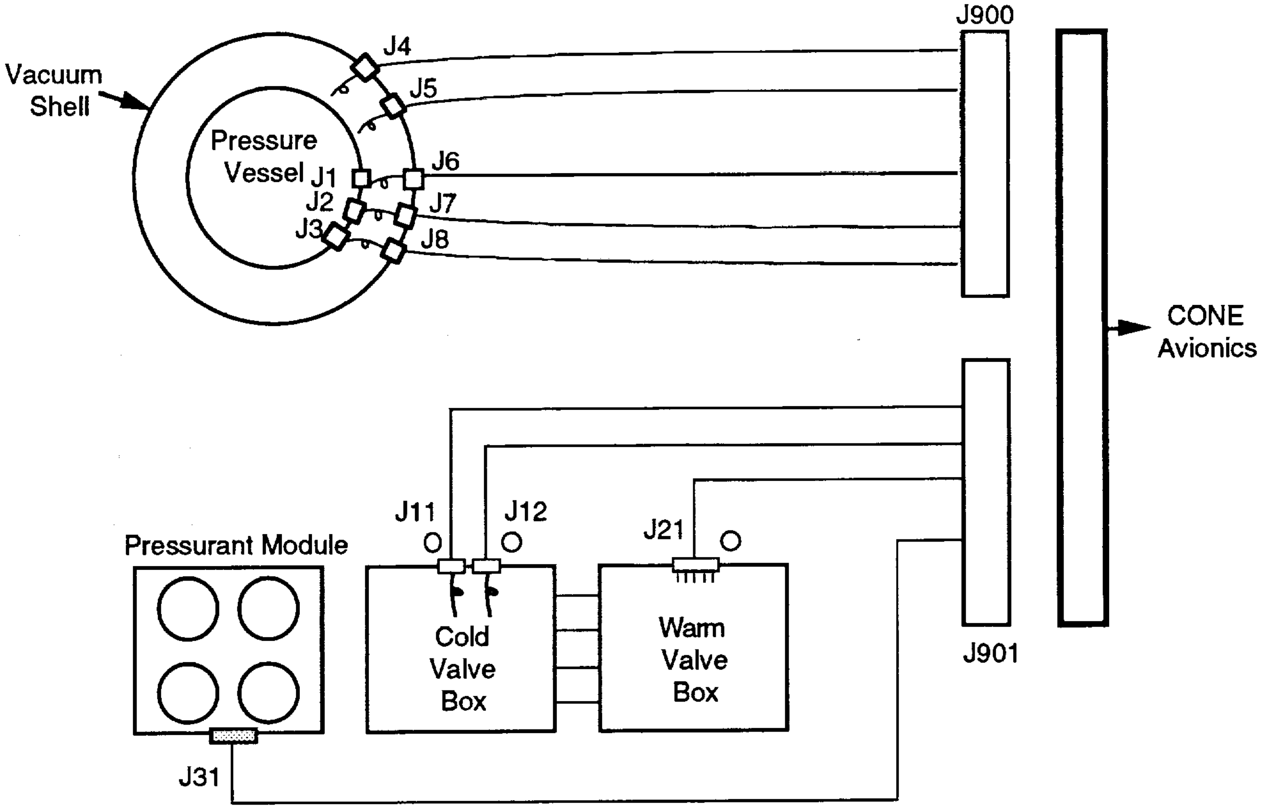


Figure 3-31, Schematic Distribution of Sensors Inside the Supply Tank.



CONNECTOR NO.	TYPE	PART NUMBER	HERITAGE
J1 - J8 J11, J12	61 pin Duetch connector	DBAS4H-24-61PN-835	XRS, COBE, SHOOT
J900, J901 J21, J31	380 pin Hypertronics connector	NPDBV19/1TMS-1PA-10 PMS-1PH-TMS/T	

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Figure 3-32, CONE Wiring Concept

Unit type	Location	Designation	# of Units	Wires per Unit	Total Wires	Total in Bundle	Exit Connector	Interface Connector	.Avionics Connector
Diodes	PV internal	T53 - T76	24	2	48	132	J1-J3	J6-J8	J900
Thermopiles	PV internal	T77 - T 94	18	2	36				
Cold valves	PV Internal	V1-V2	2	8	16				
L/V	PV internal	LV20-LV35	16	2	32				
Diodes	PV Wall	T95-T105	11	2	22	108	J4-J5	N/A	
Heaters	PV Wall	HT1-HT4	4	2	8				
Diodes	Passive TVS	T27-T38	12	2	24				
Diodes	Active TVS	T15-T24	10	2	20				
Mixer	Active TVS	MX-1	1	6	6				
Diodes	Struts	T112-T117	6	2	12				
Pressure	Vac Jacket	P1,2,6,7	4	4	16				
Diodes	Cold Box	T1-3,6-11,25,26	11	2	22	112	J11-J12	N/A	J901
Cold valves	Cold Box	V3-V10	8	8	64				
L/V	Cold Box	LV1-9	9	2	18				
Pressure	Cold Box	P5,8	2	4	8				
Diodes	Warm Box	T4,5,12-14,39	6	2	12	184	J21	N/A	
Warm valves	Warm Box	V11-V28	18	4	72				
Pressure	Warm Box	P3,4,9,10,15	5	4	20				
Regulators	Warm Box	PR1-PR7	7	4	28				
L/V	Warm Box	LV10-15,16-19	10	2	20				
Flow	Warm Box	LFM1,2	2	4	8				
		GFM1-6	6	4	24				
Diodes	Press Bottle	T40-T52	13	2	26	76	J31	N/A	
Heater	Press Bottle	HT5	1	2	2				
Warm valves	Press Bottle	V29-V34	6	4	24				
Flow	Press Bottle	GFM7	1	4	4				
Pressure	Press Bottle	P11-14,16	5	4	20				
TOTALS					612	612	9	3	2

Table 3-14, CONE Wire Count and Bundling Configuration

3.9 CONTROL ELECTRONICS

The CONE experiment command and data handling functional block diagram in Figure 3-33 shows how experiment data collection and experiment control are related to the Experiment Control Processor (ECP). The ECP combines its standard I/O cards with three special functions interface (SFI) cards to achieve the required sensor conditioning and multiplexing.

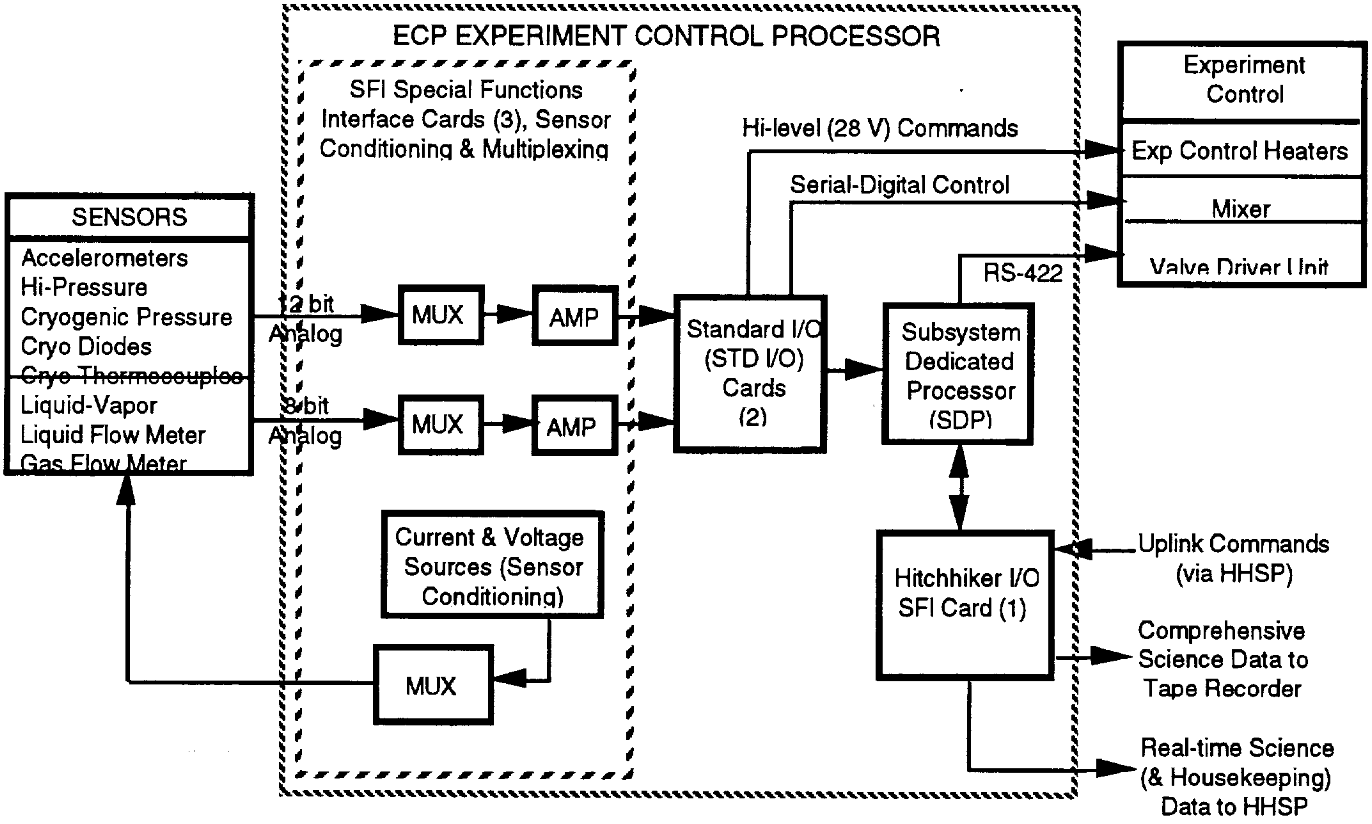


Figure 3-33, Experiment Command and Data Handling Block Diagram

Three SFI cards are required to condition the sensors and to increase the number of data channels the ECP can read. Each ECP STD I/O cards is limited to 32 analog channels per card. The SFI cards require development using standard designs and parts, so the SFI design is largely a packaging and qualification action.

Each of the sensors require a different type of conditioning source, typically either a precision current or voltage. The silicon diode conditioning/multiplexing circuit, Figure 3-34, represents a typical circuit design.

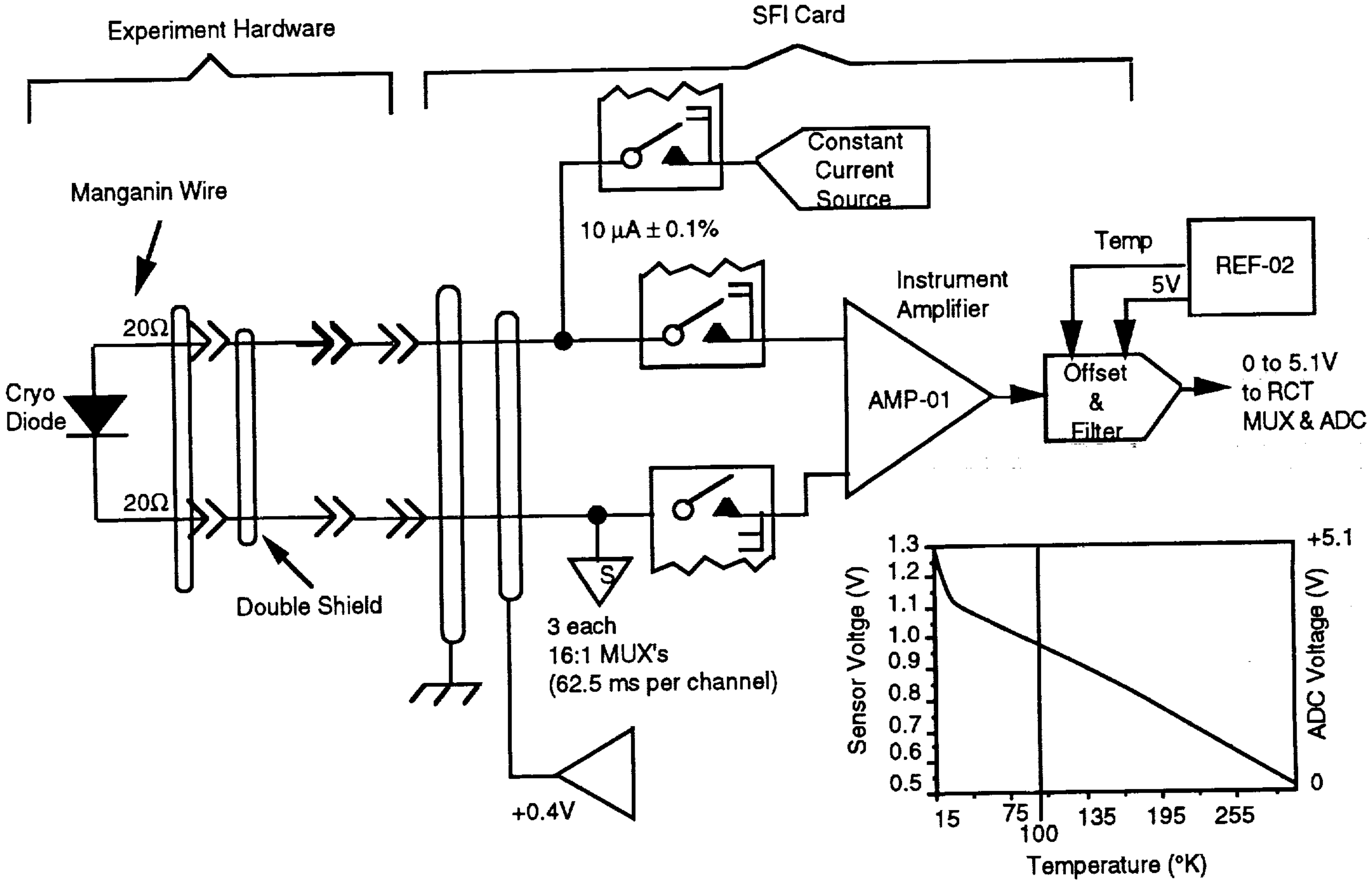


Figure 3-34, Silicon Diode Conditioning and Multiplexing Circuit

The ECP samples each sensor once per second and then outputs the science telemetry stream to the tape recorder and the real-time telemetry stream to the HH-M signal port. The real-time telemetry stream includes 60 temperatures readings, 20 liquid-vapor readings, 16 pressure readings and 8 mass flow readings output at a 1/4 Hz rate. In addition, the real-time stream has sixty bytes available for experiment specific sensor data sampled at the nominal 1 Hz rate. Table 3-15 shows which sensors are output for each of the six experiments/demonstrations. The real-time stream has been designed to accommodate the bandwidth limitations of the hitchhiker real-time channel while still providing all required real-time data.

Experiment	Temperature Sensors	Pressure Sensors	Liquid/Vapor Sensors	Flow Rate Measurements	Total Bytes	Available Bytes	Margin
Active TVS	T 15-24 T 53-76	P 1, P 7		GFM 3, GFM 4	56	60	7%
Mixing	T 53-76	P 1, P 2			39	60	35%
Stratification	T 53-76 T 77-94				39	60	35%
LAD Outflow/ Expulsion	T 7-10, T 3-5 T 12-14	P 1, P 3, P 4 P 8-10	LV 4-6 LV 7-12	LFM 1, GFM 2 GFM 4-6	38	60	37%
Passive TVS/ Standby	T 53-76, T 27-38 T 106-111			GFM 1, GFM 4	35	60	42%
PB Recharge	T 3-5, T 45-52 T 14	P 3, P 4 P 10, P 14	LV 4-6 LV 10-12	LFM 1, LFM 2	32	60	47%

Table 3-15, Real-time Telemetry 1 Hz Sensor Data

The design capacity and margins for ECP sensor channels are summarized in Table 3-16. Substantial experiment-sensor growth can be accommodated without requiring redesign. The SFI cards make efficient use of the STD I/O cards by only using 22 of 64 available analog channels, thus leaving 42 analog channels for experiment growth and housekeeping. Additional details of the avionics and ECP can be found in section 5.4.

				SFI Sub Mux's		
Bits	Telemetry	SFI Mux	STD I/O Channels	Used Chan.	Spare Chan.	Sample Rate
12	Silicon Cryo Diodes	16:1	10	99	61	1 Hz
12	Thermopile Differential Temperature Sensors	16:1	2	23	9	1 Hz
12	Cryogenic Pressure Transducers, 0 - 50 PSIA	8:1	2	12	4	1 Hz
12	High Pressure Sensors, 0 - 3000 PSIA	8:1	1	4	4	1 Hz
12	Accelerometers (3-Axes)	None	3	N/A	N/A	1 Hz
8	Liquid Mass Flow Meters (LFM), 0 - 300 lb/hr	16:1	1	2	9	1 Hz
8	Gas Flow Meters (GFM), 0 - 10 lb/hr			4		1 Hz
8	Gas Flow Meters, 0 - 0.2 lb/hr			1		1 Hz
8	Liquid/Vapor Sensing Carbon Resistors	16:1	3	35	13	1 Hz
			22 (Total)			

Table 3-16, ECP Experiment Sensor Analog Telemetry Channels

Section 4

MISSION DESIGN

Top-level mission requirements were derived from STS orbiter compatibility considerations, Hitchhiker-M carrier requirements, and mission science requirements. Hitchhiker-M and STS primary interfaces were also defined and are summarized below.

4.1 MISSION REQUIREMENTS

The primary CONE mission requirements shown in Table 4-1 are derived chiefly from technical directives from the NASA/LeRC CFTO program office.

No.	Requirement	Source	Approach	Hardware Component
0.1	Fly on the STS	Directive	STS compatibility at all levels	CONE System
0.2	Design for a three-flight lifetime: one planned flight, one reflight, one contingency flight	Directive	Payload elements designed for three flights	All CONE System Elements
0.3	Use the Hitchhiker-M carrier	Directive	Current carrier baseline is Hitchhiker-M	CONE System
0.4	Provide interfaces for future addition of receiver tank	Directive	Mass simulator provided to prove interfaces	Mass Simulator
0.5	Minimize hardware development	Design Goal	Existing hardware used where possible	CONE System

Table 4-1, CONE Mission Requirements

Technical program directives specified such details as the operational lifetime, launch vehicle, and carrier selection. Additionally, experiment derived requirements translated the scientific objectives of the mission into system and subsystem level requirements and operational restrictions. Taken in concert, these factors shaped the top-level CONE payload design.

4.2 STS REQUIREMENTS AND INTERFACES

Designation of the STS as CONE launch and flight system drove mission and system design requirements and interfaces. Table 4-2 shows the primary STS imposed requirements and interfaces which effect CONE payload design.

No.	Requirement	Source	Approach	Hardware Component
1.1	7-day nominal mission duration	STS	Mission timeline satisfies requirement	CONE System
1.2	Man-rated safety requirements	STS	Design per applicable documents	CONE System
1.3	Vent LN_2 safely at all times	STS	Primary overboard with Generic Vent System backup; astronauts control all dumping	Orbiter / CONE System
1.4	LN_2 loading on pad or in O & C building	STS	Load on pad baselined at T - 7 days	CONE System
1.5	1/4 bay STS resource allocation	STS, HH-M	Resource requirements within allocations	CONE System
1.6	Mission requires induced local gravity field	CONE Science	Low rate STS spin used to induce required field	Orbiter
1.7	Mission requires "quiet" periods with no large g-disturbances	CONE Science	STS Gravity Gradient orientations provide "quiet"	Orbiter

Table 4-2, STS Requirements and Interfaces

Mission length is constrained by STS operational duration limits. A nominal mission is 7 days in length, with 14 days the practical upper limit. Although CONE was not directed to fly within a 7-day mission, experiment analysis showed that all technical objectives could be accomplished within a 7-day timeframe. The baseline experiment timeline in Section 7.2.2 was constructed to demonstrate the feasibility of conducting the required experiments and demonstrations within an estimated window of the total mission time.

Safety is also a primary issue with STS flight operations. Astronaut control of all potentially hazardous operations is required, which effects the design of LN_2 venting procedures for nominal and contingency operations. Overboard LN_2

venting controlled by the astronauts is the CONE baseline, and the orbiter Generic Vent System has been baselined for contingency venting.

Some control of local gravity conditions is required for CONE. The baseline approach to "quiet" periods is to use one or more of the STS Gravity Gradient orientations. For inducing local g-fields, the chosen approach is to spin the orbiter at a low rate of 4 to 8 rotations per orbit. This appears to be the most effective and operationally simple approach providing the nominal 25 μ-G field required.

One asset of CONE for mixed-cargo manifesting is that it does not require any specific orbit for experimental operations. The inclination and altitude of the orbit are not important to CONE, since all that is desired is a "bare slate", with variable and controllable gravitational characteristics. However, CONE's venting of liquid nitrogen into the cargo bay will restrict its manifesting opportunities to flights where co-manifested payloads are capable of withstanding such venting.

4.3 HITCHHIKER-M REQUIREMENTS AND INTERFACES

The primary HH-M compatibility requirements are itemized in Table 4-3.

The designation of the HH-M as the CONE baseline carrier further shaped payload design. CONE consists of a number of large, relatively heavy components. These components are mounted directly to the HH-M so that fundamental frequency and load distribution requirements effect payload configuration significantly. Since CONE communicates through the HH-M avionics and CCGSE, HH-M signal formats and conventions must be followed. Astronaut and ground command requirements effect the design of power distribution subsystem hardware and procedures. Safety constraints specify the level of fault-tolerance for critical items. Finally, total energy and maximum power limits constrain CONE's consumption rates, although these were not found to be restrictive requirements.

No.	Requlrement	Source	Approach	Hardware Component
2.1	Mass properties compatible with carrier requirements	HH-M	Distributed loads and 26 % mass margin with 20% dry mass contingency allowed	CONE System
2.2	All hard-mounted components to have < 35 hz natural frequency	HH-M	All analyzed elements compliant	CONE System elements
2.3	Command and Telemetry format compatibility	HH-M	Primary overboard with Generic Vent System backup;	Orbiter / CONE System
2.4	Astronaut safing of heater bus	HH-M	SSP has ultimate control of heater bus	Electrical power subsystem
2.5	Payload must not have failure modes producing potential STS or crew hazards	HH-M	All potentially hazardous failure modes 2-fault tolerant	CONE System
2.6	SSP and ground commands required to power payload	HH-M	Incorporated in power bus design	Electrical power subsystem
2.7	Compatibility with CCGSE interfaces	HH-M	All interfaces are CCGSE compatible	CONE System
2.8	Maximum energy and power available are > 60 KwHr and 500 W	HH-M	CONE requires 17 KwHr and 141 W maximum	CONE System

Table 4-3, HH-M Requirements and Interfaces

Section 5

PAYLOAD DESIGN

Section 5 describes the analysis and design of the various subsystems that comprise the CONE support subsystems. These include the structural, thermal control, and avionics subsystems. The section begins with a description of the carrier selection task which resulted in the of the GSFC Hitchhiker-M as the CONE carrier. CONE software, both ground and flight, is also described in the last subsection. The requirements for each subsystem are given, followed by a discussion of the analysis performed and subsequent design.

5.1 CARRIER SELECTION

Early in the CONE study, a trade study determined the selection of an appropriate carrier for use with the STS. The carrier provides all mechanical, electrical, and signal interfaces to the orbiter, and must accommodate all payload requirements to facilitate satisfaction of all mission objectives. Three carrier options were considered: the Combined Release and Radiation Effects Satellite cradle, Mission Peculiar Equipment Support Structure, and Hitchhiker-M. The trade study resulted in the selection of a GSFC Hitchhiker-M as the baseline CONE carrier.

Developed, designed, and built for orbiter launch of the Combined Release and Radiation Effects Satellite, the CRRES cradle, shown in Figure 5-1, is now in storage. It is exceptionally strong and has excellent growth potential. Since the cradle is the property of the USAF, a loan, buy, or lease agreement would be required to use the existing cradle for CONE. An alternative would be to "build-to-print" a copy of the CRRES cradle which would provide LeRC with a dedicated test bed. Use of either the existing or a new cradle would require design and fabrication of avionics comparable to those provided by the HH-M.

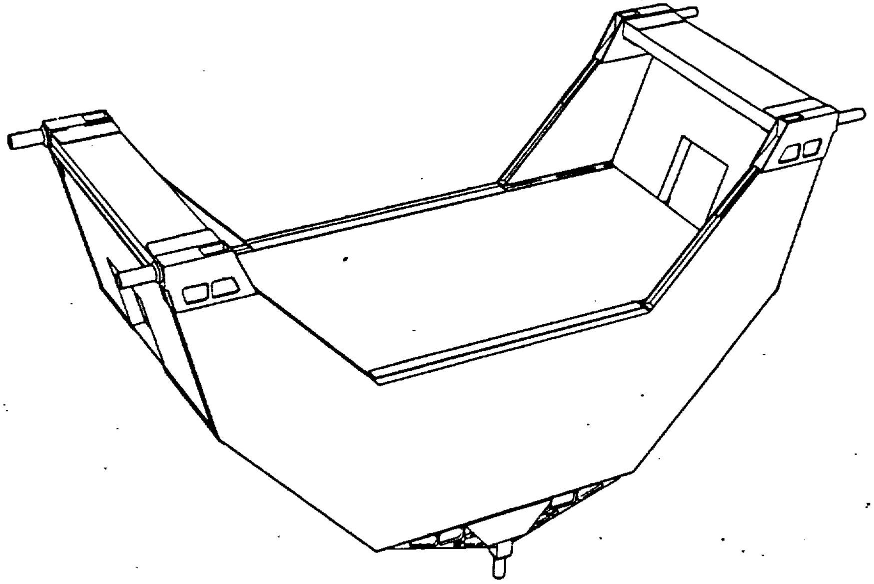


Figure 5-1, CRRES Cradle

The Multi-Purpose Experiment Support Structure shown in Figure 5-2, was designed and built by Teledyne-Brown of Huntsville, Alabama for MSFC. No avionics or other support interfaces are provided by the MPESS.

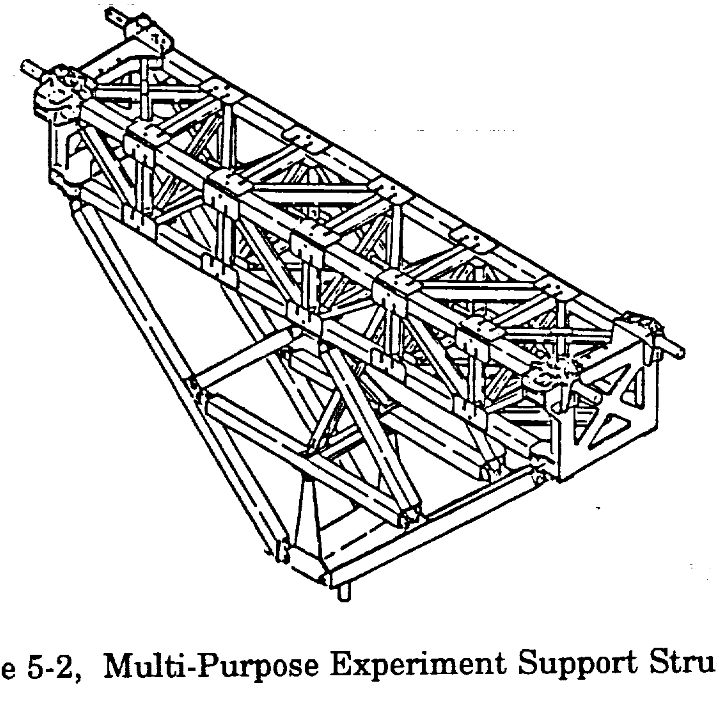


Figure 5-2, Multi-Purpose Experiment Support Structure

The MPESS is still available on a per-order basis from Teledyne-Brown. A dedicated MPESS would require addition of support avionics similar to those of the Hitchhiker-M. Development of an MPESS platform could provide LeRC a test bed suitable for a variety of CFM experiments.

The Hitchhiker-M shown in Figure 5-3 is an MPESS with the addition of avionics and mission peculiar equipment (MPE) for experiment attachment. The Hitchhiker program originated at MSFC, and in 1987 was transferred to, and is now managed by, the Hitchhiker Project Office at GSFC. The HH-M provides the capability to fly multiple small payloads, or single larger ones on the STS.

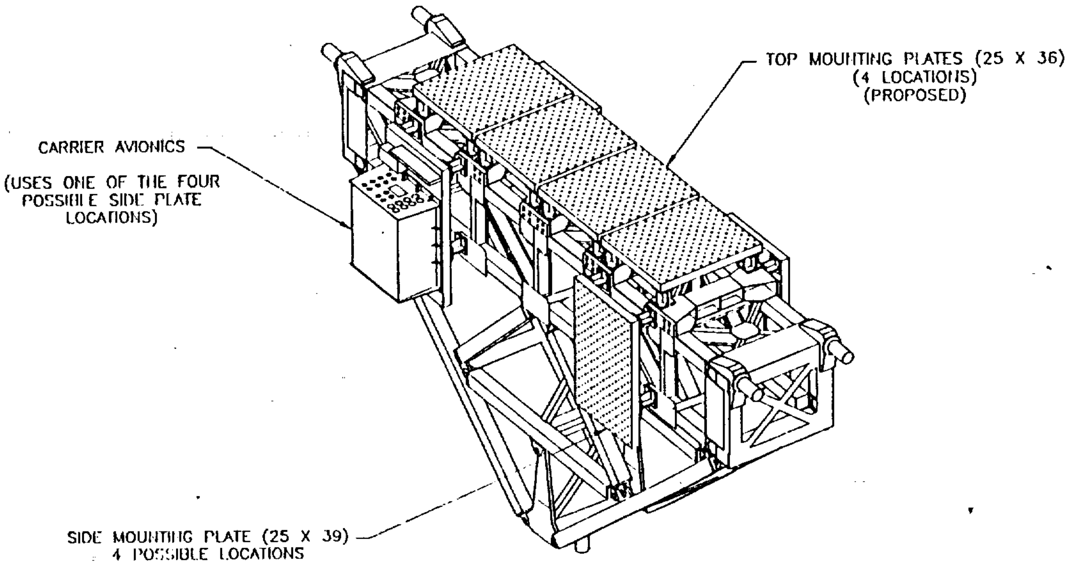


Figure 5-3, Hitchhiker-M

The carrier trade study considered key carrier parameters and projected costs to the CONE program. Primary carrier requirements and the performance of the candidates are summarized in Table 5-1. After consideration of the relative costs and merits of each alternative, the Hitchhiker-M was selected as the baseline carrier. This choice was made because the the HH-M incorporates the required STS interfaces, has the requisite payload mass and volume capacities, and has the lowest expected cost to the program.

ITEM	CONE REQUIREMENT	HITCHHIKER-M	MPESS (CRRES Avionics)	CRRES Cradle
Payload Mass	1,154 kg (w/ mass simulator)	1,746 kg	1,814 kg	4,082 kg
CG (ref. trunnion CL	-14 cm	-25 cm to 15 cm	-25 cm to 15 cm	-51 cm to 25 cm
Command Rate	< 1 Kbps	0.96 Kbps	2 Kbps	2 Kbps
Telemetry Rate				
(continuous)	≈ 1 Kbps	0.96 Kbps	16 Kbps	16 Kbps
(periodic)	≈ 1 Mbps	1.4 Mbps	N/A	N/A
Ground Commands (power switches)	7	8	13	13
Peak Power	140 W	1,680 W	2,400 W	2,400 W

Table 5-1, Carrier Trade Summary

Because the SSF FSC tank has grown beyond the capabilities of the HH-M, a new supply tank design will be required for CONE. Reexamination of the carrier trade during the beginning of Phase C/D might show that a CRRES cradle or similar carrier allowing use of the FSC tank results in a lower overall program cost.

5.2 CONFIGURATION/STRUCTURAL SUBSYSTEM

5.2.1 Configuration

As shown in Figure 5-4, the configuration of the CONE payload is driven primarily by fluid subystem requirements and objectives and carrier constraints. CONE payload elements are distributed on the upper (+Z) and fore (+X) and aft (-X) MPESS surfaces with the fluid elements on the +X side, avionics on the -X and the supply tank and receiver tank mass simulator on the +Z. This arrangement facilitates load distribution and cabling and fluid line optimization.

5.2.1.1 Requirements

CONE experiment and support configuration requirements, and the designs' approach to their satisfaction, are summarized in Table 5-2.

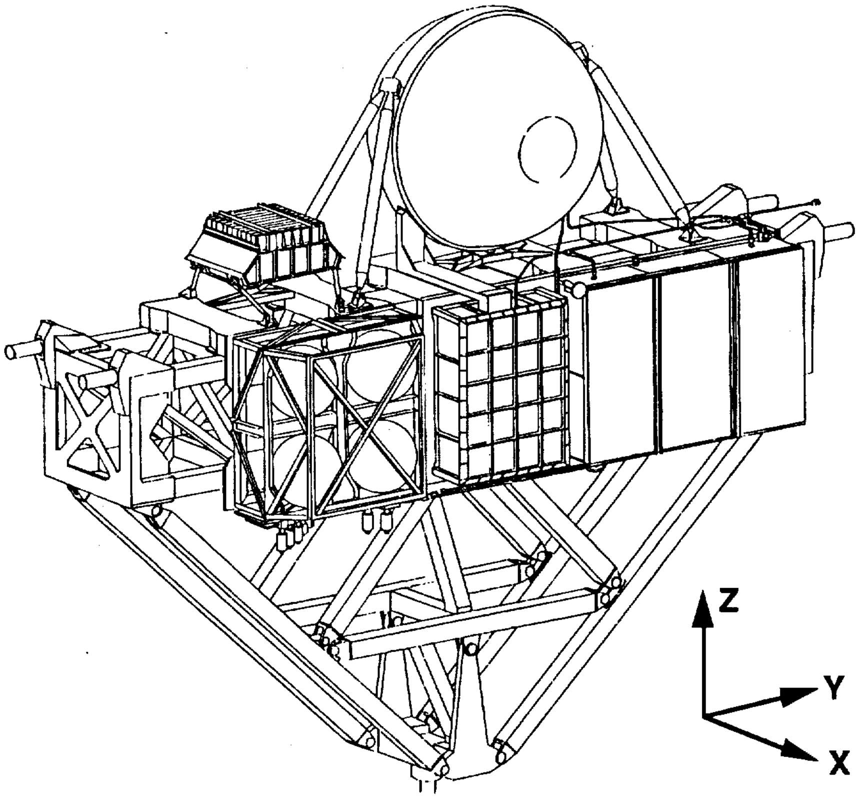


Figure 5-4, CONE Payload and HH-M Carrier

No.	Requirement	Source	Approach	Hardware Component
1.1	Payload mass properties compatible with carrier	HH-M	Distributed loads and 42% margin (wet), 20% contingency allowed	CONE System
1.2	Materials must be compatible with carrier	HH-M	All materials are HH-M compatible	All CONE System Elements
1.3	Materials must meet NSTS fracture control criteria	HH-M	All materials must meet NHB 8071.1 and/or MSFC-SPEC-522	All CONE System Elements
1.4	$-25\text{cm} \leq \text{C.G.} \leq +15\text{cm}$ referred to trunion centerline	HH-M	Current C.G. estimate is -14 cm	CONE System
1.5	Supply tank to be kinematically isolated from HH-M	Derived	4 strut and keel fitting system to support and isolate tank	Supply Tank Assembly
1.6	Minimize cable harness and plumbing runs	Design Practice	Group related modules on "front", "top" and "back" faces	All CONE Modules
1.7	Group cold components to simplify isolation and reduce vacuum jacketed lines	Derived	Mount cold components on an insulated plate inside a single vacuum box and use common jacket for lines	Vacuum Module Cold Box
1.8	Provide interfaces for addition of receiver tank	Design Goal	Provide Mass Simulator	Mass Simulator

Table 5-2, CONE Configuration Requirements

Several primary criteria shaped the configuration. STS requirements effect design practices and materials selections. Fracture control requirements and stress corrosion are particularly sensitive issues. Pressure vessels, and plumbing lines and fittings are also effected. The Hitchhiker-M also levies configuration requirements that effect equipment location and mounting. CONE is made up of large, massive elements which attach directly to the HH-M. Load distribution, kinematic isolation, and thermal stress mitigation are all issues. Finally, CONE cryogenic subsystem requirements effect fluid component layout. Grouping of cold components to allow control of heat leaks and providing of interfaces for a possible future receiver tank also are considerations. Coordinated design of the experiment and support subsystem configurations allowed satisfaction of all these requirements with a simple, integrated design.

5.2.1.2 Design

Figure 5-5 shows the +X view which visualizes the fluid component face of CONE. The fluid components are grouped on the +X face to minimize plumbing runs, and to minimize undesired, as opposed to desired, heat leaks. Starting at the left of the figure, the first component pictured is the pressurant module.

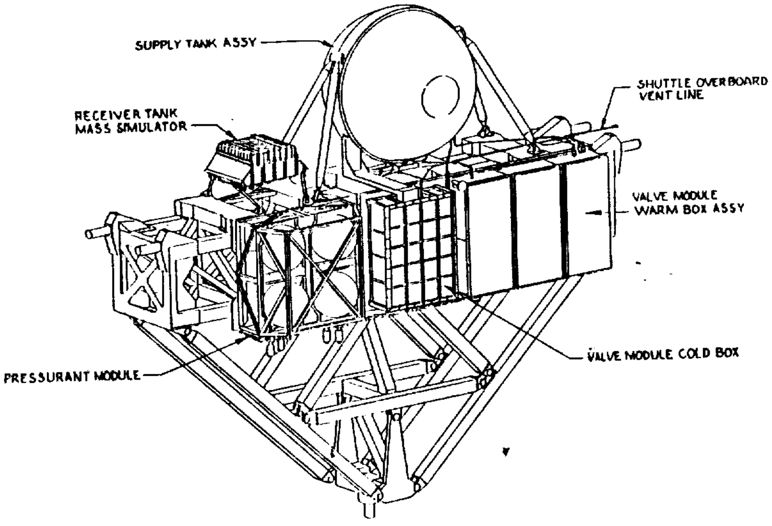


Figure 5-5, CONE Fore (+X) View

This assembly contains the four GN_2 pressurant tanks and their associated control components. One of these tanks will also be used for the pressurant tank recharge demonstration. This module mounts directly to the HH-M structure and is covered by MLI. The next item is the cold valve module. This is an evacuated, MLI insulated, module which contains all cold fluid components not located in the supply tank assembly. The cold valve module is connected to the supply tank by a common vacuum jacketed "snorkel" to minimize line heat leaks. To the right of the drawing, and sharing a common mounting plate with the cold valve module, is the warm valve module which contains other fluid components. This enclosure is really just an MLI covered framework which serves as an environmental enclosure for the fluid components mounted within. Finally, note the shuttle overboard vent line which is located to the right of the drawing. This is the primary vent for all expended cryogen. The connection to the STS generic vent which is provided for contingency venting is not shown in the drawing.

Figure 5-5 also depicts the supply tank and receiver tank mass simulator mounted on the upper surface of the HH-M. Kinematic isolation of the supply tank from the HH-M required an extensive design effort resulting in a strut and keel fitting arrangement which supports and isolates the tank, while satisfying the minimum fundamental frequency requirement. The mass simulator was added to permit proof of the mechanical interfaces for the receiver tank. The mass simulator mechanical interface to the HH-M duplicates that of the supply tank, and is identical to that of the proposed receiver tank. These components are located on the +Z face due to their large masses and volumes and to simplify interconnection between the supply tank and the future receiver tank.

The avionics components are located on the aft (-X) face of the CONE payload as depicted in Figure 5-6. To the left of the figure is the Hitchhiker-M avionics unit which provides electrical and signal interfaces between the payload and the orbiter. It mounts to one of the carrier side mounting locations using a standard mounting plate. To the right of the HH-M avionics is the CONE payload avionics module. It mounts to another standard mounting plate and includes the experiment control processor (ECP), data storage unit (DSU), power distribution unit (PDU), and valve driver unit/mixer control electronics (VDU/MCE). These elements are individually mounted and thermally controlled. Location of all electronics on a common face minimizes cabling runs and isolates units with large heat dissipations from the cryogenic subsystems.

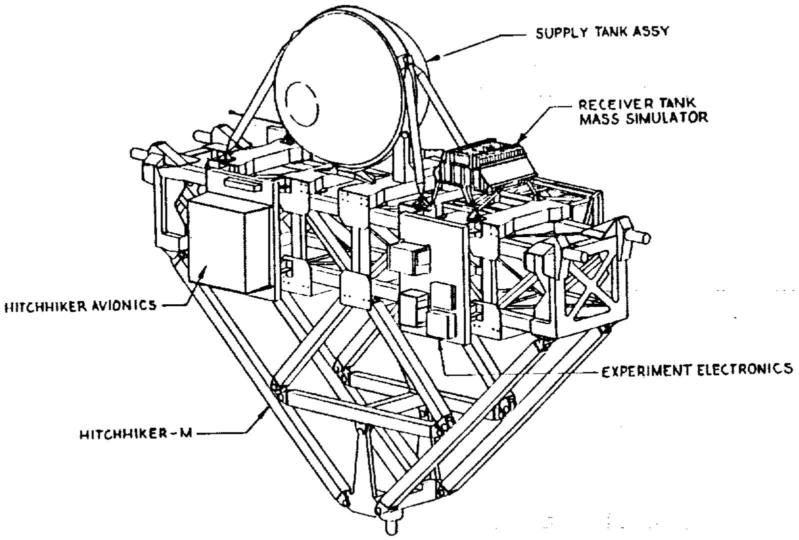


Figure 5-6, CONE Aft (-X) View

5.2.1.3 Mass Properties

Preliminary CONE mass properties are shown in Table 5-3. The center of mass of the payload is at -14 cm which is within the allowable range of -25 cm to 15 cm, referenced to the trunnion centerline. The receiver tank mass simulator is included in this estimate. The subsystem element masses are best estimates with no contingency added. A system level contingency of 20% of the dry mass was added to account for any missed items. The mass properties estimate is conservative given the present level of system definition. The total system mass of 1,294 kg, including contingency, is well within the HH-M capability of 1,746 kg.

5.2.1.4 Drawing Tree

The preliminary CONE drawing tree is shown in Figure 5-7. Unique drawings include carrier and STS specific documentation.

COMPONENT	QUANTITY	MFG	DIMENSIONS (mm/((in))	Mass (kg/(lb)) EACH	Mass (kg/(lb)) TOTAL	HERITAGE/ COMMENTS	SUBTOTALS (kg/((lb))
Thermal Control							7.2 / (15.8)
MLI Blankets	1	Sheldahl	TBD	4.5 / (10.0)	4.5 / (10.0)	SIR-A, SIR-B, SIR-C	
Thermostats	8	Sunstrand	N/A	0.4 / (0.8)	0.4 / (0.8)	STS, Viking, ERBS	
Heaters	4	Minco	TBD	0.45 / (1.0)	1.8 / (4.0)	ERBS, CRRES	
Paints / Finishes	1	TBD	N/A	0.45 / (1.0)	0.45 / (1.0)	ERBS, CRRES, SP-18	
Structural							169.6 / (374.3)
Struts, Supply Tank	4	BASG	1118x2x64 d. / (2.5 d.x 44x0.08)	3.6 / (8.0)	14.4 / (32.0)		
Keel Ftg, Supply Tank	1	BASG		3.6 / (8.0)	3.6 / (8.0)		
GN2 Module	1	BASG		37.8 / (83.3)	37.8 / (83.3)		
Valve Plate Assy.	1	BASG		29.5 / (65.0)	29.5 / (65.0)		
Standard HH Mtg. Plate	1	BASG		27.2 / (60.0)	27.2 / (60.0)		
Valve Box, warm & cold	1 each	BASG	TBD	13.6, 43.5 / (30, 96)	13.6, 43.5 / (30.0, 96.0)	STS PRSA, VICA box	
Power Distribution							17.3 / (38.1)
Power Control Unit	1	BASG	229x190x38 / (9x7.5x1.5)	1.4 / (3.1)	1.4 / (3.1)		
Harness	1	BASG	N/A	15.9 / (35.0)	15.9 / (35.0)		
Avionics							12.1 / (26.6)
Tape Recorder	1	Odetics	325x257x180 / (12.8x10.1x7.1)	8.9 / (19.6)	8.9 / (19.6)		
ECP	1	BASG	249x145x121 / (9.8x5.7x4.8)	3.2 / (7.0)	3.2 / (7.0)	IRAD	
Experiment							946.1 / (2085.8)
Supply Tank	1	BASG		209.1 / (461.0)	209.1 / (461.0)	Modified SSF Design	
Liquid Nitrogen	1	GFE	N/A	411.6 / (907.4)	411.6 / (907.4)		
Pressurant Tanks	4	Arde	289x373 d. / (14.7 d.x15.3)	12.5 / (27.5)	50.0 / (110.0)		
Pressurant (GN2)	4	GFE	N/A		31.4 / (69.3)		
Instrumentation	1		N/A		0.0 / (0.0)		
VDU/MDU	1	BASG	229x190x38 / (9x7.5x1.5)	2.7 / (6.0)	2.7 / (6.0)		
Check Valves	16	Circle Seal	91x51 dia / (3.6x 2dia)	0.1 / (0.3)	2.2 / (4.8)	S-IVB, LN2 OAMP	
Regulators	7	Fairchild	91x76 / (3.6x3 dia)	1.0 / (2.2)	7.0 / (15.4)	OAMP, STS, IABS	
Accelerometers	1	TBD					
Valves, Warm, Solenoid	24	Velcor	38x107x135 / (1.5x4.2x5.3)	1.4 / (3.1)	33.7 / (74.4)	LN2 OAMP, STS	
Valves, Cold	10	Utah State	53x91x159 / (2.1x3.6x6.25)	1.2 / (2.7)	12.0 / (27.0)	SHOOT, XRS, SAFIRE	
Valves, Manual	2	Nupro	38x114x152 / (1.5x4.5x6.0)	1.4 / (3)	2.8 / (6.0)	CLAES, Long Life Cooler	
Relief Valves	4	Circle/Velcor	102x51 dia / (4x 2dia.)	0.2 / (0.5)	0.9 / (2.0)	Delta, Saturn, Atlas	
Burst Disks	2	Ketema	81x56 dia / (3.18x 2.2dia)	0.6 / (1.4)	1.2 / (2.8)	SHOOT, COBE, CLAES	
Mixer / ATVS	1	BASG/TBD		6.8 / (15)	6.8 / (15.0)		
Lines	1	BASG	18,000 (700 in.) SS tubing	3.7 / (8.2)	3.2 / (8.2)		
Mass Simulator	1	BASG		171.5 / (378.0)	171.5 / (378.0)		
Payload Totals					1152.3 / (2540.6)		1152.3 / (2540.6)
Dry Contingency (20%)		accounts for missed H/W, brackets, design maturity			141.9 / (312.7)		
Hitchhiker Carrier		includes HH-M avionics and mounting plate			907.2 / (2000.0)		
CONE Totals					2201.4 / (4853.3)		

Table 5-3, Preliminary CONE Mass Properties

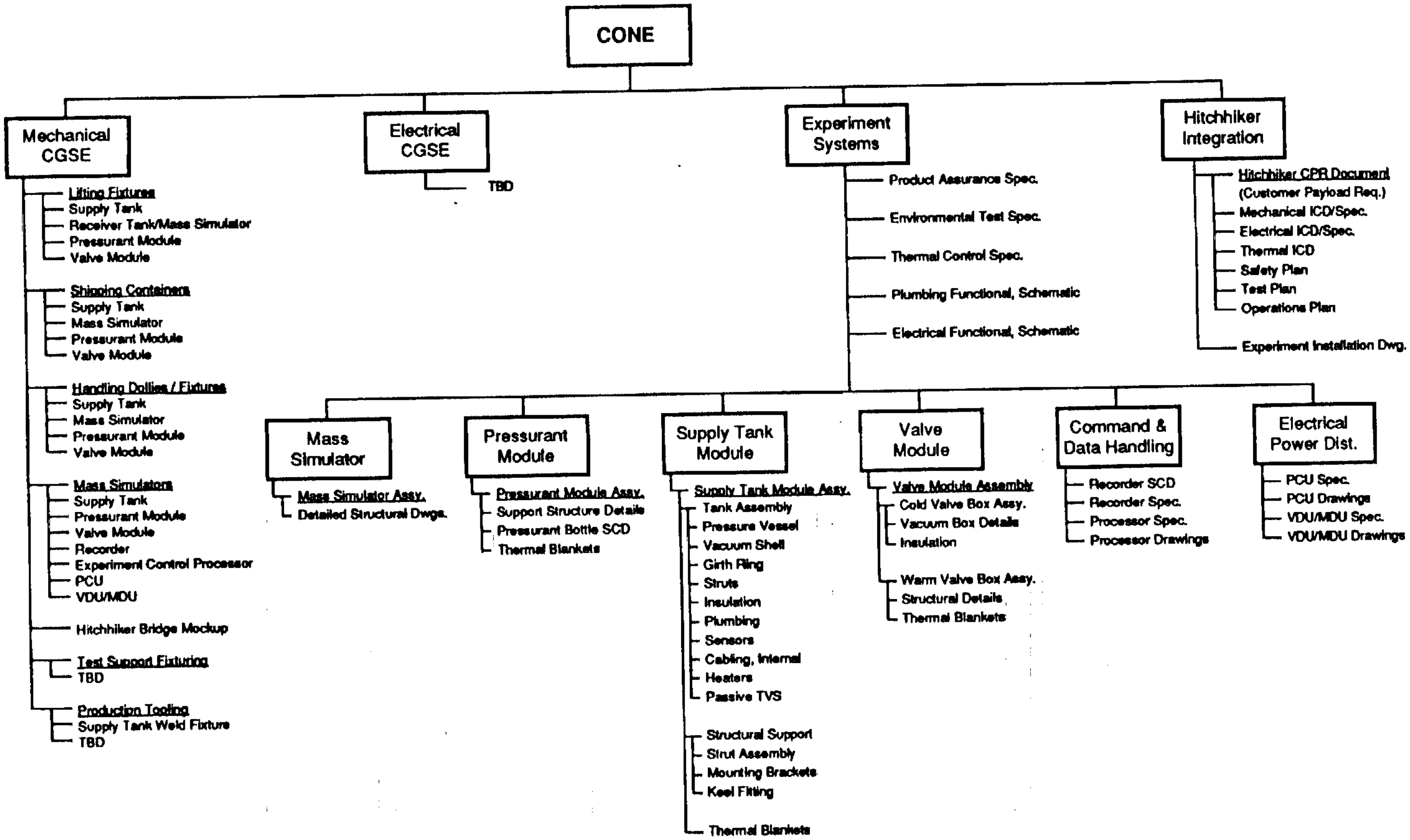


Figure 5-7, CONE Preliminary Drawing Tree

5.2.2 Structural Subsystem

The CONE structural subsystem provides the mechanical interface to the Hitchhiker-M carrier and the orbiter. It is designed to satisfy Hitchhiker-M and STS requirements, and provides the requisite support and isolation of CONE payload elements.

5.2.2.1 Structural Requirements

Primary CONE structural requirements are shown in Table 5-4. The items shown comprise the major design, analysis and test requirements which must be satisfied by the payload and individual structural elements.

No.	Requirement	Source	Approach	Hardware Component
1.1	Factors of Safety with Test Verification (Ultimate) = 1.4	HH-M	Comply with test verification	All CONE structural components
1.2	Materials must be compatible with carrier	HH-M	All materials are HH-M compatible	All CONE structural components
1.3	Materials must meet NSTS fracture control criteria	HH-M	All materials must meet NHB 8071.1 and/or MSFC-SPEC-522	All CONE structural components
1.4	Preliminary load factors per HHG-730-1503-05	HH-M	Analysis uses required load factors	All CONE structural analysis
1.5	Supply tank to be kinematically isolated from HH-M	Derived	4 strut and keel fitting system to support and isolate tank	Supply Tank Assembly
1.6	Fundamental frequency <35 Hz for components (hard mounted)	HH-M	Minimum frequency is 37 Hz (Mass Simulator)	All CONE structural components
1.7	Margins of Safety to be > 0 where MS = $\frac{\text{Allowable Stress}}{\text{FS x Actual Stress}} - 1$	HH-M	Design to satisfy requirement. Minimum MS is > 0	All CONE structural components
1.8	Finite element model required for all low-frequency (< 50 Hz) components	HH-M	Models generated for all low-frequency components	Supply Tank, Mass Simulator, Valve Module, Pressurant Module
1.9	Quasi-static testing required	HH-M	Test incorporated in Integration and Test Plan	CONE payload
1.10	Random vibration testing required	HH-M	Test incorporated in Integration and Test Plan	CONE components
1.11	Acoustic testing optional	HH-M	Test incorporated in Integration and Test Plan	CONE payload

Table 5-4, CONE Structural Requirements

5.2.2.2 Structural Design

The CONE structural subsystem is made up of a number of distinct payload elements which interface directly with the Hitchhiker-M structure.

5.2.2.2.1 Supply Tank

The supply tank uses a strut arrangement for mounting onto the Hitchhiker. One of the three equatorial mounts on the tank girth ring is adapted to interface with a keel bracket that restricts X and Y axis motions. The upper two tank fittings interface with the four struts that accept X and Z axis loads. The struts and keel bracket attach directly to the Hitchhiker "dog bone" fittings. Plumbing to and from the supply tank and cold box is a vacuum sealed "snorkel" assembly which houses the five lines between these modules. Two other separate lines connect the warm box to the supply tank.

5.2.2.2.2 Mass Simulator

The mass simulator is intended to provide the capability to add a receiver tank to the experiment later in the program without impacting the configuration or structural response of an already integrated and tested experiment. The mass simulator consists of a bolted aluminum frame with stacked steel ballast weights supported by four struts and a keel fitting. This arrangement is essentially identical to the proposed receiver tank with respect to weight, inertia, mounting arrangement, and dynamic response. In fact, the strut assemblies can be directly adapted to the receiver tank assembly. These struts also mount directly onto the Hitchhiker "dog bone" fittings.

5.2.2.2.3 Pressurant Module

The pressurant module is a bolted aluminum framework that supports the four high pressure gaseous nitrogen tanks. A honeycomb panel mounts to one side for locating some of the tank-peculiar plumbing. The module interfaces directly onto the Hitchhiker by bolting through the interface feet. There are four plumbing connections which interface the pressurant module to the experiment. Each nitrogen tank is kinematically mounted to the frame to ensure that no torsional or bending loads can be induced into the tanks.

5.2.2.2.4 Valve Module

The valve module is a plate assembly containing most of the experiment plumbing which is separated into a cold box and a warm box. Both boxes are mounted onto a single two-inch thick honeycomb plate. This plate uses a flexure arrangement for structural integration onto the Hitchhiker since the module spans two "bays" across the Hitchhiker bridge. The flexures allow bending to occur independently between the module and the Hitchhiker structure.

The cold box is a sealed vacuum container capable of handling a 103 kPa (15 psi) differential. The box is a welded aluminum tub configuration with a bolted lid using redundant O-ring seals. A 103 kPa (15 psi) burst disc mounted in the floor of the box is an added safety measure in the event of an internal valve failure. The warm box is essentially a thermal cover to insulate the "warm" components that mount directly to the two inch honeycomb plate. The cover of the box is removable to facilitate making the plumbing feedthrough connections and for test and inspection.

5.2.2.2.5 Avionics Module

The avionics module uses a standard Hitchhiker-M mounting plate, the same as is used for the Hitchhiker-M avionics. The ECP, VDU/MCE, PDU, and DSU are individually mounted on this pallet. Flexures similar to those used for the valve module provide the mechanical interface to the HH-M.

5.2.2.3 Structural Analysis

Stress and dynamics analysis was performed for key CONE elements to provide preliminary design guidance and estimate loads, fundamental frequencies, and margins of safety for the payload elements. NASTRAN modelling was performed for the Valve Module, Mass Simulator, Pressurant Module, and Supply Tank.

Table 5-5 summarizes the structural models produced for the NASTRAN analysis.

Component	# of Nodes	Element Types
Pressurant Module	218	Bar, Quad4, Rod, Tria3
Valve Module	15	Bar
Supply Tank	12	Bar, Rod
Mass Simulator	16	Bar, Rod

Table 5-5, CONE Structural Model Overview

The external quasi-static acceleration load factors shown in Table 5-6 were applied per HH-M documentation. Final load factors are determined by the Hitchhiker office using coupled loads analysis.

Translation (g's)			Rotation (rad/sec^2)		
Tx	Ty	Tz	Tz	Tz	Tz
±11	±11	±11	±85	±85	±85

Table 5-6, Preliminary Load Factors

Component modes resulting from dynamics analysis are shown in Table 5-7. Note that the 35 Hz minimum frequency is exceeded for all elements. The low frequency of pressurant module modes reflects the need for further design refinement as the structure is presently quite inefficient. The first supply tank and mass simulator modes are both low due to the keel fittings' inability to accept Z axis loads. These components warrant further design iteration during the Phase C/D program.

Component	Mode	Frequency (Hz)	Description
Pressurant Module	1	37.6	Z-Axis Unison Bottles
	2	57.5	Z-Axis Alternate Bottles
	3	73.5	Z-Axis Alternate Bottles
Valve Module	1	198.	X-Axis Cold & Warm
	2	258.	Y & Z Axis Cold & Warm
	3	340.	Y-Axis Cold Box
Supply Tank	1	36.8	X-Axis
	2	282.	Y-Axis
	3	8410.	Z-Axis
Mass Simulator	1	36.7	X-Axis
	2	86.0	Y-Axis
	3	102.	Z-Axis

Table 5-7, Component Modes

Maximum external reaction loads and structural component forces are shown in Table 5-8.

Component	Reaction Description	Reaction	
		(N)	(LB)
Pressurant Module	Base Reaction	7,120	1,600
	Bottle Vertical Reaction	1,600	360
	Bottle Horizontal Reaction	1,840	414
Valve Module	Flexure Shear	16,700	3,760
	Flexure Tension	10,300	2,320
	Post Tension	2,140	481
Supply Tank	Strut Tension	19,800	4,460
	Upper Boss Axial	8,900	2,000
	Upper Boss Shear	36,500	8,200
	Keel Boss Shear	94,300	21,200
Mass Simulator	Primary Strut Force	25,900	5,830
	Keel Strut Shear	20,600	4,640

Table 5-8, Reaction Loads

Finally, margins of safety are summarized in Table 5-9. Note that all margins of safety are positive, although the valve module flexure supports are marginal in buckling.

Component	Item	Failure Mode	Strength		Stress		Margin of Safety
			MPa	Ksi	MPa	Ksi	
Pressurant Module	Bottom Perim. Beams	Bndg. Tens.	241	35.0	25.9	3.75	+ 5.7
	Center Side Posts	Buckling	188	27.3	0.821	0.119	> + 10
	Corner Posts	Buckling	216	31.3	1.03	0.150	> + 10
	Cntr Diagonal Braces	Buckling	188	27.3	0.0896	0.013	> + 10
	Perim. Diag. Braces	Buckling	241	35.0	71.7	10.4	+ 1.4
	Bottle Sup. Channels	Flng. Crippling	185	26.9	91.7	13.3	+ 0.44
Valve Module	Flexure Supports	Buckling	177	25.7	128	18.6	+ 0.00
	Post Supports	Buckling	9.52	1.38	3.31	0.480	+ 1.05
Supply Tank	Primary Struts	Buckling	216	31.3	104	15.1	+ 0.48
Mass Simulator	Primary Struts	Buckling	134	19.4	40.0	5.80	+ 1.40
	Keel Struts	Buckling	132	19.1	31.7	4.60	+ 1.90

Table 5-9, Margins of Safety

In summary, several payload structural elements are especially noteworthy. The supply tank fundamental mode is of special interest because of the nature of the structural mounting of this element. The tank design requires that all loads must be tangential in nature, necessitating the use of the sliding keel fitting. This system requires that the four struts react all local vertical loads, creating the potential for a low fundamental frequency. Strut design must therefore consider both buckling margin of safety criteria and frequency tuning. The mass simulator mounting design is similarly constrained and therefore requires similar treatment. Also, the present pressurant module is not structurally optimized. Design and analysis iteration will be required to minimize structural mass and provide optimum support to the pressurant tanks.

5.3 THERMAL CONTROL SUBSYSTEM

The thermal control subsystem (TCS) provides required temperature control for all CONE system elements. Environments specified by HH-M documentation were used as input conditions, allowing simulation of external fluxes using

TRASYS. Temperature predictions were modeled using SINDA based upon the TRASYS output fluxes and estimated component thermal and electrical characteristics. Analysis indicates that heaters are not required for the avionics components, but are required for the pressurant modules. Ultimate heater control is exercised by astronauts using the Standard Switch Panel to provide requisite system safety. All TCS components are flight qualified.

5.3.1 Thermal Control Requirements

CONE thermal control requirements are shown in Table 5-10.

No.	Requirement	Source	Approach	Hardware Component
1.1	Accommodate worst-case conditions expected in STS bay	NSTS	Analysis conditions reflect worst-case ranges	CONE System
1.2	Maintain all CONE components within their allowable limits	Derived	All components compliant	All CONE System Elements
1.3	Active control components must have redundant elements and 50% design margin	NSTS	Design to meet requirement	All active control components
1.4	Astronaut safing of heater bus required	HH-M	SSP is ultimate control for heater bus	Heater Bus

Table 5-10, Thermal Control Requirements

Operating and non-operating temperature limits for the specific payload components are shown in Table 5-11. The average power dissipation for each applicable unit is also shown.

COMPONENT	AVG. POWER DISSIPATION(W)	TEMPERATURE RANGES			
		OPERATING		NON-OPERATING	
		MIN(C)	MAX(C)	MIN(C)	MAX(C)
Experiment Control Processor	35 W	-10	+40	-20	+55
Power Control Unit	10 W	-10	+40	-20	+55
VDU/MDU	4 W	-10	+40	-20	+55
Tape Recorder Unit	16 W (24 P.B.)	-10	+40	-20	+45
Pressurant Tanks	N/A	+0	+60	-20	+60
Supply Tank Shell	N/A	-60	+50	-60	+50

Table 5-11, Component Temperature Limits

5.3.2 Thermal Control Design

The TCS design goal was to create the simplest, most cost-effective concept capable of satisfying the TCS requirements with requisite crew safety. Specifically, the design approach should:

- Use flight-proven components and materials
- Make maximum use of passive thermal control techniques
- Use electrical heaters to handle off-nominal conditions
- Isolate the experiment to the maximum possible extent from the HH-M structure to minimize undesirable thermal coupling

TRASYS and SINDA simulations were used to determine the payload thermal parameters, and to facilitate selection of an optimum set of surface coatings and insulation packages.

The CONE thermal design concept is shown in Figure 5-8. Surface finishes and MLI requirements are indicated in the figure for all payload elements. These surface finishes were used in the associated thermal analysis. Note that the effective MLI emittance was assumed to be 0.03.

Heaters are not required for the avionics and electronics components for any of the modeled environmental conditions. Heaters of approximately 2 W each are required for the pressurant tanks. All heaters are operated by thermostats with Standard Switch Panel and ground command backup.

5.3.3 Thermal Analysis

TRASYS and SINDA simulations characterized the radiation environment and payload transient temperatures for anticipated conditions.

5.3.3.1 TRASYS Analysis

A TRASYS model of the major CONE subsystems, HH-M avionics box and STS payload bay was constructed.

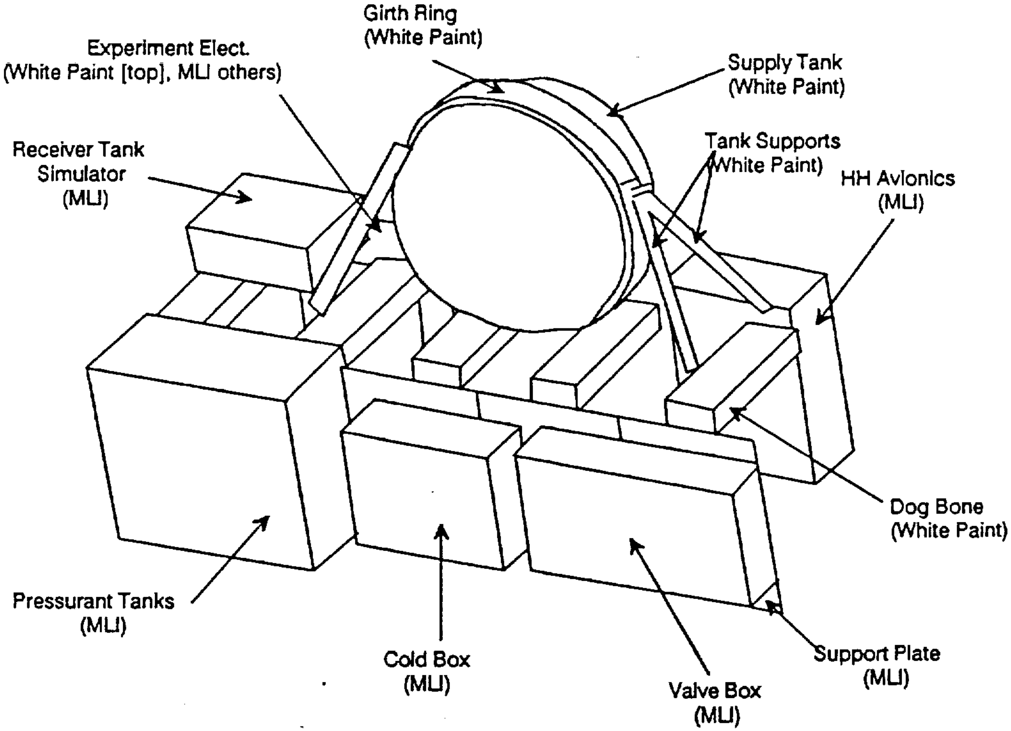


Figure 5-8, CONE TCS Concept

The model uses a simplified orbiter bay representation that simulates the bay liner, bulkheads, and blockage by adjacent payloads. Major CONE subsystems included in the model are: avionics box, supply tank, warm and cold valve boxes, pressurant module, HH-M attachment fittings and mounting plate.

The TRASYS model calculated radiation exchange factors for all external surfaces and orbital fluxes. The orbital attitudes simulated were the following:

• +Z - LV (Bay-to-Earth)	Bay facing the earth is the primary STS attitude while on orbit. This is the nominal attitude for beginning worst-case cold and hot analysis.

+Z - SI (Bay-to-Sun)	Bay facing the sun attitude is the worst-case hot condition for analysis. The operational requirement is 30 minutes in this attitude.
-Z - POP (Bay-to-Space)	Bay facing to space attitude is the worst-case cold condition for analysis. The operational requirement is 60 minutes in this attitude.
Gravity Gradient	This attitude minimizes RCS firings and the resulting g-level disturbances. There are six stable orientations for GG. For analysis purposes, a beta angle of zero was used with +Z-POP.

The CONE TRASYS model is shown in Figure 5-9. The payload bay is modeled as a shortened, 15-foot long, half-cylinder with full disks at each end. This allows simulation of the bay liner, other payloads, and the bay bulkheads. The thermal properties for the bay liner and bulkheads were taken from NSTS 21000-IDD-STD. The Hitchhiker-M structure was not modeled since it has a minimum effect on the payload radiation environment. The HH-M avionics module was included for radiation exchange and absorbed heating calculations.

TRASYS results were used as input for subsequent SINDA temperature analysis.

5.3.3.2 SINDA Analysis

Description

A 95 node SINDA math model was constructed and used to establish the temperature characteristics of CONE elements under the environmental conditions listed above. In particular, transient analysis was completed for +Z-LV, +Z-SI, gravity gradient, and bay-to-space conditions. Steady-state analysis was completed for +Z-LV, +Z-SI, and bay-to-space orientations. Limitations for the bay-to-space and bay-to-sun (+Z-SI) conditions were established, but are well within STS requirements for payload operations in these attitudes.

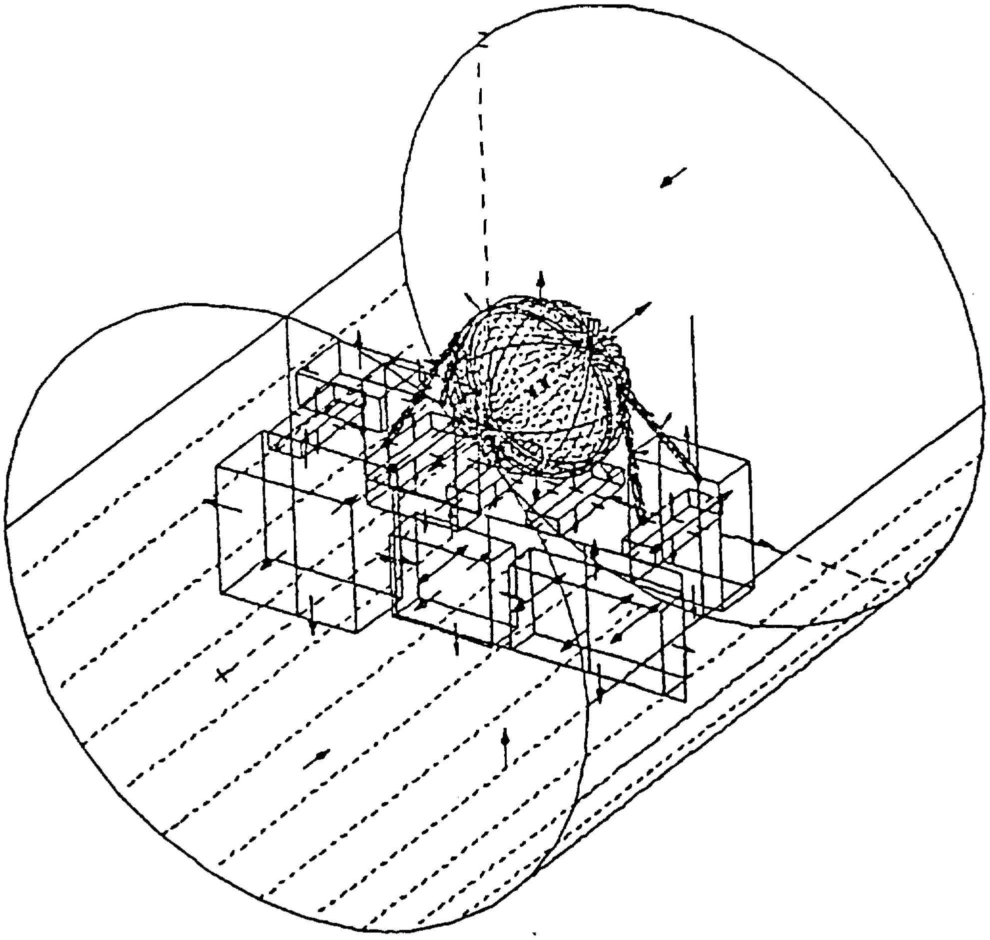


Figure 5-9, CONE TRASYS Model

Simplified representations of the STS bay, HH-M carrier structure, and adjacent payloads were used. The STS cargo bay was modeled as a half-cylinder with closed ends. The ends represented adjacent payload blockages and/or the bay bulkheads and the interior surface of the half-cylinder represented a quarter-bay section of the payload bay liner surface. All of these surfaces were modeled as arithmetic nodes. The HH-M structure was modeled as a boundary node. The temperature used for this node depended on the STS orientation. For hot case analyses, the node was set to 60 C, and for cold conditions to -49 C. The suitability of these temperature choices must be evaluated during the C/D phase.

Results

Figures 5-10 and 5-11 present results from the nominal (+Z-LV) transient analysis for CONE avionics and supply tank wall temperatures. The orbital variation of electronic component temperatures is about 3 C and the tank walls vary about 7 C during an orbit.

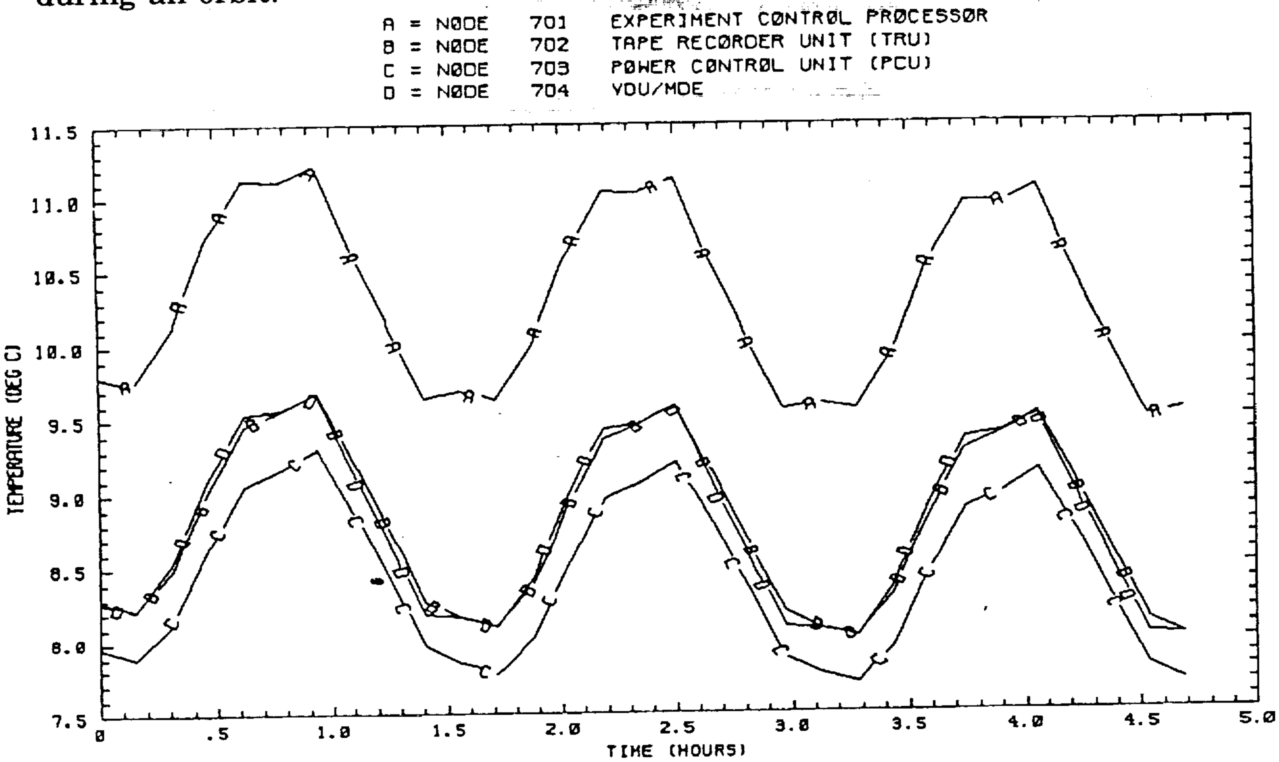


Figure 5-10, Electronics Temperatures (Nominal)

Figures 5-12 and 5-13 show the same data for the worst-case cold condition. This analysis used the nominal steady-state conditions for the initial temperatures of the components. All external fluxes were removed and the temperatures allowed to decrease. No heaters were simulated for the analysis. The maximum operational requirement for this attitude is 90 minutes. All components remained within their operating temperature ranges even for the prolonged exposure. The tank wall temperatures, however, decrease at a much faster rate and reach a lower temperature, yet remain within the allowable range.

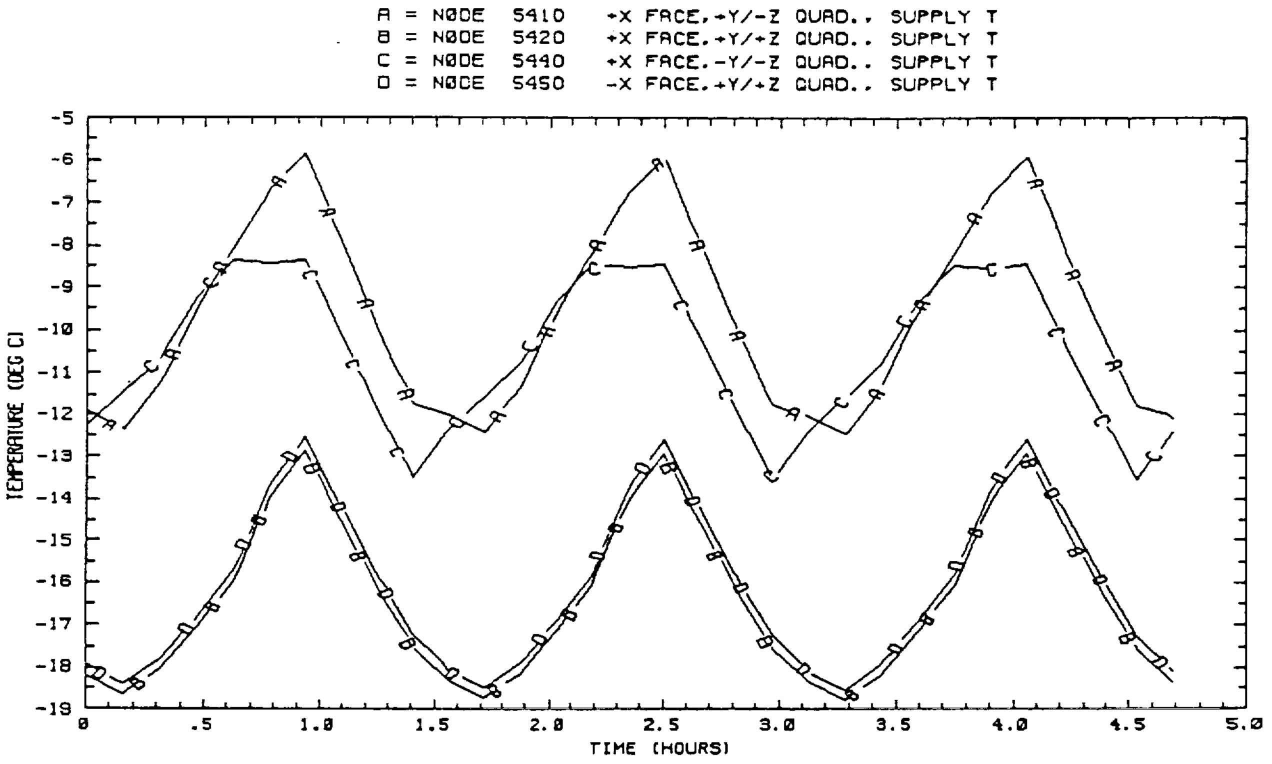


Figure 5-11, Supply Tank Wall Temperatures (Nominal)

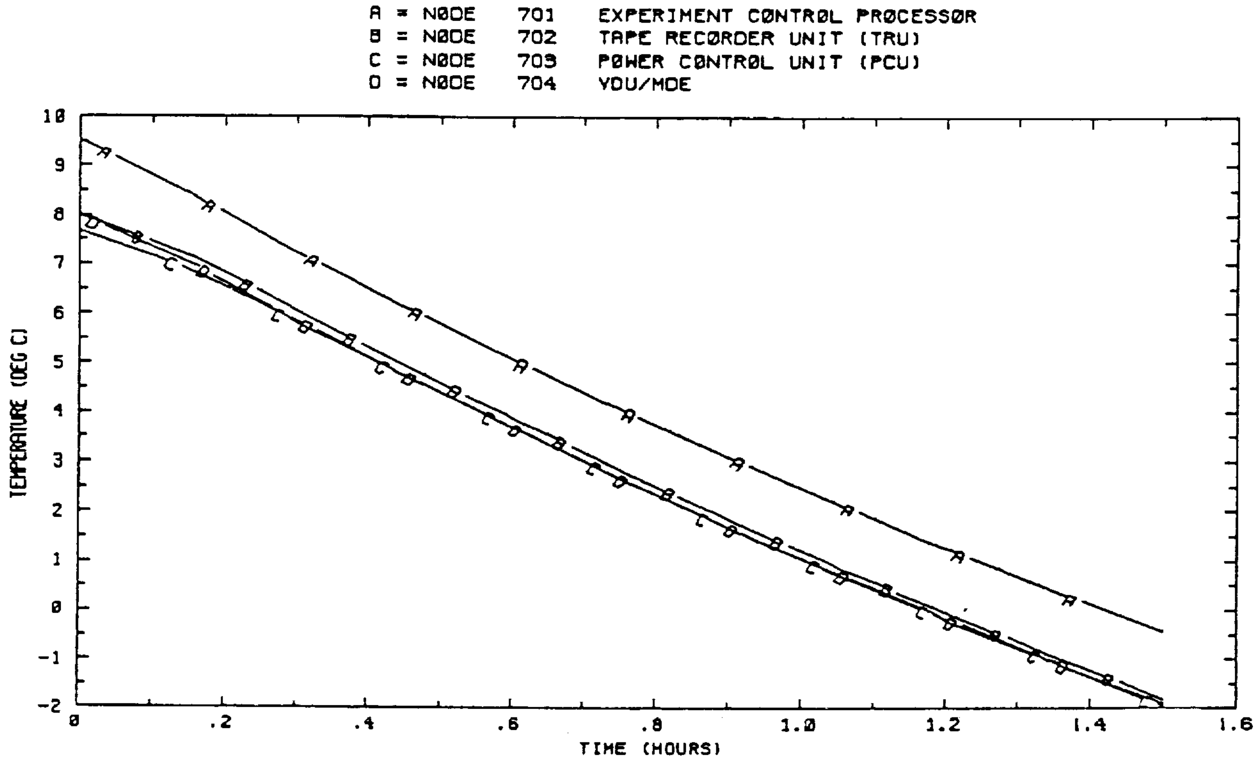


Figure 5-12, Electronics Temperatures (Bay-to-Space)

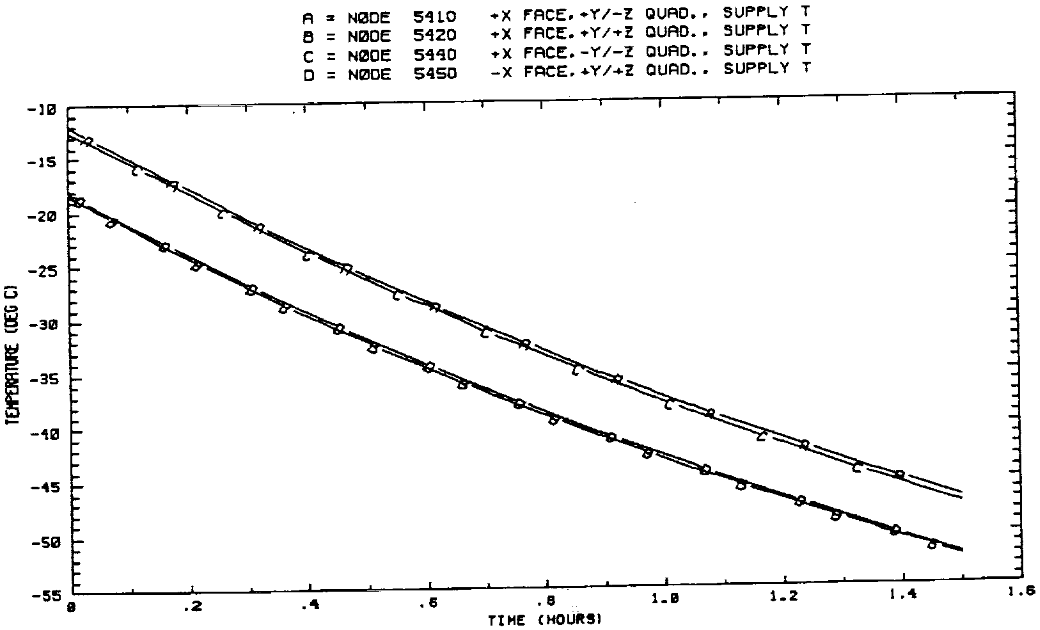


Figure 5-13, Supply Tank Wall Temperature (Bay-to-Space)

Figures 5-14 and 5-15 present transient data for the worst case hot condition (bay-to-sun) The operational requirement for this attitude is 30 minutes. All components remained within their allowable operating temperatures for the entire 30 minute period. The tank wall temperatures remained within allowable maximums during the entire 30 plus minute exposure. However, the tank shell gradients increase and will have to be evaluated for acceptability during the C/D phase.

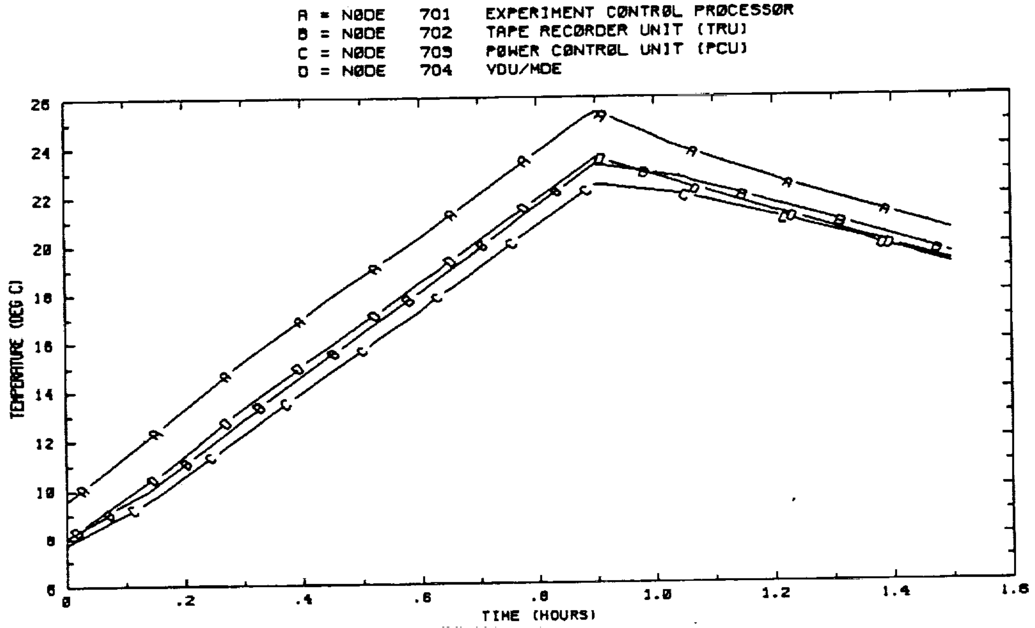


Figure 5-14, Electronics Temperatures (Bay-to-Sun)

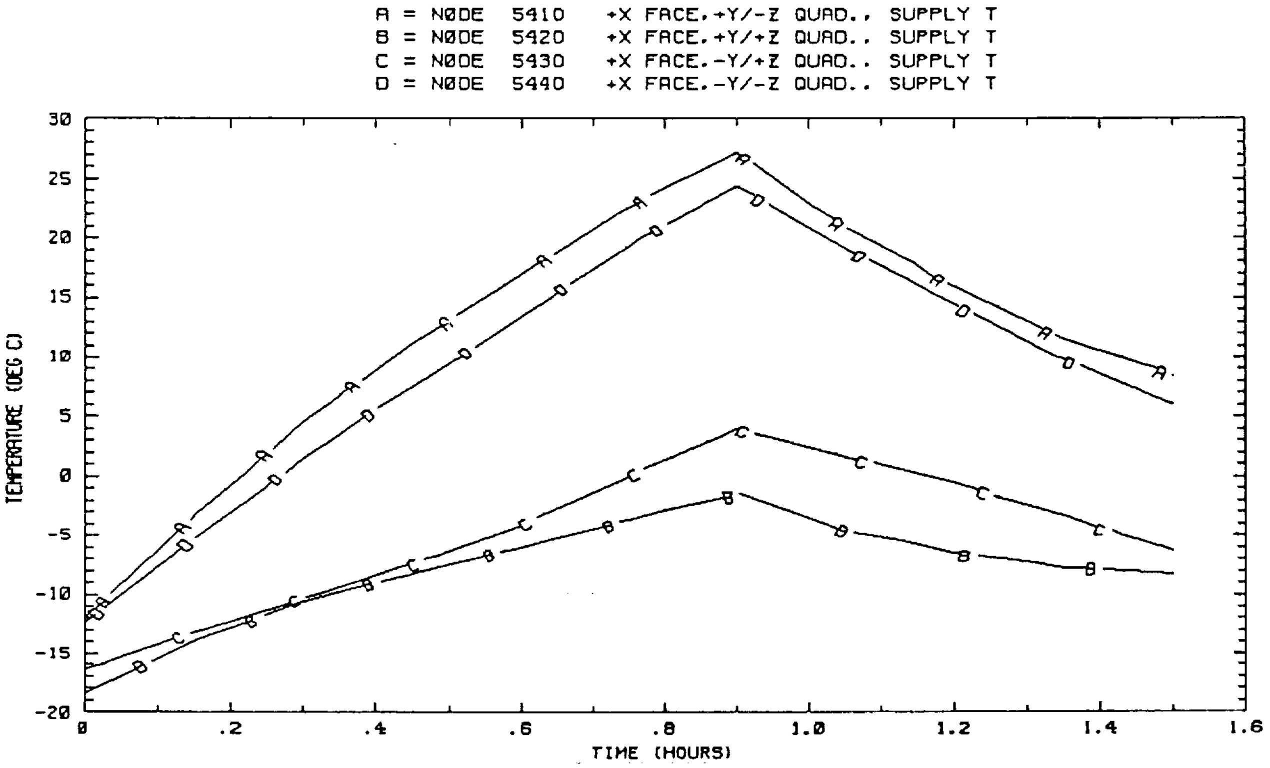


Figure 5-15, Supply Tank Wall Temperature (Bay-to-Sun)

5.3.4 Thermal Control Components

A thermal control subsystem component summary is shown in Table 5-12. All components are qualified and have been flown by Ball.

Component	Catalog No.	Vendor	Heritage	α	ε
Heaters, fiilm	S-311-79	Minco	ERBS, SATCOM		
Thermostats	975-0406-202	Sundstrand	STS, ERBS		
White Paint	Z-306	Lord Corp.	ERBS, P-78	0.20	0.85
Tapes	TBD	Sheldahl	ERBS, SME		
VDA x 0.5 mil Mylar x VDA	G405260	Sheldahl	ERBS, SIR-A,B		
2 mil Kapton x VDA	G405260	Sheldahl	ERBS, SIR-A,B		
Beta Cloth / PTFE coated	389-7	GFE (Dodge)	SIR-A, SIR-B	0.32	0.80
Dacron netting		TBS	ERBS, CRRES		

Table 5-12, Thermal Control Component Summary

5.4 AVIONICS

The CONE avionics provide experiment command and data handling, as well as electrical power distribution. Avionics requirements are summarized in Table 5-13. The requirements were satisfied with a low-cost system design which was responsive to the experiment requirements with minimal redundancy. The primary design driver for the avionics was implementation of a single-string system (for simplicity and cost), which was responsive to STS safety and experiment control requirements.

Parameter	Requirement	Source	Performance	Comments
Redundancy	Single string, except for safety requirements	Allocated, NSTS	Complies	
Radiation Tolerance	1. 10 krad total dose 2. No parts shall exhibit destructive latch-up	Allocated	1. 20 krad total dose 2. Complies	
Command	Hitchhiker-M compatible	TD 3	HHSP asynchronous uplink	All active control components
Telemetry	Hitchhiker-M compatible	TD 3	1. HHSP asynchronous downlink (real-time) 2. HHSP medium rate Ku-band downlink (P/B)	Heater Bus
Catastrophic Failures	2 failure tolerant	NSTS 1700.7B	Heater power system complies	Only catastrophic failure identified
Critical Failures	1 failure tolerant	NSTS 1700.7B	1. Liquid vent system complies 2. ECP has backup circuit to safe experiment	Only critical failures identified
Power Up	Both ground and astronaut commands required	HHG-730-1503-05	Complies	
Fusing	Power buses must be fused for fire protection	HHG-730-1503-05	Complies	

Table 5-13, Avionics Design Requirements

The current CONE avionics architecture shown in the avionics system functional diagram, Figure 5-16 is flexible, accommodates new safety requirements, and takes advantage of ongoing design efforts on other projects and IR&D programs. The avionics architecture is centered around the Experiment Control Processor (ECP), which performs most of the experiment command and control functions.

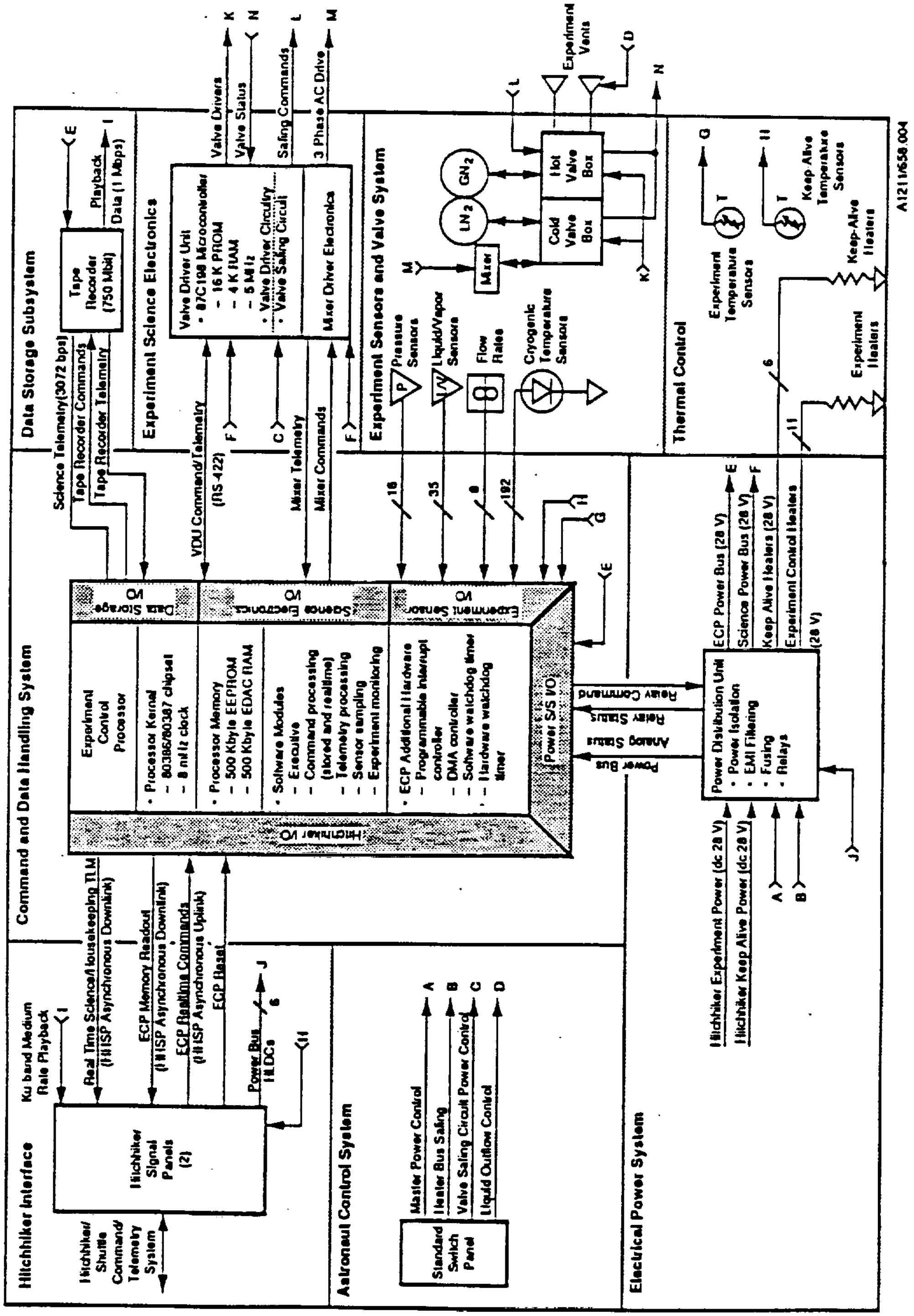


Figure 5-16, CONE Avionics Functional Diagram

The ECP contains an 80386/80387 processor and associated memory, sensor interface circuitry, and Hitchhiker I/O circuits. The remaining units provide for experiment control (mixer control and valve actuations), power distribution, and data storage. Four separate units, Table 5-14, comprise the CONE avionics; functional descriptions are contained in the remaining body of this section.

Component	Unit Mass (kg)	Envelope (mm) (L x W x H)	Power (W)	Temp Limits (Operating)	Temp Limits (Survival)	Heritage
ECP	5.0	249 x 145 x 121	35.0	-10 C to 40 C	-20 C to 55 C	Ball IR&D
PDU	1.4	229 x 190 x 38	10.0 (Avg.)	-10 C to 40 C	-20 C to 55 C	SP-18
VDU/MDE	2.7	229 x 190 x 76	4.0	-10 C to 40 C	-20 C to 55 C	XRS
DSU	8.9	325 x 257 x 180	16.0 (24.0 P/B)	-10 C to 40 C	-20 C to 45 C	CRRES

Table 5-14, CONE Avionics Summary

5.4.1 Command and Data Handling

The command and data handling (C&DH) subsystem is focused around the ECP and provides the following functions:

- Bi-directional experiment communication via the Hitchhiker-M
- Data collection, storage and downlink
- Experiment control

To complement the ECP, the C&DH subsystem also has a tape recorder and a Valve Driver Unit (VDU) / Mixer Control Electronics (MCE) assembly which provide additional electrical interfaces for experiment command and control. The ECP interfaces with each of the units in the C&DH subsystem and the Hitchhiker-M, thus providing a centralized design. This centralized design provides a good baseline for CONE because C&DH operations and interfaces are easily defined, and makes use of the Ball modular spacecraft processor (MSP) IR&D program for reduced subsystem cost.

5.4.1.1 Hitchhiker-M Interfaces

Hitchhiker-M interfaces can be grouped into two categories: Hitchhiker signal panel (HHSP) electrical and astronaut standard switch panel (SSP). The Hitchhiker/astronaut interface design minimizes the number of HHSP's required (2) and the number of astronaut switch commands (4). Minimizing these interfaces simplifies experiment integration and test and reduces the number of operational constraints induced by the level of required astronaut participation.

The HHSP interface, Figure 5-17, provides the following C&DH interfaces between CONE and the Hitchhiker/STS:

- Uplink command
- Downlink telemetry: two real-time and one tape playback service
- Keep-alive (CONE not powered) telemetry
- Ground based ECP reset and experiment power application

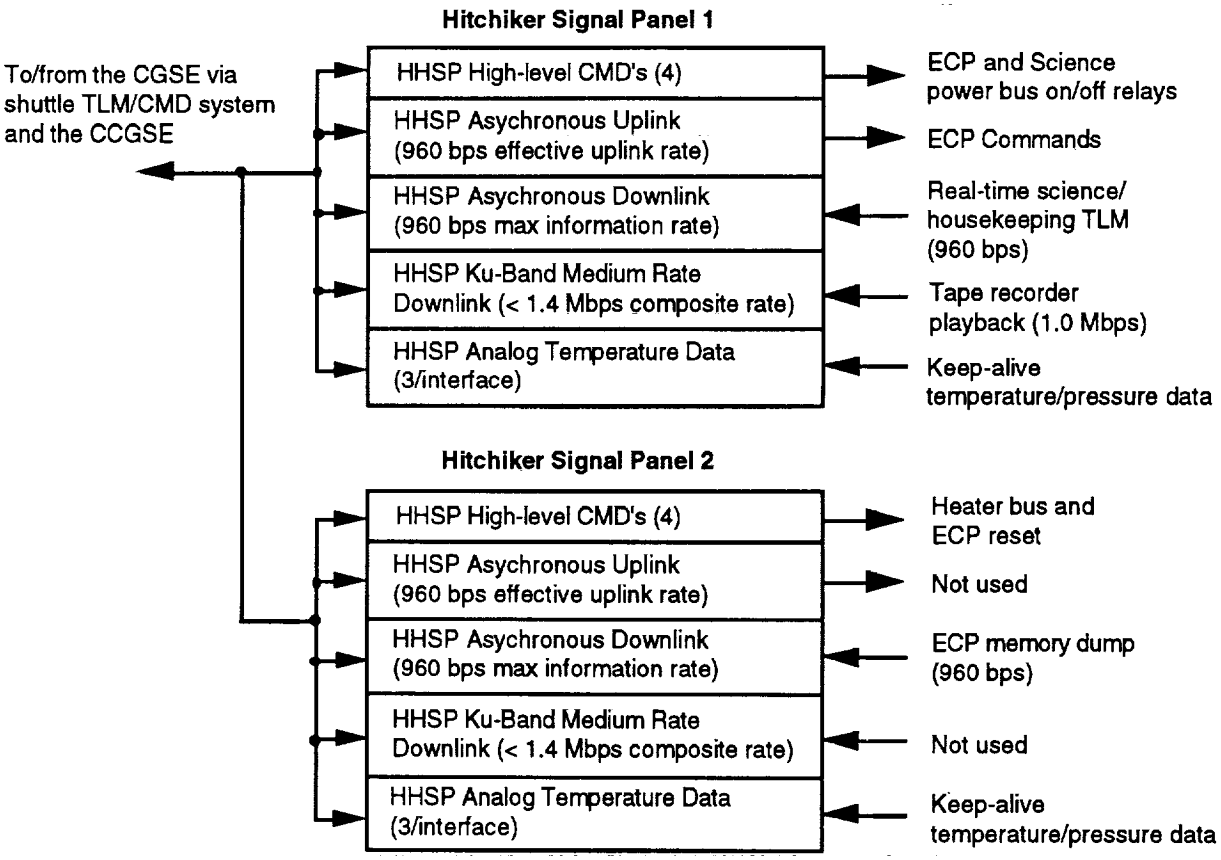


Figure 5-17, Hitchhiker Signal Panel Interfaces

The interface design uses standard Hitchhiker services to meet requirements at the lowest cost. The SSP interfaces, Figure 5-18, provide those functions required by the Hitchhiker manual or STS safety requirements. By minimizing astronaut interfaces, experiment operation, integration and test are simplified. The current design accommodates all anticipated requirements, but can easily be modified should more astronaut involvement become required.

Those experiment functions requiring astronaut control (and the reason) are currently identified as:

- Master experiment power control (Hitchhiker/STS requirement)
- ECP backup manifested in a valve safing sequence (safety reqt.)
- Master liquid outflow control (safety requirement)
- Heater bus power on/off control (catastrophic safety requirement)

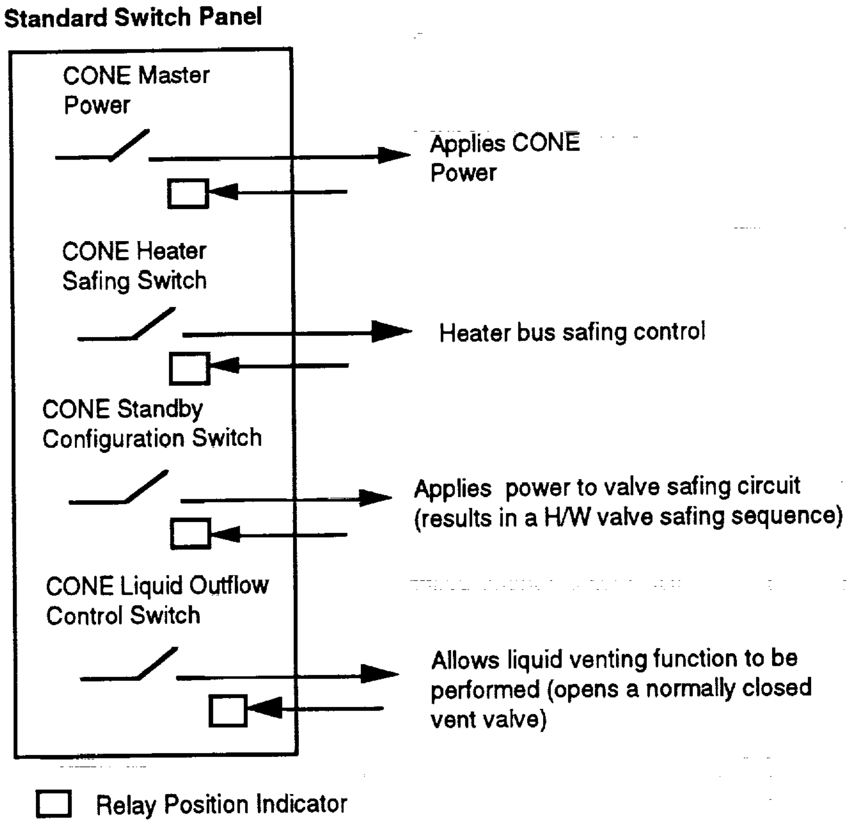


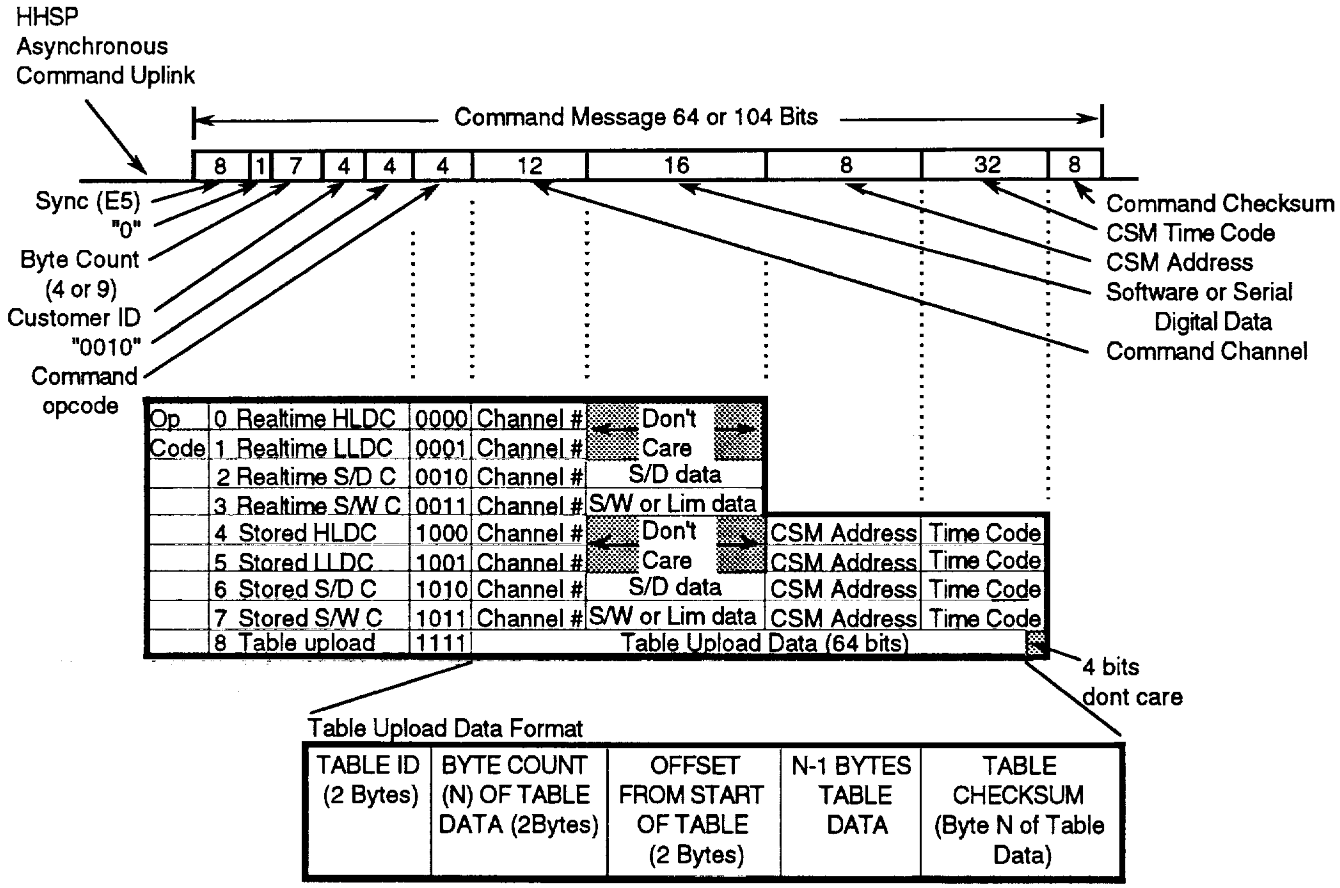
Figure 5-18, Standard Switch Panel Interface

5.4.1.2 Command and Telemetry

CONE command formats are consistent with both Hitchhiker interface specifications and proven formats used successfully on previous Ball spacecraft. The three CONE command types use the Hitchhiker asynchronous uplink to provide the following command functions:

- ECP commands
- Ground based power application commands (HHSP commands)
- Mission event time (MET) updates

The majority of CONE commands will be ECP commands (i.e. commands interpreted and processed by the ECP). The MET and HHSP commands correspond to formats defined in the Hitchhiker user's manual. The ECP command format, Figure 5-19, provides real-time and stored command functions.



Op Code	0 Realtime HLDC	0000	Channel #	Don't Care		
	1 Realtime LLDC	0001	Channel #			
	2 Realtime S/D C	0010	Channel #	S/D data		
	3 Realtime S/W C	0011	Channel #	S/W or Lim data		
	4 Stored HLDC	1000	Channel #	Don't Care	CSM Address	Time Code
	5 Stored LLDC	1001	Channel #		CSM Address	Time Code
	6 Stored S/D C	1010	Channel #	S/D data	CSM Address	Time Code
	7 Stored S/W C	1011	Channel #	S/W or Lim data	CSM Address	Time Code
	8 Table upload	1111	Table Upload Data (64 bits)			

Table Upload Data Format

TABLE ID (2 Bytes)	BYTE COUNT (N) OF TABLE DATA (2Bytes)	OFFSET FROM START OF TABLE (2 Bytes)	N-1 BYTES TABLE DATA	TABLE CHECKSUM (Byte N of Table Data)

Figure 5-19, ECP Command Format

Command channel allocations have been divided between HHSP commands, ECP commands and VDU commands. VDU commands are processed by the ECP, but the channel is physically contained in the VDU and thus is distinct. Command channel requirements and performance analysis, see Table 5-15, indicate ample margin is available for all command types.

Command Type	Number Required	Number Allocated	Margin (Percent)
SSP Switches	4	N/A	N/A
HHSP HLDC's	7	8	12.5
ECP HLDC's	34	64	47
ECP LLDC's	0	64	100
ECP Analog	0	8	100
ECP Serial Digital	3	8	62.5
VDU Valve Drivers	35	40	12.5

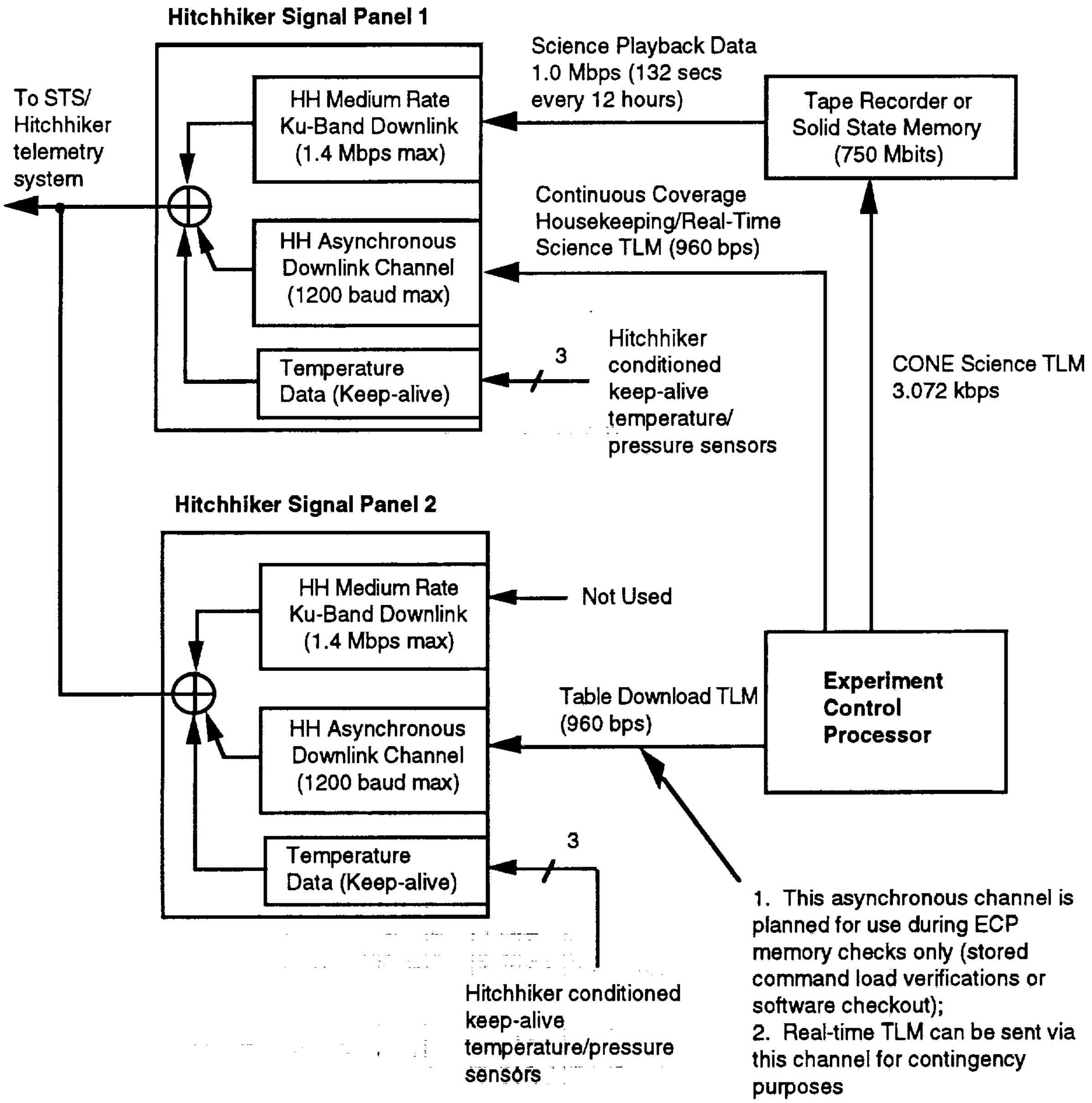
Table 5-15, CONE Command Channel Margins

The CONE telemetry design, Figure 5-20, provides maximum flexibility in receiving real-time data, providing troubleshooting capability and permitting ECP software verification while minimizing the number of HHSP's required. The HHSP telemetry services used are:

- Real-time science/housekeeping telemetry
- ECP table download (memory readout) telemetry
- Science data playback

The two primary telemetry formats are the real-time and science frames. The science frame represents the primary telemetry format, Figure 5-21, with each sensor sampled once per second. Because the asynchronous downlink has a maximum effective bit rate of 960 bps, the science stream is recorded and played back vis the STS Ku-band downlink throughout the mission, nominally every 12 hours, in a manner similar to most low earth orbiting satellites.

The real-time frame provides real-time experiment data (sampled at 1 Hz) and general experiment data (subcommed at 1/4 Hz) as shown in Figure 5-22.



1. This asynchronous channel is planned for use during ECP memory checks only (stored command load verifications or software checkout);
2. Real-time TLM can be sent via this channel for contingency purposes

Figure 5-20, CONE/HHSP Telemetry Interfaces

Word	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	Frame Sync Pattern (FAF320)			Exp ID	Frame Count			ECP Status	Mission Event Time				Last Executed Command				15
16	Cryo Diode Temp Samples (T1,T2)			L/V (LV1)	Cryo Diode Temp Samples (T3,T4)			L/V (LV2)	Cryo Diode Temp Samples (T5,T6)			L/V (LV4)	Cryo Diode Temp Samples (T7,T11)			Flow Rt. (LFM1)	31
32	Cryo Diode Temp Samples (T12,T13)			1 Sec Accelerometer Average (3 axis, 12 bit sample)					Cryo Diode Temp Samples (T14,T15)			L/V (LV5)	Cryo Diode Temp Samples (T16,T17)			L/V (LV7)	47
48	Cryo Diode Temp Samples (T18,T20)			L/V (LV8)	Cryo Diode Temp Samples (T22,T23)			Flow Rt. (LFM2)	Pressure Sensor Samples (P1,P2)			1 Sec Accelerometer Maximum (3 axis, 12 bit sample)					63
64	Cryo Diode Temp Samples (T24,T25)			L/V (LV10)	Cryo Diode Temp Samples (T26,T27)			L/V (LV11)	Cryo Diode Temp Samples (T28,T30)			L/V (LV16)	Cryo Diode Temp Samples (T32,T34)			Flow Rt. (GFM1)	79
80	Cryo Diode Temp Samples (T38,T42)			Valve Status (40 Valves)					Cryo Diode Temp Samples (T44,T45)			L/V (LV17)	Cryo Diode Temp Samples (T47,T49)			L/V (LV18)	95
96	Cryo Diode Temp Samples (T39,T52)			L/V (LV 19)	Cryo Diode Temp Samples (T40,T41)			Flow Rt. (GFM2)	Pressure Sensor Samples (P3,P4)			CMD Accept	Pressure Sensor Samples (P5,P6)			CMD Reject	111
112	Cryo Diode Temp Samples (T53,T56)			L/V (LV20)	Cryo Diode Temp Samples (T59,T62)			L/V (LV22)	Cryo Diode Temp Samples (T65,T68)			L/V (LV24)	Cryo Diode Temp Samples (T71,T74)			Flow Rt. (GFM3)	127
128	Cryo Diode Temp Samples (spare)			ECP Temp	ECP 5 V	ECP 15 V	ECP -15 V	ECP 28 V	Thermocouple Temp Samples (T77,T79)			L/V (LV26)	Thermocouple Temp Samples (T81,T84)			L/V (LV32)	143
144	Cryo Diode Temp Samples (T86,T88)			L/V (LV33)	Cryo Diode Temp Samples (T91,T94)			Flow Rt. (GFM4)	Pressure Sensor Samples (P7,P8)			HTR 1 Current	HTR 2 Current	HTR 3 Current	HTR 4 Current	HTR 5 Current	159
160	Cryo Diode Temp Samples (T95,T100)			L/V (LV 34)	Cryo Diode Temp Samples (T101,T105)			L/V (LV35)	Cryo Diode Temp Samples (T106,T108)			L/V (Spare)	Cryo Diode Temp Samples (T110,T111)			Flow Rt. (GFM5)	175
176	Cryo Diode Temp Samples (spare)			HTR 6 Current	HTR 7 Current	HTR 8 Current	HTR 9 Current	HTR 10 Current	Thermocouple Temp Samples (spare)			L/V (Spare)	Thermocouple Temp Samples (spare)			L/V (Spare)	191
192	Cryo Diode Temp Samples (spare)			L/V (Spare)	Cryo Diode Temp Samples (spare)			Flow Rt. (GFM6)	Pressure Sensor Samples (P9,P10)			HTR 11 Current	Pressure Sensor Samples (P11,P12)			HTR Status 1	207
208	Cryo Diode Temp Samples (T8,T9)			L/V (LV3)	Cryo Diode Temp Samples (T10,T19)			L/V (LV6)	Cryo Diode Temp Samples (T21,29)			L/V (LV9)	Cryo Diode Temp Samples (T31,T33)			Flow Rt. (Spare)	223
224	Cryo Diode Temp Samples (T35,T36)			HTR Status 2	ESS Volts	ECP Current	SCI Current	Spare	Thermocouple Temp Samples (T78,T80)			L/V (LV12)	Thermocouple Temp Samples (T82,T83)			L/V (L/V 13)	239
240	Cryo Diode Temp Samples (T37,T43)			L/V (LV14)	Cryo Diode Temp Samples (T46,T48)			Flow Rt. (Spare)	Pressure Sensor Samples (P13,P14)			TRU Motor I	TRU Pre-amp	TRU Servo E	TRU Pres	TRU Temp 1	255
256	Cryo Diode Temp Samples (T50,T51)			L/V (LV15)	Cryo Diode Temp Samples (T54,T55)			L/V (LV21)	Cryo Diode Temp Samples (T57,T58			L/V (LV23)	Cryo Diode Temp Samples (T60,T61)			Flow Rt. (Spare)	271
272	Cryo Diode Temp Samples (T63,T64)			TRU Temp 2	TRU Position	TRU Status 1	TRU Status 2	Power Status	Thermocouple Temp Samples (T83,T85)			L/V (LV25)	Thermocouple Temp Samples (T89,T90)			L/V (LV27)	287

Minor Frame Length: 3072 bps
Minor Frames/Major Frame: 0

Science Telemetry Major Frame Map

Figure 5-21, Science Frame

Word	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
288	Cryo Diode Temp Samples (T66,T67)			L/V (LV28)	Cryo Diode Temp Samples (T69,T70)			Flow Rt. (Spare)	Pressure Sensor Samples (P15,P16)			ATVS P final	Pressure Sensor Samples (spare)			ATVS LV volts	303
304	Cryo Diode Temp Samples (T72,T73)			L/V (LV29)	Cryo Diode Temp Samples (T75,T76)			L/V (LV30)	Cryo Diode Temp Samples (T96,T97)			L/V (LV31)	Cryo Diode Temp Samples (T98,T99)			Flow Rt. (Spare)	319
320	Cryo Diode Temp Samples (102,103)			VDU 5V	VDU Temp	VDU Current	Mixer 5 V	Mixer 15 V	Thermocouple Temp Samples (T92,T93)			L/V (Spare)	Thermocouple Temp Samples (spare)			L/V (Spare)	335
336	Cryo Diode Temp Samples (T104,T107)			L/V (Spare)	Cryo Diode Temp Samples (T109,T112)			Flow Rt. (Spare)	Pressure Sensor Samples (spare)			STRAT P final	LAD P d	LAD M out	LAD LV volts	PB CHG M total	351
352	Cryo Diode Temp Samples (T113,T114)			L/V (Spare)	Cryo Diode Temp Samples (T115,T116)			L/V (Spare)	Cryo Diode Temp Samples (T117,spare)			PB CHG T p	Cryo Diode Temp Samples (spare)			MIXER T max	367
368	Cryo Diode Temp Samples (spare)			Mixer Current	Mixer Speed	Mixer Temp	Mixer Pres.	Mixer -15 V	Thermocouple Temp Samples (spare)			L/V (Spare)	Thermocouple Temp Samples (spare)			L/V (Spare)	383

Minor Frame Length: 3072 bps
Minor Frames/Major Frame: 0

Science Telemetry Major Frame Map (cont.)

Word	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	Frame Sync Pattern (FAF320)			Exp ID	Frame Count			ECP Status	C&DH Subsystem Data				Cryo Diode Temp Samples			L/V or Flow Rt.	15
16	Cryo Diode Temp Samples			L/V or Flow Rt.	Cryo Diode Temp Samples			L/V or Flow Rt.	Accelerometer , Valve Status and Cryo Temp Samples						Cryo Diode Samples		31
32	Temp (cont)	L/V or Flow Rt.	Cryo Diode Temp Samples			L/V or Flow Rt.	Thermocouple Temp Samples			L/V or Flow Rt.	Pressure Sensor Samples			Cryo Diode Temp Samples			47
48	L/V or Flow Rt.	Experiment Heater Currents			Power Data	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	63
64	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	79
80	▨	▨	▨	▨	▨	▨	Experiment Specific Sensor Data (Six formats, 60 bytes/sec available)					▨	▨	▨	▨	▨	95
96	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	111
112	▨	TRU Data		VDU Data	Pressure Sensor Samples			Mixer Data									119

Minor Frame Length: 960 bps
Minor Frames/Major Frame: 4

Real-time Science/Housekeeping Telemetry Minor Frame Map

Figure 5-22, Science Frame (Cont.) and Real-Time Frame

The ECP telemetry channel allocations, Table 5-16, show acceptable margins for the present level of design.

Telemetry Type	Number Required	Number Allocated	Margin (Percent)
VDU Valve Status	35	40	12.5
ECP Analog	53	64	17
ECP Bi-level	25	64	61
ECP Serial-Digital	2	8	75
Exp Temperatures	117	192	39
Exp Pressures	16	24	33
Exp Flow/Rate	7	16	56
Exp Liquid/Vapor	35	48	27

Table 5-16, CONE Telemetry Channel Margins

5.4.1.3 Experiment Control Processor

The ECP provides the command and control functions for CONE (except for the valves) by using a microprocessor, currently under development on Ball IR&D, coupled with CONE specific circuits to accommodate the experiment measurements and Hitchhiker interface. The Ball processor has been baselined because of the flexibility exhibited in its cardset, Table 5-17.

Circuit Card	Processor	Memory	I/O		Comments
			Command	Telemetry	
Subsystems Dedicated Processor (SDP)	80386/ 80387	0.5 M EEPROM 0.5 M EDAC-RAM			RS-232 and RW-422 ports 8 Counter timers
Memory Expansion Card (MEMEX)		1.0 M EEPROM 1.0 M EDAC-RAM			
Standard I/O Card (STD I/O)			32 HLDC 32 LLDC 4 Analog (12 bit) 4 S/D Ports	32 Analog Channels 32 Bi-level Channels 4 S/D Channels	
Special Function Interface Card (SFI)			Hitchhiker Interface CGSE Interface Experiment Sensor Conditioning Sensor Multiplexing Circuits		DMA controller Watchdog timers

Table 5-17, ECP Cardset

The ECP requires seven circuit cards to meet C&DH processing and I/O requirements:

- 1 Subsystems Dedicated Processor (SDP) card
- 2 Standard I/O cards
- 1 SFI card for Hitchhiker I/O
- 3 SFI cards for experiment sensor multiplexing and conditioning

The SDP and STD I/O cards are being developed on Ball IR&D, while the SFI cards require project-specific development (although they do use standard circuit designs). The ECP chassis can support up to eight cards, providing built-in circuit margin, which could be used to accommodate future requirement changes, i.e., the addition of a receiver tank. The ECP block diagram, Figure 5-23, shows that the various circuit cards are interconnected primarily on the processor address and data busses making hardware and software changes easy to accommodate.

The ECPs primary role will be to gather/output data and issue commands (real-time or stored), so that the ground has control over command issuance timing. The second role the ECP plays is to monitor certain critical telemetry during key parts of each experiment. Should the experiment reach an out-of-range condition the software will stop the experiment. The experiment monitoring function is provided to allow experiments to be conducted while out of TDRS view and to prevent latency in the STS command and telemetry system from preventing immediate corrective action as the result of an out-of-limit condition during the experiment. The experiment monitoring software is limited to those activities in which latency or being out of view might cause a problem, making the design as simple as possible while still allowing all experiments and demonstrations to be accommodated.

A critical area of the C&DH subsystem design, because the ECP is single string, is the susceptibility and response of the ECP to failures induced by environmental effects and/or part failures. The ECP will use a watchdog timer scheme exactly like the one being used on the RADARSAT program (a high reliability satellite with a 5 year on-orbit mission) to guard against ECP operational failures.

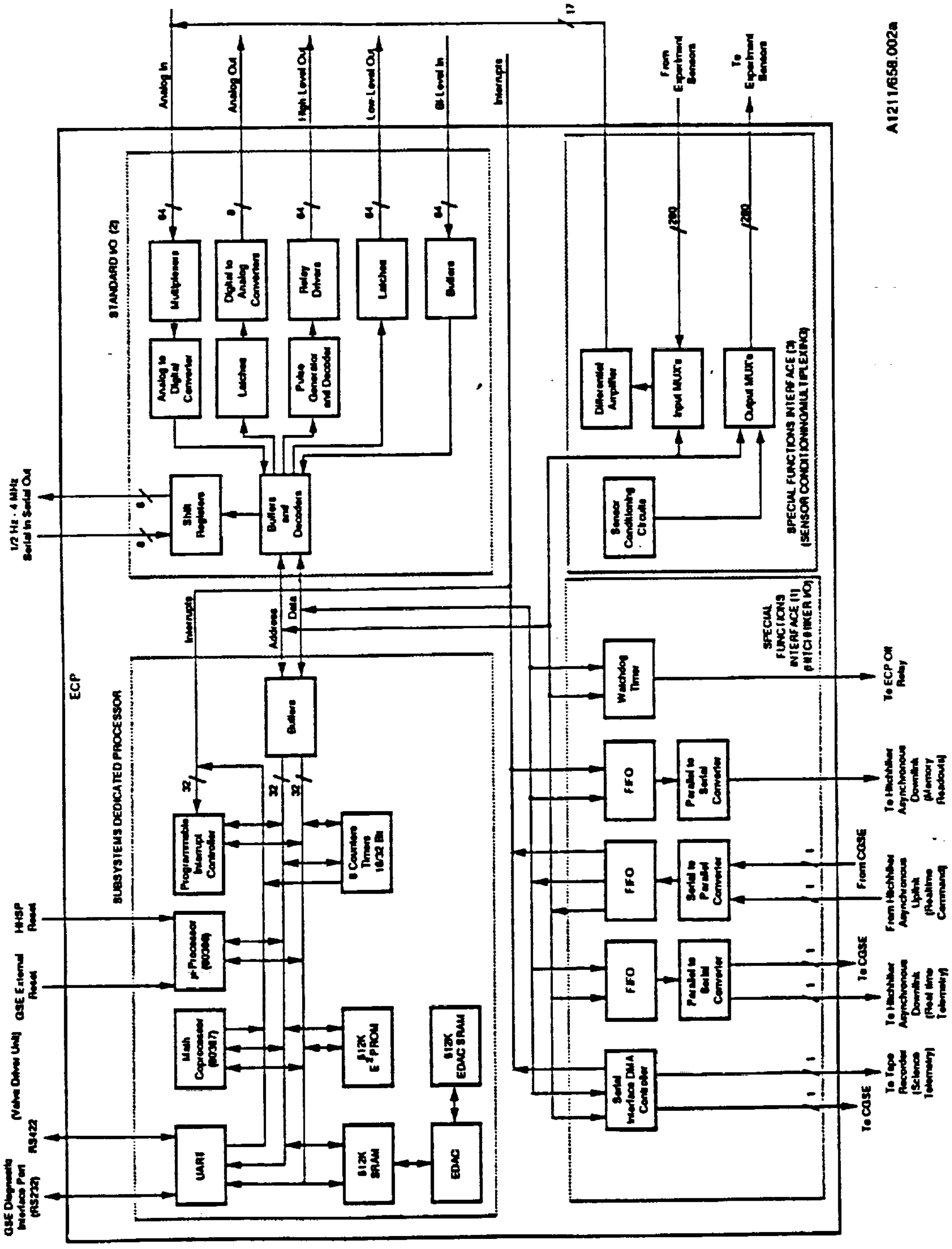


Figure 5-23, ECP Block Diagram

The watchdog timer will reset the ECP micro-processor, if the watchdog is not reset by ECP software once per second, to prevent a runaway computer situation. The timer will guard against single event upsets (SEUs) and part failures which are cause faulty program flow. The astronauts also have control of the valve safing sequence (implemented in hardware) which can be initiated from the SSP if there is reason to believe the ECP is not working properly or there is a perceived astronaut hazard. Although the CONE system is a single string design, measures have been taken to ensure both mission success and astronaut safety.

The ECP is designed to accommodate failures induced by environmental effects. However, it should be noted that any anomalous condition would be very unusual. Preliminary analysis taken from an IBM Space Station Freedom study, for an orbit of 500 km at 28° inclination, shows the 80386 to go into a non-destructive latch-up once every 2,300,000 yrs and experience an SEU once in 1,400 yrs. The operating RAM is error-detected-and-corrected and EEPROM SEU's only occur during read/writes. Because all code is checksummed as it is downloaded, this condition can be tolerated. The ECP has been designed to tolerate environmental effects and is properly suited to perform as the CONE processor in a single-string configuration.

5.4.1.4 Tape Recorder/Mass Memory

The tape recorder (or mass memory) will record data and downlink it periodically via the Hitchhiker Ku-band medium rate (< 2 Mbps) downlink service. This allows the program use a recorder which has lower storage requirements and uses less power, and guarantees that all data will be relayed prior to STS return from orbit.

The tape recorder selected is the model currently being flown on the CRESS program. Its capacity is 750 Mbits and it requires only 20 W of operating power. The 750 Mbits of recorded data would allow the experiment to run continuously for 67 hours, although the baseline would be to play back data every 12 hours.

A tape recorder was selected for data storage because of its flight heritage and low cost. It would be appropriate to consider solid-state at the start of the phase C/D program, because solid-state memories are undergoing rapid development and may prove to be viable tape recorder replacements in terms of cost and risk.

5.4.1.5 Valve Driver Unit/Mixer Driver Electronics

The VDU provides four basic functions as shown in Figure 5-24:

- Cold valve stepper motor controller (in software)
- Hot/cold valve drivers (2 Amps)
- Valve safing circuit (a series of hot valve driver commands to safe the experiment if the ECP crashes during a critical part of any experiment)
- Valve status

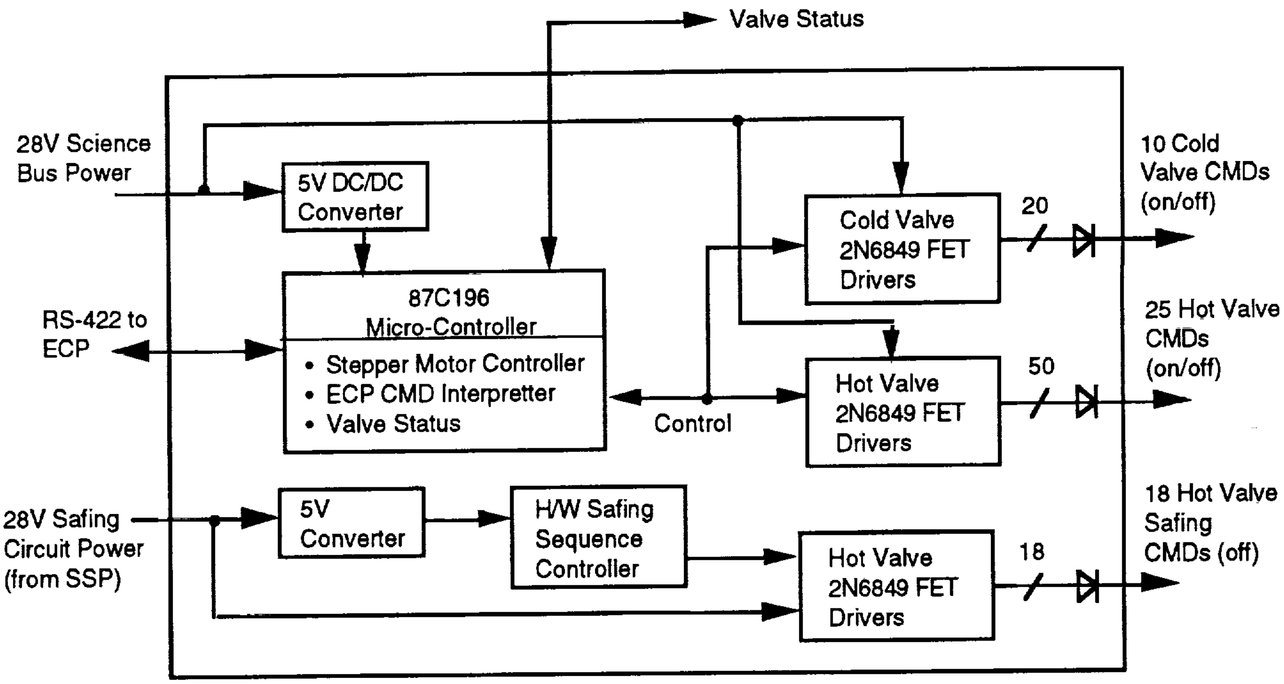


Figure 5-24, Valve Driver Unit Functional Diagram

The VDU is driven by an 87C196HC micro-controller which receives, interprets, and issues valve driver commands sent to it from the ECP over an RS-422 link. The VDU also gathers and sends back valve status data upon request by the ECP. Because the 87C196KC contains memory, timers, an A/D converter and a watchdog timer; there is no other peripheral hardware associated with its use. Valves are driven using 2N6849 FETs because the drive-current requirements are extremely high (2 Amps). The 87C196HC also contains the software required to drive the stepper motor in the cold valves. The safing circuit is only powered when the astronauts power it via the standard switch panel. The VDU contains all the logic associated with driving and telemetering valve status, and thus should the valve requirements change, the VDU will be the only unit requiring modification. A similar VDU is currently under development at Ball as part of the XRS program.

The MCE will be contained in the same chassis as the VDU, separated by aluminum for shielding. The MCE will convert DC power to a three-phase AC variable-frequency drive signal. The motor requires 2 W maximum and will have a variable speed control. The only command input to the unit will be the mixer speed. Telemetry will include current, pressure, temperature, internal power supply voltages and a tachometer.

5.4.2 Electrical Power

The CONE electrical power subsystem provides power distribution and protection of the experiment against out-of-limit current situations. The power subsystem is required to provide the following functions for either experiment control or to meet Hitchhiker and STS safety requirements

- EMI filtering of the STS primary input power
- Fusing of all circuits
- A method for astronaut direct control of power removal for heaters
- Power distribution circuitry

5.4.2.1 Power Distribution Unit

The PDU is primarily a passive unit which houses the subsystem power relays, CONE power bus current/voltage sensors, EMI filtering as required to condition shuttle power, and fusing. The only active circuit in the PDU is a DC/DC converter which acts as an isolation transformer. The DC/DC converter makes ground test and experiment integration easy by ensuring that at no time will new grounds be introduced to the experiment electronics. The PDU block diagram, Figure 5-25, shows that CONE will have three power busses to accommodate heater safing and ECP re-boot (power cycle) without effecting other units.

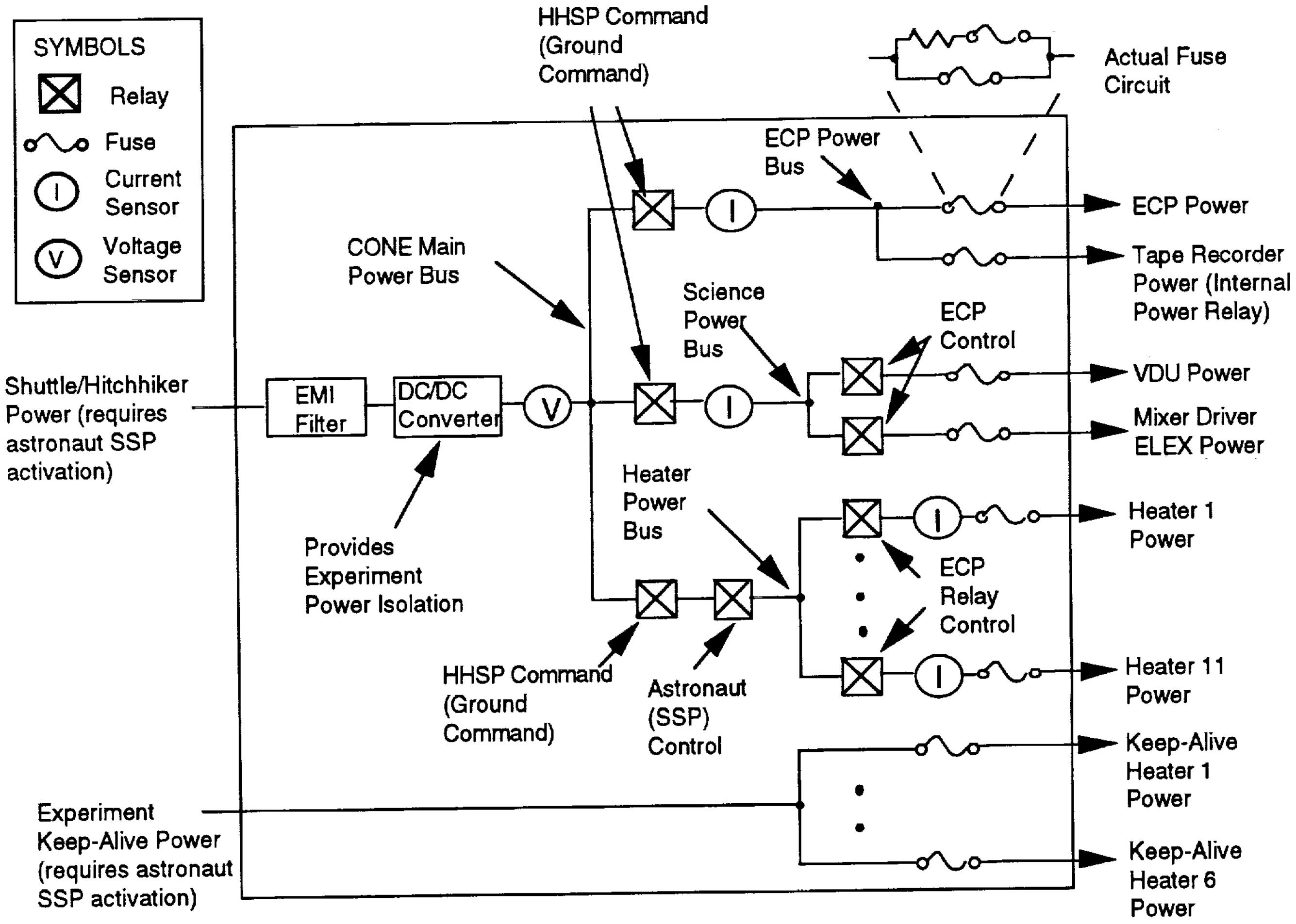


Figure 5-25, Power Distribution Unit Functional Diagram

The PDU receives either primary experiment power or standby heater power via the astronauts who control power application with the standard switch panel. The primary experiment power is EMI filtered and distributed on one of three power busses: the ECP bus, the science bus and the heater bus. All power bus commands are issued by the HHSP (via ground command) to meet the requirement that both ground and astronaut commands are required to power-up the experiment. The ECP bus powers the ECP and the tape recorder, to allow checking of experiment telemetry, and to start data recording, prior to starting any specific experiment operations. The science bus powers the MCE and VDU electronics and the heater bus controls the experiment heaters required to control experiment thermal operation. The heater bus has a normally open relay in-line with the power bus which requires astronaut control to close, adding an inhibit against heater runaway. Standby (keep-alive heater) power is run through the PDU so that it can be fused prior to being sent to standby heaters.

5.5 SOFTWARE

The software required for CONE can be divided into two major categories: flight software and ground software. Flight software will require the most development, although this effort is decreased by the fact that the VDU software will be developed primarily on the XRS program. In terms of performance, the flight software represents the critical path, since ground software can always use delayed processing techniques to accommodate non-critical processing requirements.

The estimations in this section provide a proof of concept of the software functionality and compatibility with the CONE mission. ECP software requirements represent over 90% of the flight software burden. The basis of estimate comes from two sources: the previous COLDSAT software estimations and the SP-18 source listings (SP-18 is a current Ball spacecraft using an 80C86/80C87 for similar functions). In addition, margin has been added to account for the fact that the ECP is an 80386 (32 vs 16 bit) processor. The timing and sizing analysis shows the ECP to be running at less than 20 % of capacity in both throughput and program sizing.

- Program memory sizing shows 90 out of 500 kbytes used
- Program timing shows greater than 1000% margin on throughput

5.5.1 Flight Software

The CONE ECP software has been divided into eleven modules to provide the following four basic functions:

- Command processing (stored and real time)
- Telemetry gathering and output (experiment and housekeeping data)
- Experiment monitoring (critical functions only)
- Background functions (watchdog timer, memory scrubbing, etc..)

The ECP software is driven by the cryogenic diode sample requirement of 62.5 msec of settling time between samples. To facilitate this, the ECP data collection software is driven by a 62.5 msec interval timer to control the command, telemetry and experiment control functions. Figure 5-26 shows how data collection and command processing are managed at the interrupt level. During each interrupt the ECP gathers experiment data and then processes commands and performs critical experiment monitoring functions.

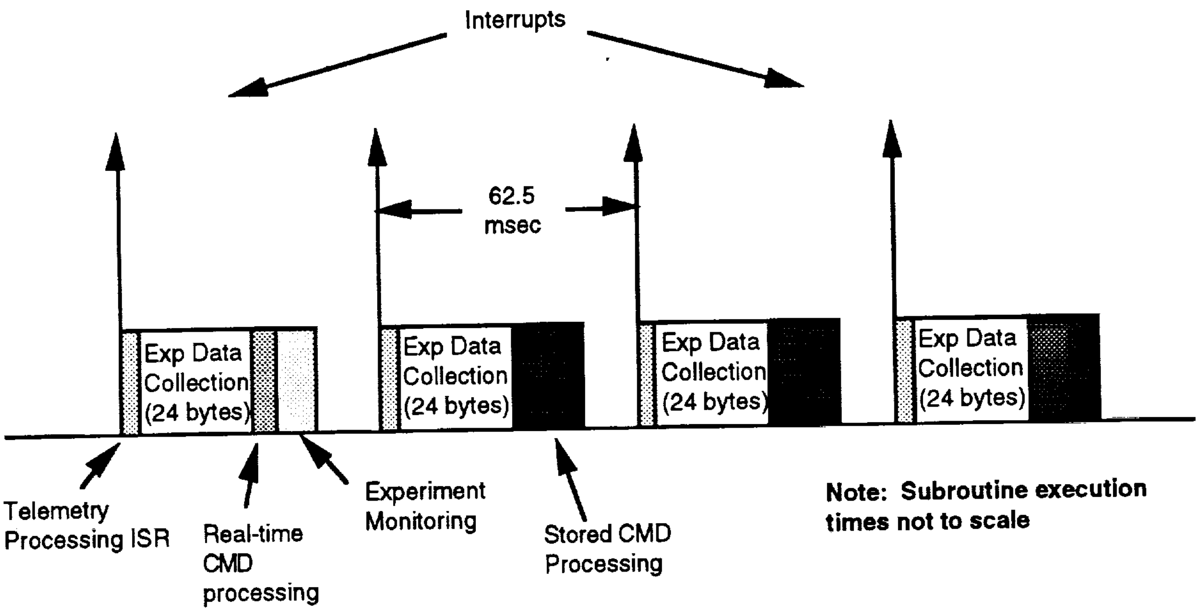


Figure 5-26, ECP Interrupt Level Processing Structure

ECP program flow is divided between interrupt level processing and background processing functions. The ECP program flow diagram, Figure 5-27, shows the relationship between the background and interrupt processing loops.

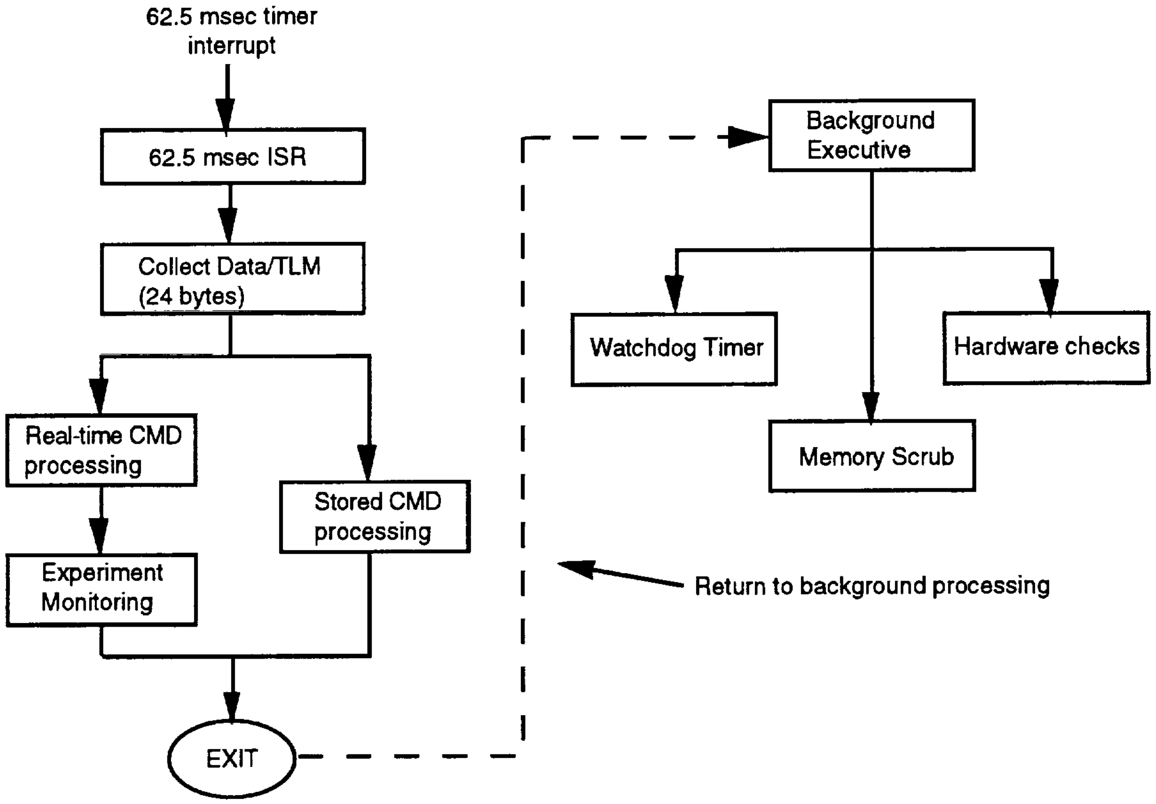


Figure 5-27, ECP Program Flow

The background processing software is being developed on Ball IR&D (in conjunction with the processor development) and therefore does not represent a significant development effort. The interrupt level software is mission unique. However, the architecture is similar to other Ball software being used on a number of programs. The functional characteristics of the eleven major ECP software modules and any heritage is described below.

5.5.1.1 Initialization

This module only runs during ECP boot-up. Its primary function is to initialize the ECP hardware and to download code from the EEPROM to the error detect and correct (EDAC) SRAM. Operating code (i.e. non-bootstrap) is run out of RAM to facilitate fast program flow. Most of this code is inherited from other Ball programs.

5.5.1.2 ECP Background

The ECP background module can perform several functions, some of which are not clearly defined at this point. Two functions which will be included are a watchdog timer reset and a memory scrub function. Memory scrubbing eliminates SEU's which may be resident in RAM by reading and writing back to the same location. Other candidate background tasks are device checking and possibly some operating code checks. These functions will become better defined as software requirements flow down during the phase C/D development effort.

5.5.1.3 Telemetry Processing Interrupt Service Routine

This is a 62.5 msec interrupt service routine (ISR) and represents the only ISR used in the ECP. This routine keeps track of which 62.5 msec interrupt the ECP should be processing and which real-time science minor frame is being processed. Thus, it also acts as a telemetry processing executive.

5.5.1.4 Science Frame Telemetry Processor

This is the critical experiment data collection routine. This routine always runs first during interrupt processing to provide a constant settling time between science data samples. During this routine the ECP will sample the various data points and set the analog MUX's for the next read as soon as the reading is complete to allow consistent settling times. Following collection of all data, 24 bytes (18 readings) per interrupt, science data is placed in a DMA section of ECP memory with output being controlled by the ECP DMA controller.

5.5.1.5 Real-time Science/Housekeeping Frame Telemetry Processor

This processor outputs real-time data by obtaining data from the science telemetry processor as needed. The real-time processor works in conjunction with the science frame to collect and output data. The science frame is designed to accommodate the real-time processor since data is collected in the same relative space within the two frames, thus simplifying the data collection software burden.

5.5.1.6 Real-time Command Processor

The real-time command processor operates at 4 Hz to accommodate the maximum uplink command rate supported by the STS (2 CMDs/sec). The real-time command processor works by polling a 4k ECP command buffer. If a full command is in the buffer, the ECP reads it in to a command lookup table and executes the command if it is of proper format. The polling rate (i.e. command processing rate) can be easily changed should the maximum command rate through the Hitchhiker change.

5.5.1.7 Stored Command Processor

The stored command processor works during interrupts when the real-time command processor is not working, Figure 5-28.

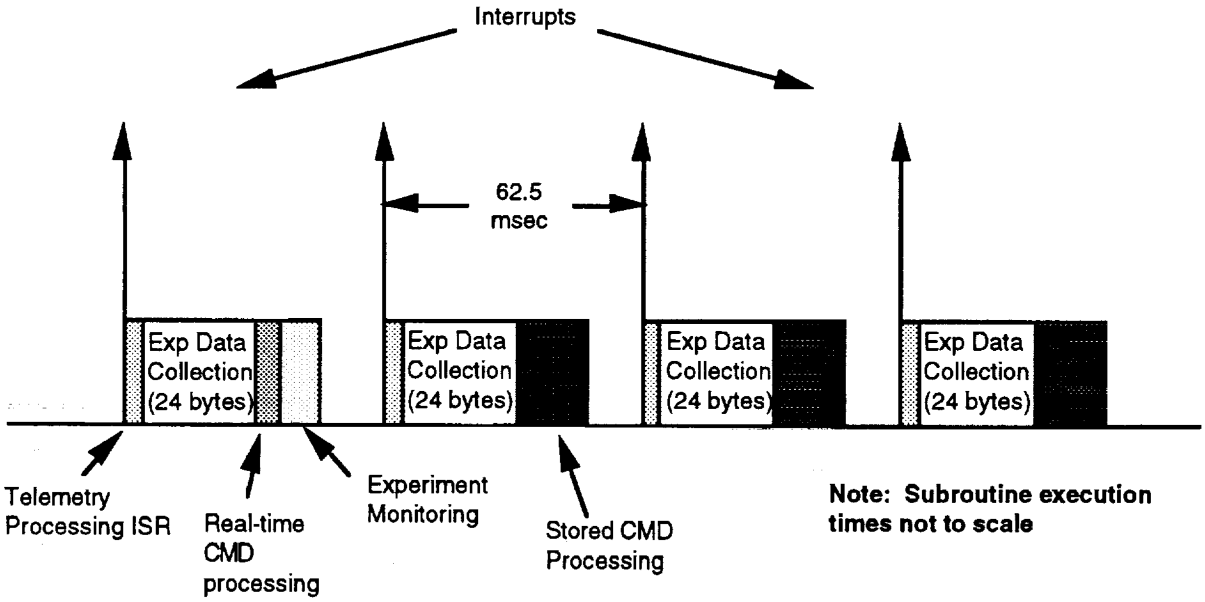


Figure 5-28, CONE Stored Command Processing

The stored command processor scrolls through a list of 256 commands per second, or approximately 20 per interrupt. The processor works by reading the Mission Event Timer status (kept in the ECP and updated from the ground periodically) and then scanning approximately 20 commands and issuing those commands which have a matching MET time tag.

5.5.1.8 Experiment Monitoring and Control

This function is performed at a maximum rate of 4 Hz and will consists of critical telemetry checks which when met start a predefined sequence of experiment termination or shutdown. There is no action taken by this software during nominal experiment conditions.

5.5.1.9 Table Management

This software manages the uplinking of software into RAM or the downlink of software resident in either RAM or EEPROM. The estimates are made from the SP-18 listings, which perform the exact same function as performed on CONE.

5.5.1.10 Utilities

The utilities are a collection of routines which are used by a number of the software modules and represent I/O functions primarily. Other functions will be included as required. Most utilities will be included with the processor as part of the IR&D effort.

5.5.1.11 Experiment Safing Sequence

This is a file in EEPROM which contains a sequence of commands which will safe the CONE in an orderly fashion. When this command is sent to the ECP, all command processing is disabled until the sequence is completed. The baseline sequence calls for 18 solenoid valve commands to be issued 300 msecs apart. The identical function is provided in hardware by the Valve Driver Unit in case of an ECP malfunction (see Section 5.4.1.5).

5.5.2 Software Sizing Estimate

Table 5-18 shows the current source lines of "C" code required for each of the eleven modules.

Software Module	SLOC Estimate	ECP Memory Required
Initialization	200	6.4 k
ECP Background	100	3.2 k
Telemetry Processing ISR	100	3.2 k
TLM Processing - Sci Frame	300	9.6 k
TLM Processing - RT Frame	300	9.6 k
Real-time CMD Processing	400	12.8 k
Stored CMD Processing	100	3.2 k
Experiment Monitoring	250	8.2 k
Table MGMT (Code uploads and downloads)	300	9.6 k
Utilities	600	19.2 k
Safing Sequence	100	3.2 k
	ECP Memory Required	90 k
	ECP Memory Size	500 k
	Margin	> 500 %

Notes: 1. SLOC Estimate is in lines of "C" code
2. Memory conversion is 32 bytes/SLOC

Table 5-18, ECP Software Sizing

The estimate used to convert SLOC to program memory was 32 bytes/line of source code (8 instructions/line). This is a conservative memory estimate, since past programs at Ball have compiled at 4-6 instructions per line of code. The sizing estimate shows the ECP provides a sufficient amount of program memory for the present state of the design.

The timing estimate is based on real-time executable code estimations as summarized in Table 5-19. Each of the major modules which execute in real-time are estimated based on the amount of code run during its particular interval and the number of intervals per second.

Software Module	Executable SLOC/Interva	Freq (Hz	SLOC/se	ECP Instruction per second (IPS
Initialization	N/A			
ECP Background	100	1	100	0.8 k
Telemetry Processing ISR	50	16	800	6.4k
TLM Processing - Sci Frame	400	16	6400	51.2 k
TLM Processing - RT Frame	75	16	1200	9.6 k
Real-time CMD Processing	100	4	400	3.2 k
Stored CMD Processing	50	12	600	4.8 k
Experiment Monitoring	50	1	50	0.4 k
Table Uploads	50	4	200	1.6 k
Table Downloads	50	1	50	0.4 k
Utilities	N/A			
Safing Sequence	N/A			

Total IPS	80 kips
ECP Capability	2000 kips
Throughput Margin	> 1000 %

Notes: 1. Executable SLOC/interval refers to lines of code run during a particular interrupt
2. SLOC/second to IPS conversion is 8 IPS/SLOC

Table 5-19, ECP Software Timing

The estimation factor used to convert SLOC to executable code is 8 instructions per line of code (because the primary function of the ECP is data handling, the number of instructions per SLOC is expected to be less than 8). The only factor this throughput analysis does not take into account is ECP wait states, those of the A/D converter being the most significant. A/D conversions should increase the time required to complete the 62.5 msec interrupt by 400 microseconds, which can be easily handled by the ECP. The throughput estimate assumes that all ECP functions are running simultaneously with all telemetry downlinks enabled and maximum command processing. The timing at this estimate shows the ECP throughput to be within acceptable limits for this stage of the program.

The VDU software, contained in the 87C196 micro-controller, represents a typical software load for a micro-controller of this variety. A detailed sizing and timing analysis is not included because of the relative simplicity of its function and because the same part (for a similar application) is being used on XRS. Proof of concept is achieved through similarity of function.

5.5.2 Ground Software

Ground system software always represents a program-specific design to meet ground processing requirements. The CONE baseline is a micro-processor based ground system, known as the CONE Test and Control System (CTCS). It simplifies the ground system software development effort because the large number of PC's at Ball permit parallel software development.

The critical area of a micro-processor based ground system software development effort is understanding how to link the functions together. The CONE ground system software design must include the following functions to meet experiment objectives:

- Command generation and execution uses the Spacecraft Test and Operations Language (STOL)
- Telemetry decommutation, conversion and storage
- Communication between machines
- Limit checking
- Archiving of all ground related functions

Figure 5-29 shows how the major ground processing software modules are connected. The final CONE configuration will be determined during phase C/D by final processing requirements.

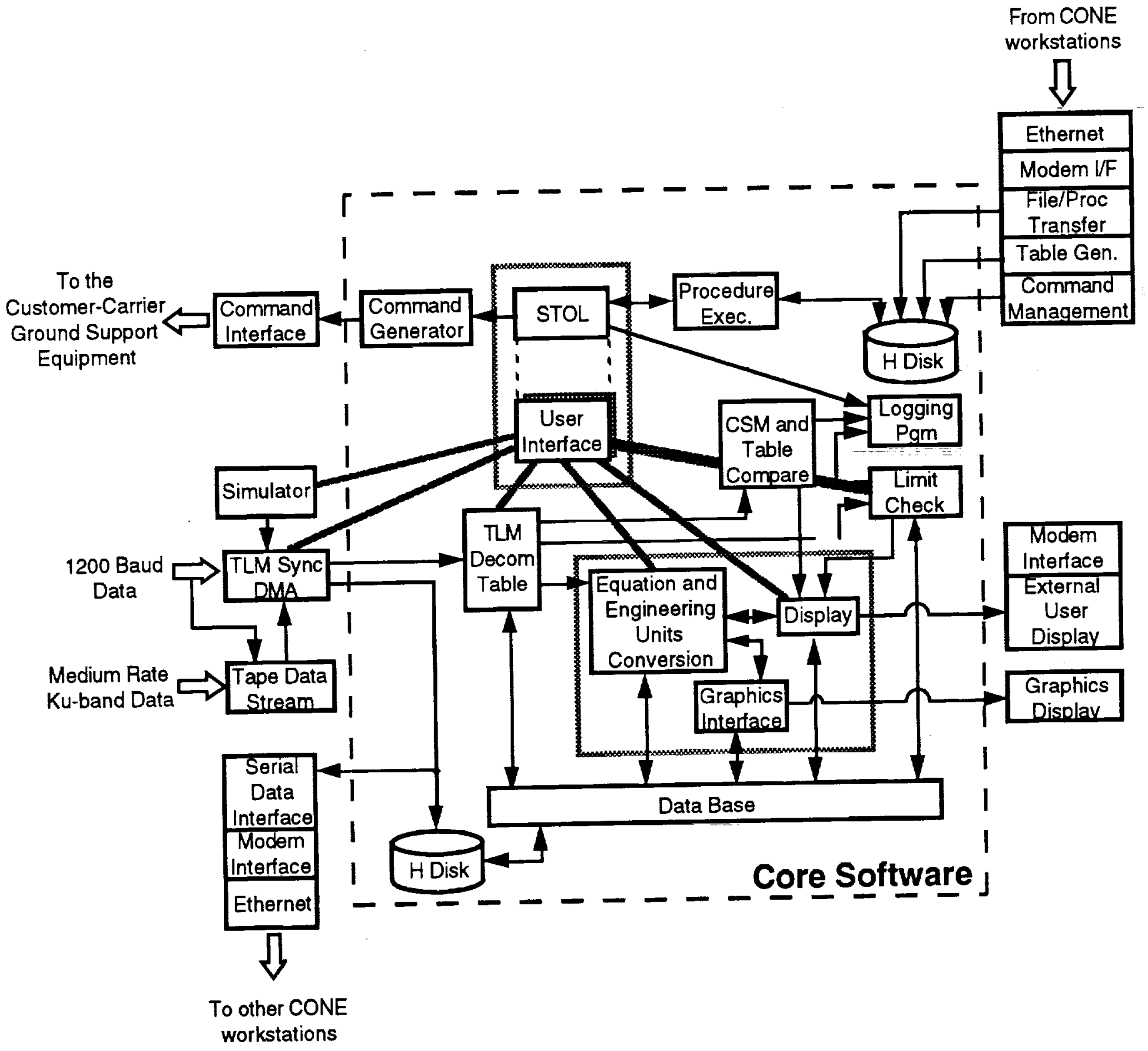


Figure 5-29, CONE Test and Control System Software Functional Diagram

Section 6

INTEGRATION AND TEST

This section describes CONE integration and test from the delivery of components through fabrication, assembly, and integration, to shipment of a fully assembled and tested payload.

6.1 INTEGRATION FLOW PLANNING

To facilitate the overall CONE verification and integration activity, the experiment and support subsystems will proceed in parallel. Figure 6-1 shows the overall CONE verification and test flow up to preparation to ship to the integration site. Detailed discussion in the rest of this section focuses on the experiment subsystem since it is on the verification and integration critical path.

During the assembly/fabrication process a number of in-process tests are completed. These tests are conducted at critical times during the flow and minimize risk to the program. Costly rework is avoided by verifying early in fabrication that subassemblies, components, and assemblies function as required. The types of in-process testing include:

- Radiographic inspections of welds (100%)
- Dye penetrant inspections
- Pneumatic pressure tests
- Cold shocks
- Helium leak checks
- Verification of internal wiring
- Functional cycling of components
- Vacuum acquisition/bakeout
- Fit checks

An early programmatic question critical to the overall verification and integration flow will be whether the carrier is delivered to Ball for use during this process. Carrier delivery to Ball is the recommended approach.

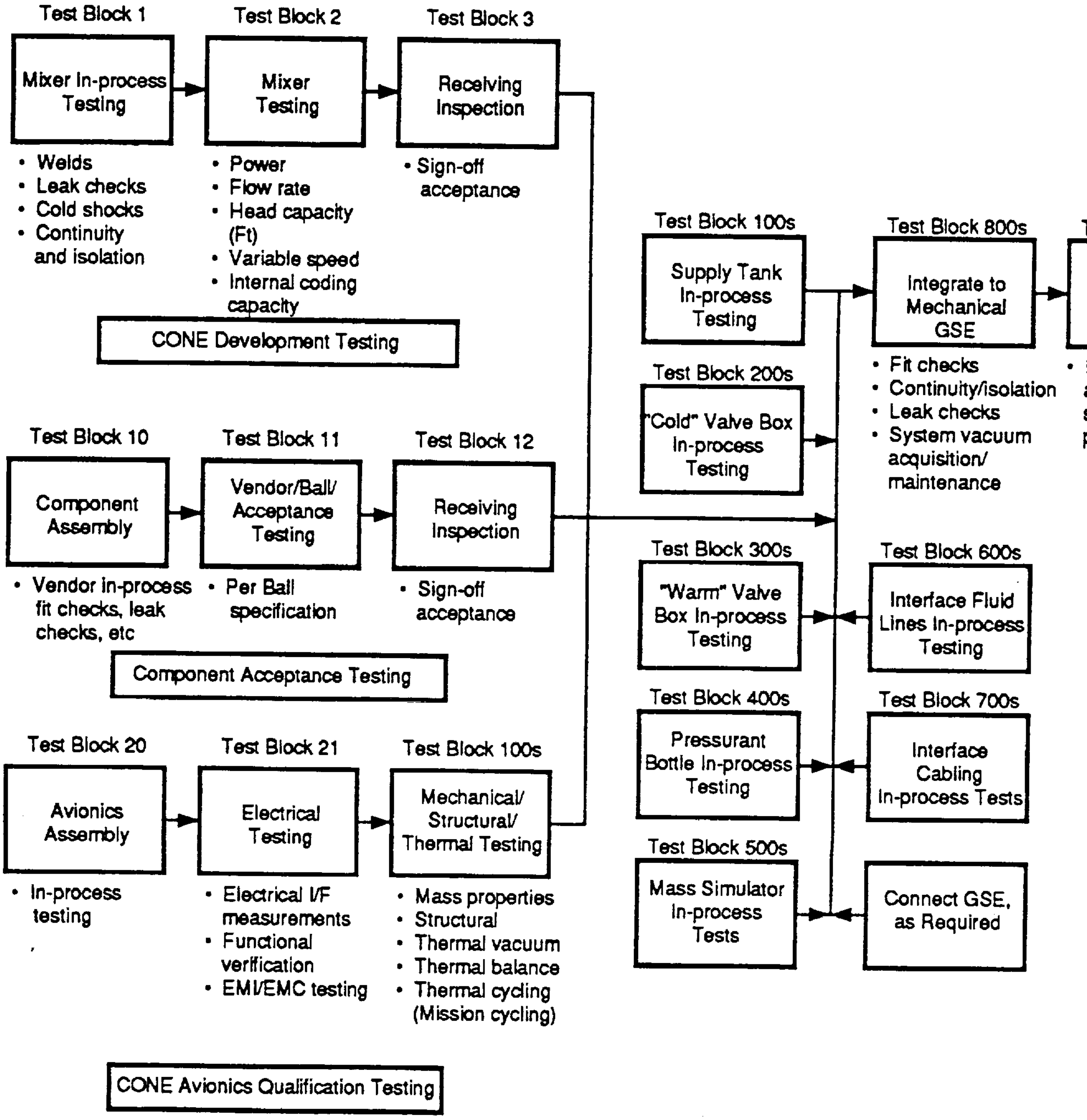
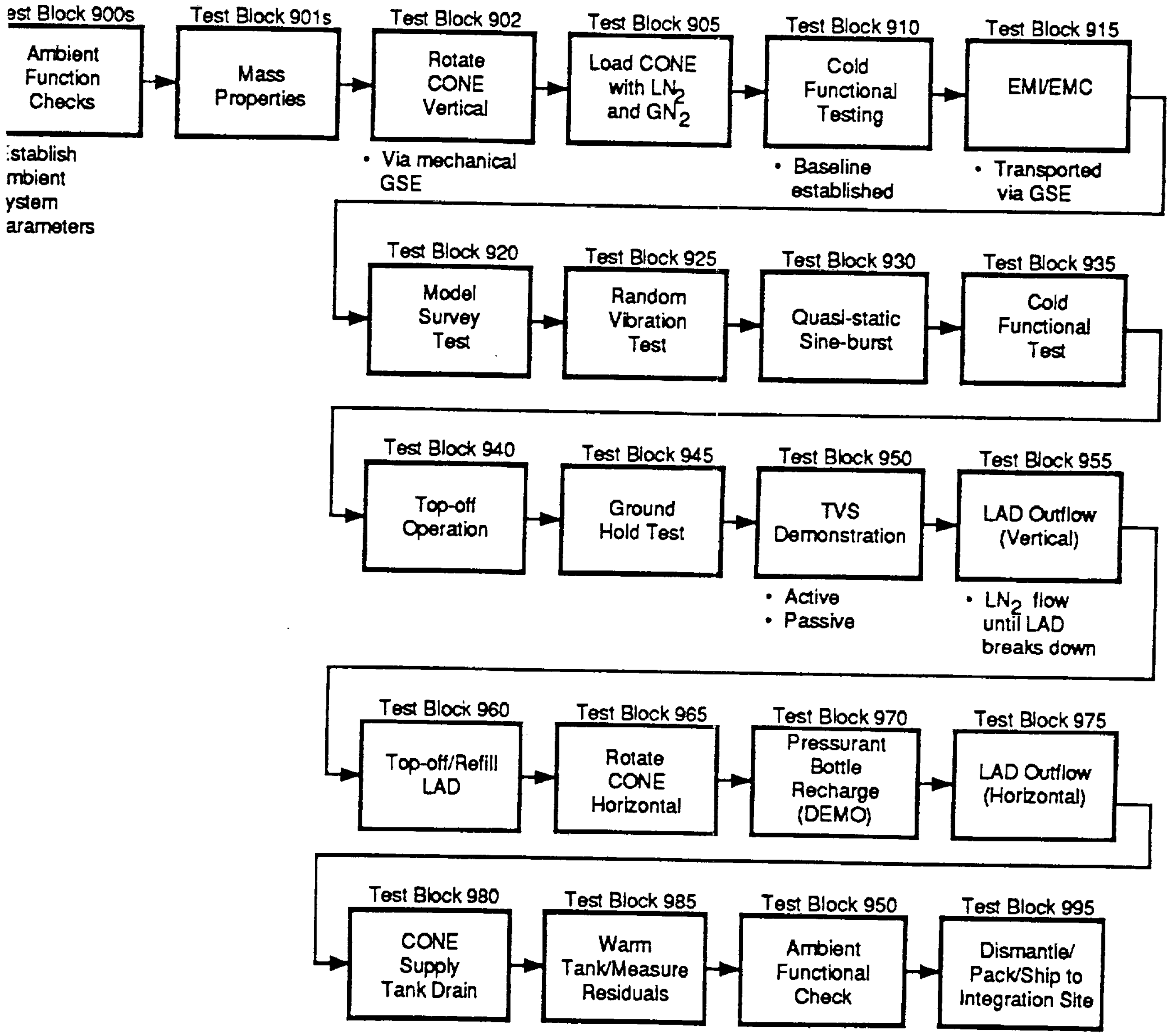


Figure 6-1, CONE Verification and Test Flow

2.

FOLDOUT FRAME



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Although the process can be accomplished without the actual carrier, it will be much more complicated and costly since a large intricate mock-up will be required to simulate the actual mounting scheme to the HH-M. Additionally, a complete re-verification of the experiment will be required at the carrier integration site, since CONE must be disassembled for shipping then reassembled there. As illustrated in Figure 6-1, this would require re-performance of test blocks 800 through 945, 965, and 975 through 990. The approach depicted in Figure 6-1 assumes that the carrier has not been delivered to Ball, and only represents the initial verification activity at Ball.

The major test activities completed will include proof testing, structural testing (modal survey, random vibration, and quasi-static sine-burst), EMI/EMC, LAD functionals, ground hold, and system performance tests.

6.1.1 LN_2 Distribution Subsystem Processing

After PDR, long-lead items must be ordered. They generally require a minimum of 6 months from order to delivery. This will require that procurement specifications and vendor selection are complete. Such items include the PV domes, the OS domes, the support struts, and the electrical connectors. All these items are on the critical path of the assembly program. Subcontracted activity, i.e. LAD and mixer, must also be well under way during this phase.

Figure 3-20 shows the supply tank production flow plan. This an example of the production flow plans that will be generated for the other assemblies which make up the LN_2 system. The figure shows that a number of steps are required to assemble this tank. At the end of each of these steps, in-processing test must be successfully completed prior to moving to the next step. The associated test activity includes test blocks 1 through 3, 10 through 12, 100, 200, 300, 400, 600, and the 700 series of Figure 6-1. Upon successful completion of these activities, the LN_2 system is ready for test block series 800: integration onto the carrier mock-up.

The above holds true for the CVB, WVB, pressurant module, interfacing fluid lines, and cabling.

6.1.2 Support Subsystems Flow

Similar production plans to those for the LN_2 distribution subsystem will be generated for the support subsystem. The appropriate test blocks will be run for this subsystem as indicated on Figure 6-1.

6.1.3 CONE Payload Flow

Upon completion of the assembly/fabrication activity, CONE will move into the system verification phase. This includes all test blocks 900 through 990. The majority of critical testing is accomplished here. Dismantling and shipment to the integration site is the final task completed at Ball.

At the integration site, CONE is reassembled and a series of verification tests are run. These are followed by integration testing including verification of compatibility with the POCC.

Section 7.0

CONE OPERATIONS

The CONE operations are divided into ground processing operations and flight operations. In both of these areas CONE will take full advantage of the NASA/GSFC support services provided through the Tracking and Data Relay Satellite System (TDRSS), the Attached Shuttle Payloads Center (ASPC), NASA Communications (NASCOM), and other GSFC resident support facilities. Utilizing the standard services and avoiding any unique mission hardware and software configurations allows for a cost effective and efficient mode of operation. Figure 7-1 shows a representative mission operations flow chart for CONE.

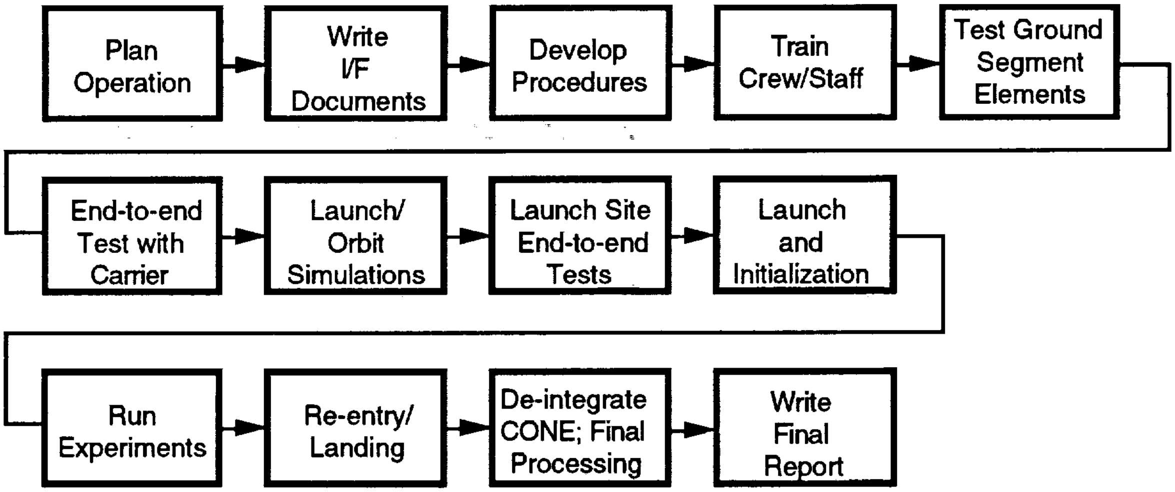

Figure 7-1, Typical Operations Flow Chart

7.1 GROUND PROCESSING OPERATIONS

7.1.1 Ground Support Equipment (GSE)

Cryogenic, mechanical, and electrical GSE is required to support CONE during initial test and verification, integration to the HH-M, pre-launch and launch operations, and recovery and de-integration activity. Table 7-1 lists the required CONE GSE, and Figure 7-2 illustrates the wide variety of operations supported by the GSE.

Mechanical	**Cryogenic**	**Electrical**
Handling dollies Hoisting fixtures Installation fixture Proof load fixture Transporter Vibration fixture Shipping containers	Valve module LN_2 supply dewar Vacuum support module Interconnecting fluid transfer lines GN_2 supply bottles MSLD	Instrumentation monitor panel Data reduction system Interconnecting cables Cryogenic GSE control panel CONE Test and Control System (CTCS) GSE software Special test equipment (STE)

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Table 7-1, CONE GSE

	CRYOGENIC SUPPORT EQUIPMENT				ELECTRICAL SUPPORT EQUIPMENT				
OPERATION	GN_2 SUPPLY MODULE	LN_2 SUPPLY MODULE	FLUID TRANSFER LINES	VACUUM SUPPORT MODULE	INSTRUMENTATION MONITOR PANEL	GSE ELECTRICAL CONTROL MODULE	DATA ACQUISITION REDUCTION SYSTEM	ELECTRICAL INTERFACE CABLES	MSLD
IN-PROCESS TESTING									X
BAKE-OUT/VAC. PUMP DOWN					X	X	X	X	X
VACUUM PUMP DOWN			X	X	X	X	X	X	X
LEAK CHECKS			X	X	X				X
PRECOOL DEWAR/INST.	X	X	X	X	X	X	X	X	X
LN 2 DEWAR FILL	X	X	X	X	X	X	X	X	X
REFILL NITROGEN	X	X	X	X	X	X	X	X	X
TOPOFF	X	X	X	X	X	X	X	X	X
RAPID CRYOGEN DUMP (LN $)_2$			X	X	X	X	X	X	
GROUND HOLD				X	X		X	X	
MONITOR TEMP/PRESSURE					X	X	X	X	

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Figure 7-2, Typical Operations which Require GSE

Figure 7-3 illustrates the CONE-GSE interfaces. The GSE requirements for the various facilities where it will be used are summarized in Table 7-2.

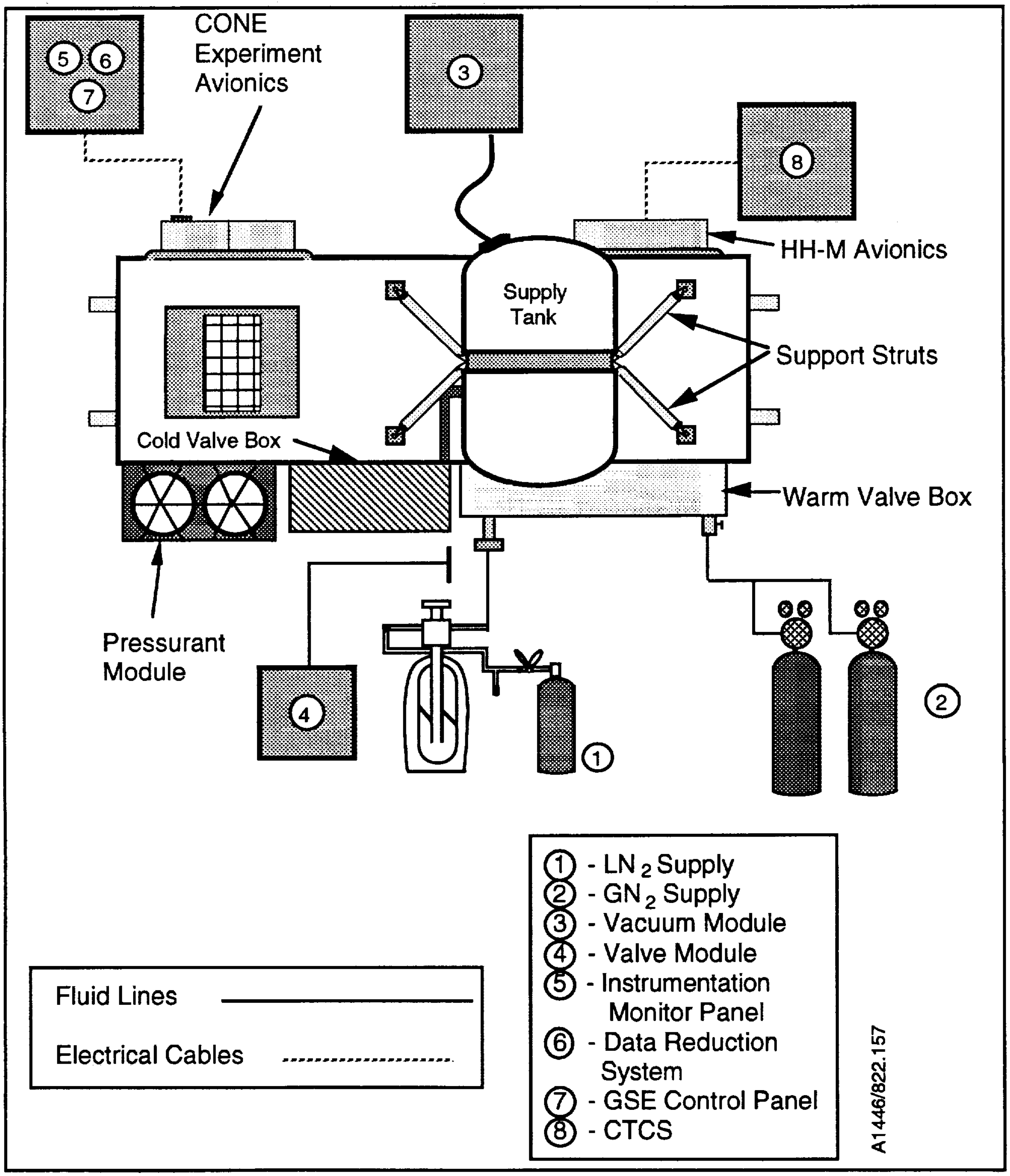

Figure 7-3, Layout of CONE GSE Interfaces

Equipment	Envelope (cm)	Weight (kg)	Power	Coolant Water	Compressed Air
VACUUM SUPPORT MODULE	90 x 90 x 150	<500	208 V, 3ϕ 110 V, 1ϕ	8 L/min	YES
VALVE MODULE	90 x 90 x 150	<500	N/R	N/R	YES
ELECTRICAL CONTROL MODULE	90 x 90 x 180	<500	208 V, 3 ϕ 110 V, 1 ϕ	N/R	YES
DATA ACQUISITION/ REDUCTION SYSTEM	90 x 90 x 180	<500	110 V, 1ϕ	N/R	NO

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Table 7-2, GSE Facility Requirements

7.1.1.1 Cryogenic GSE

The cryogenic GSE (CGSE) is the nitrogen (both liquid and gaseous) loading and vacuum systems required to support CONE for all ground fluid operations. The CGSE will also provide the following capabilities: supply tank fill, topoff, and drain in either the vertical or horizontal configuration; vacuum acquisition and maintenance at 1.3 mPa (1 x 10^{-5} torr) or less; evacuation of the supply tank and associated plumbing; GHe and/or GN$_2$ purges of the system; mass spectrometer leak-test capability; and supply-tank warming to room temperature.

7.1.1.2 Mechanical GSE

The mechanical GSE (MGSE) will be used during test, integration, and ground operations. It includes handling dollies, hoisting fixtures, and shipping containers for the CONE, CGSE, electrical GSE, spares, handling fixtures, miscellaneous parts, and tooling.

The MGSE will meet these program requirements: mass and center of gravity determination; structural verification; identification plates to show name, maximum working load, and proof loading data; special tools/fixtures to integrate CONE; use standard available power; be safe by using mechanical braking, electrostatic grounding, and warning lights; and use a factor of 5 safety except for non-metallic components which will use 10.

7.1.1.3 Electrical GSE

The electrical GSE (EGSE) supports all subsystem and system tests for CONE, including control and monitoring of the CGSE and checkout of the flight avionics. The EGSE fulfills the following programmatic requirements for CONE: provide an independent means to operate and monitor CONE without the use of fight avionics; monitor the CGSE; provide ground data handling and reduction; and provide flight operation data handling and reduction.

The CONE Test and Control System (CTCS) is critical to the EGSE. It provides the direct link to the avionics and will be a direct derivative of a system developed by Ball. Figure 7-4 illustrates the hardware configuration for the CTCS and Table 7-3 lists the major components which are included within the CTCS. The software developed will support both the ground and flight operations, and the top level architecture is shown in Figure 7-5.

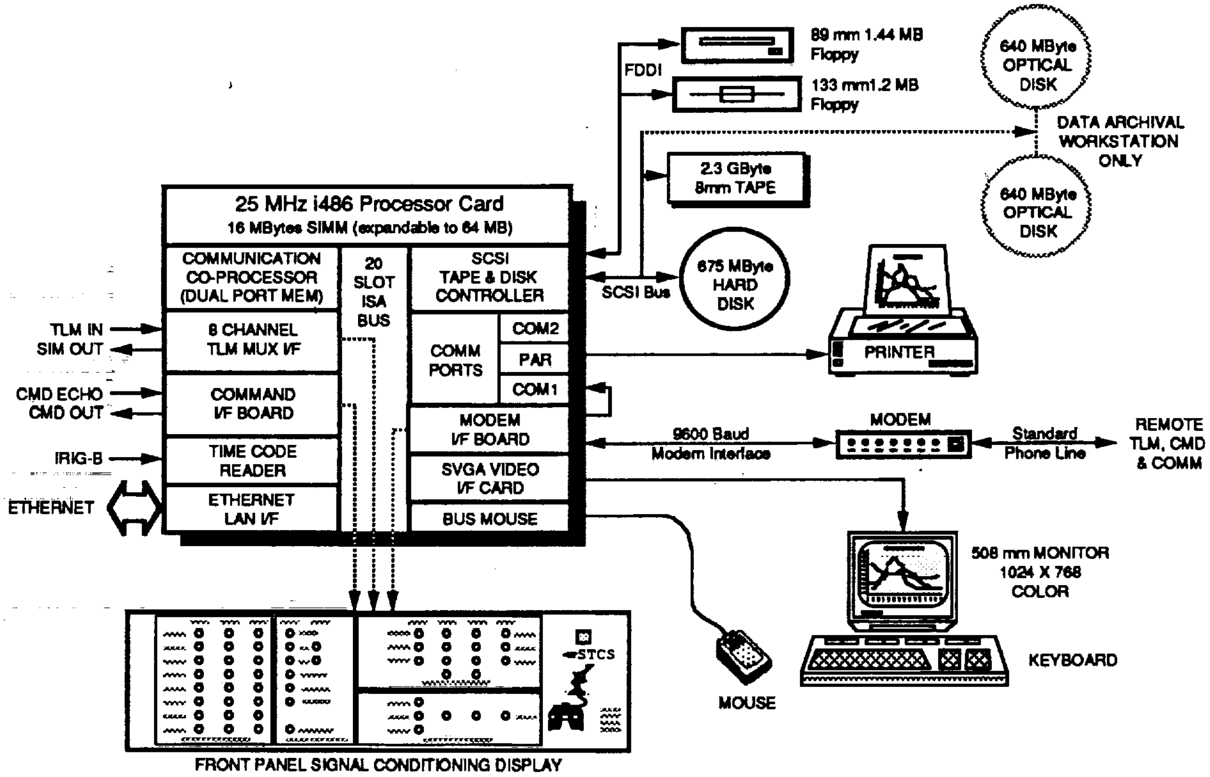


Figure 7-4, CTCS Hardware Configuration

COMPONENT & VENDOR - MODEL	WT (kg)	SIZE (H x W x D mm)	OPERATING POWER (W, V)	COMMENTS
Microprocessor DTI CAT-100 & Misc. Peripherals	27.2 kg	178 x 483 x 584	250 watts 120v	25 MHz - Intel 486 processor
Tape Data Streamer	Included in Micro	Included in Microprocessor	Included in Microprocessor	Redundant in each computer
Exabyte 2.3 GB	Included in Micro	Included in Microprocessor	Included in Microprocessor	Redundant in each computer
Serial Communications Boards Quatek SCB-200	1.1 kg	41 x 185 x 279 Table Mount	23 watts 120v	Redundant with each computer
Communications Modems Multitech V32	9.5 kg	150 x 455 x 361 Table Mount	120 watts 120v	Redundant with each computer, 9600 baud
Printers Epson FX-850	Incl. in μ-proc.	Incl. in μ-proc.	Incl. in μ-proc.	Redundant w/ comp.
IRIG Time Code Reader	11.3 kg	89 x 483 x 457	Included in Microprocessor	Not spared, affects ability to range
Bancomm/Datum PC03XT	Included in Micro	Included in Microprocessor	Not Available	
GPS Station Clock Datum Model 9393-5500	Not Available	Not Available	Included in Microprocessor	
675 Mbyte Hard Drive Maxtor Xt-8760S	Included in Micro	Included in Microprocessor		
20" Super VGA Monitor NEC MS-5D				

Table 7-3, CTCS Major Components

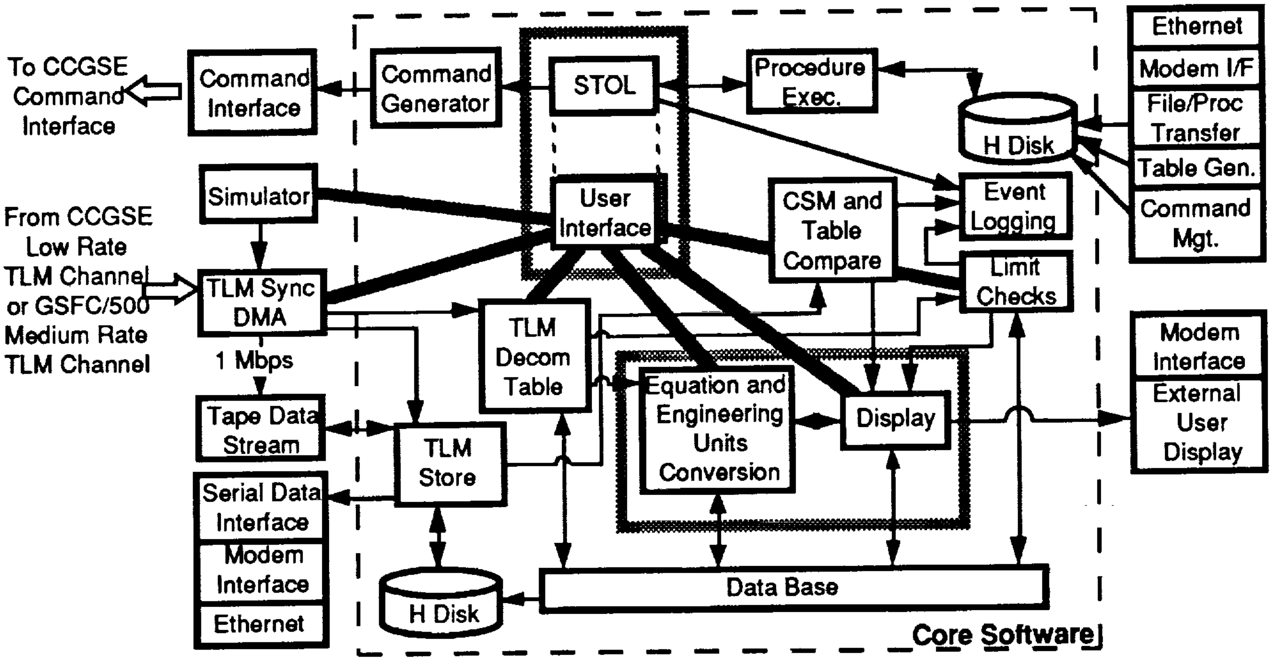


Figure 7-5, Top Level CTCS Software Architecture

7.1.2 Ground Processing Flow

The Kennedy Space Center (KSC) pre-launch activities will commence with the arrival of CONE and its GSE. Horizontal processing is baselined for CONE, but the basic CONE design does not preclude vertical processing. The facility used for horizontal processing would be the Operations and Checkout Building (O&C BLDG), and vertical processing would be in the Vertical Processing Facility (VPF). Figure 7-6 shows the relative locations of these facilities at KSC. The proposed launch site processing is illustrated in Figure 7-7. After CONE has been unpacked and inspected, a comprehensive series of tests will be run and the data compared to previous tests. CONE is then warmed to ambient and maintained until final loading for launch. Upon completion of initial processing, the payload is loaded into the Horizontal Canister Transporter to the Orbiter Processing Facility (OPF). A final end-to-end test, or CITE test will be completed upon completion of integration into the orbiter. Once CONE is integrated, it follows the orbiter processing through the Vertical Assembly Building (VAB) to the launch pad (either 39A or 39B).

After the orbiter processing has been completed and hazardous propellant loaded, CONE is readied for launch by loading LN_2 and GN_2 into the supply tank and pressurant module. Final inspections and close-out are completed and the payload bay doors are closed. After final close-out, CONE is monitored via the T-0 umbilical or with the line-of-sight RF antennas. Figure 7-8 illustrates these two monitoring options. Post-flight recovery can occur at either site since CONE will be empty prior to de-orbiting. CONE is removed from the orbiter after arrival at OPF and is then transported to the Payload Processing Facility (PPF) for post-flight processing. Figure 7-9 represents an estimate of the processing schedule for CONE.

The CONE design can tolerate any contingency operation since the ground hold time prior to activation of the passive vent components is greater than 30 days. If the system did begin to vent for some unanticipated reason, the vent is connected to the orbiter generic vent which is routed outside of the payload bay. Thus the requirement to accommodate contingency operations with no interaction with CONE is satisfied.

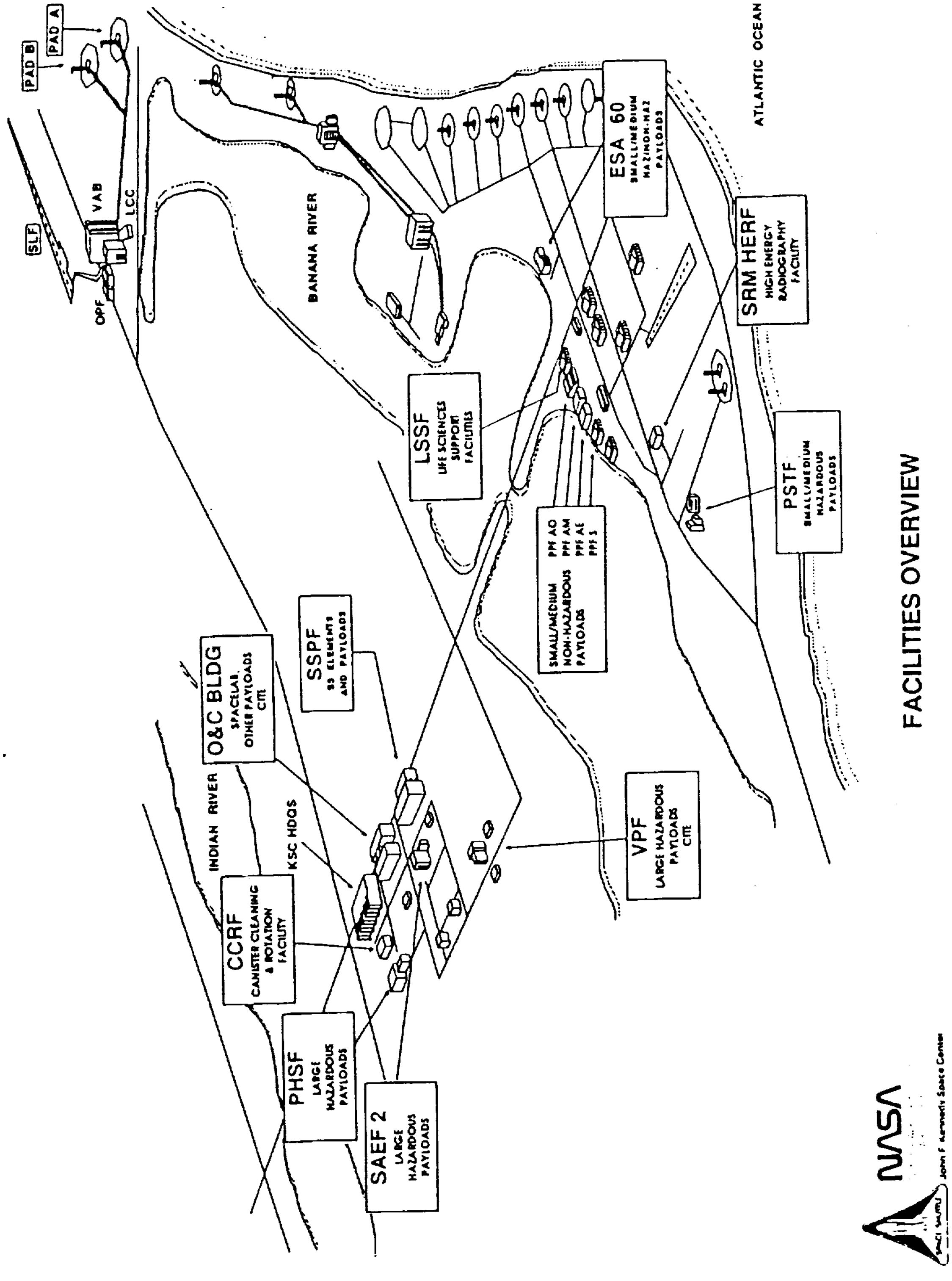


Figure 7-6, KSC Facilities Overview

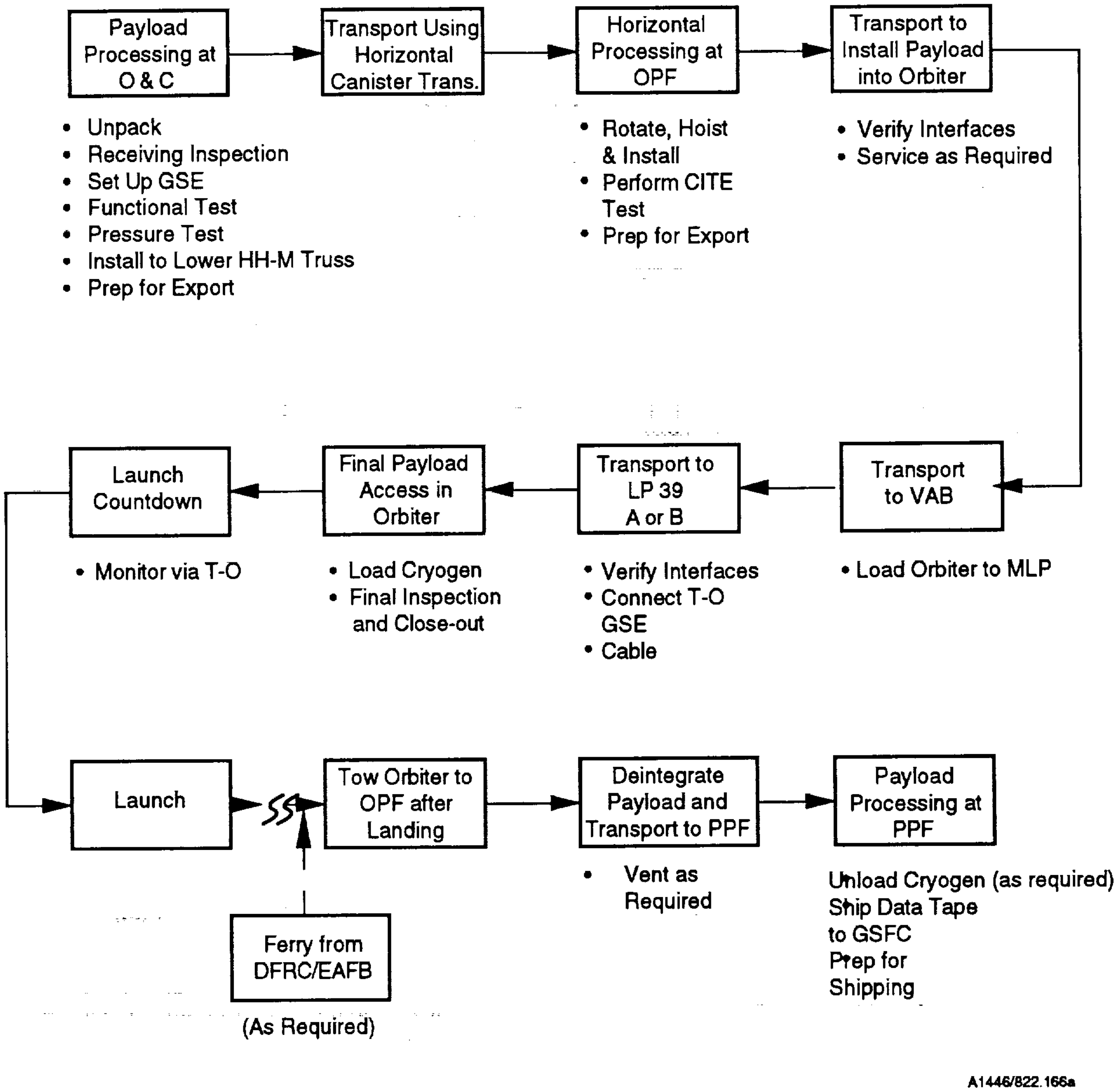
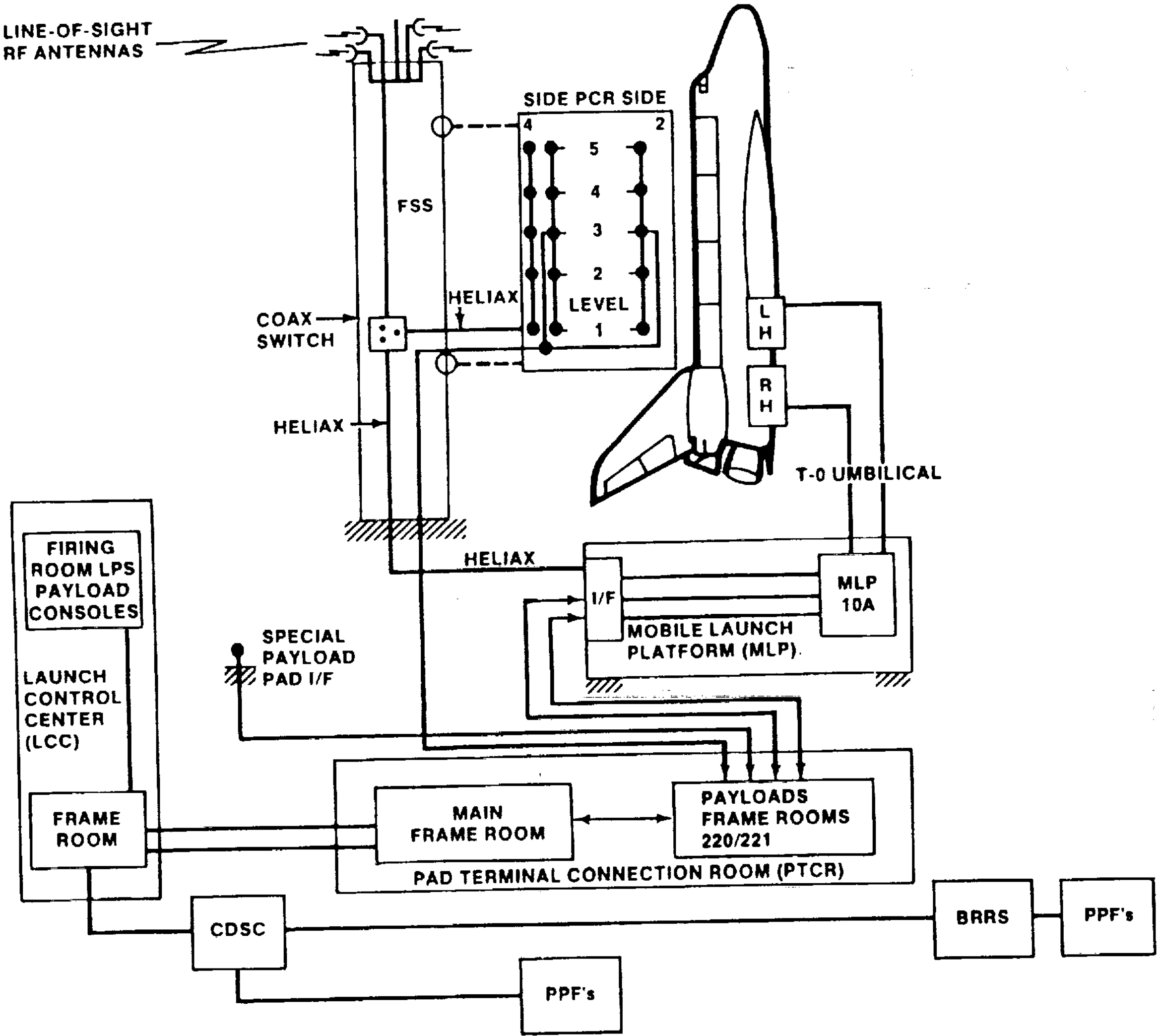


Figure 7-7, Baseline for CONE Horizontal Processing



BRRS - BANANA RIVER REPEATER STATION
CDSC - COMMUNICATIONS DISTRIBUTION AND SWITCHING CENTER
COAX - COAXIAL CABLE
FSS - FIXED SERVICE STRUCTURE
GA - GAUGE
HELIAX - HELIAXIAL CABLE
I/F - INTERFACE
LCC - LAUNCH CONTROL CENTER

LH - LEFT HAND
MLP - MOBILE LAUNCH PLATFORM
PCR - PAYLOAD CHANGEOUT ROOM
PPF - PAYLOAD PROCESSING FACILITY
PRD - PROGRAM REQUIREMENTS DOCUMENT
PTCR - PAD TERMINAL CONNECTION ROOM
RH - RIGHT HAND
RSS - ROTATING SERVICE STRUCTURE
W/B - WIDE BAND

NOTES:
- KSC USES COAX OR W/B FOR ALL HIGH BIT RATE DATA
- SERVICE REQUESTED VIA PRD
- FOR ADDITIONAL INFORMATION SEE KSC-DL-116

Figure 7-8, CONE Monitoring Options

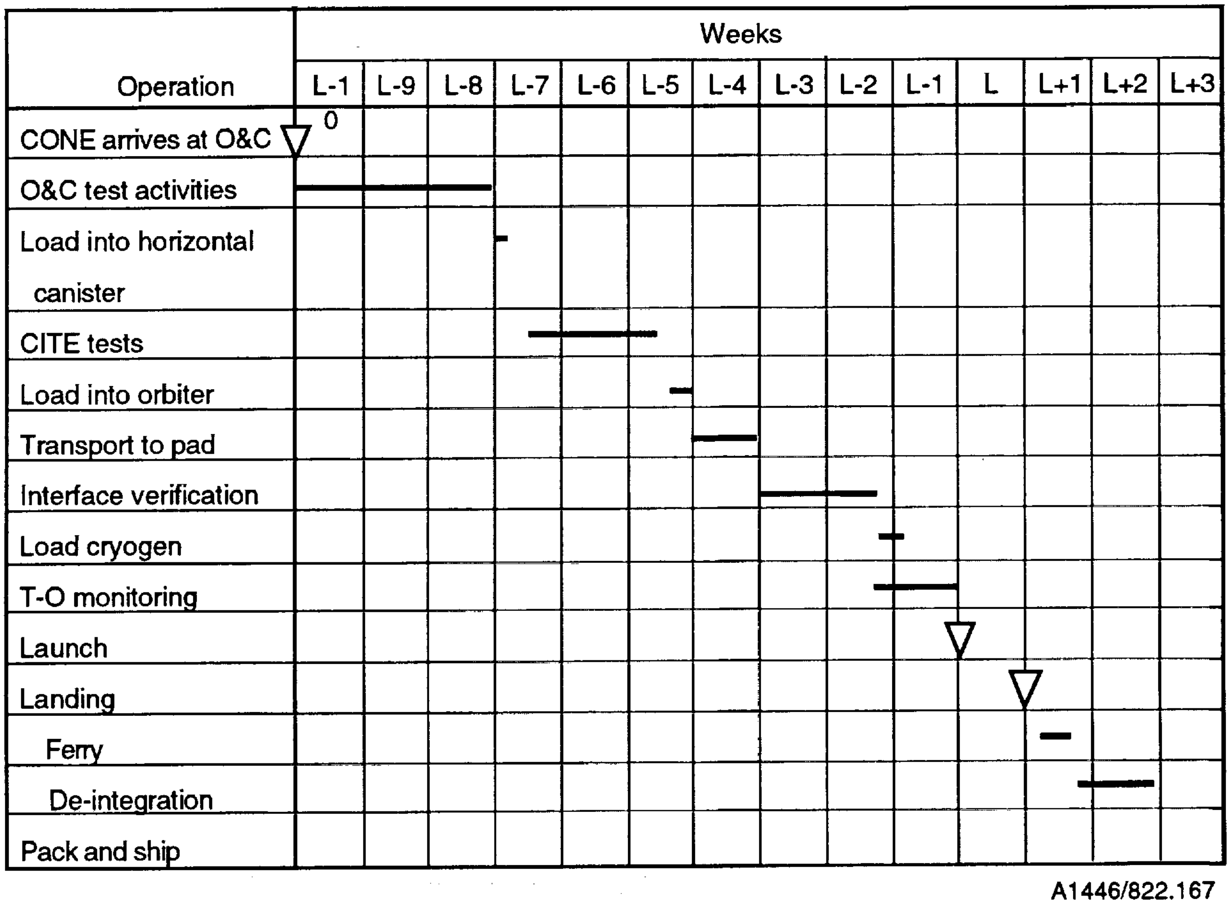


Figure 7-9, CONE Launch Processing Schedule

7.2 FLIGHT OPERATIONS

7.2.1 Ground Data and Communications Equipment

Section 7.1.1.3 introduced the CTCS hardware and software used for ground test and flight operations. Use of the CTCS for both test and the mission provides several benefits. The overall cost is reduced through the reuse of the system. Mission operations also benefit since training and simulations are performed using the same equipment and user interface as the mission. This has proven to be an effective and economical approach to POCC and TOCC operations as proven on a recent Ball satellite program.

Communication between the CTCS and the payload occurs through HH-M Customer and Carrier Ground Support Equipment (CCGSE) which provides the following functions:

- Command interface between the CGSE and customer payload
- Customer payload data as telemetered by the HH-M avionics
- Orbiter ancillary data

The CTCS commands the payload and receives telemetry through the end-to-end signal flows shown in Figure 7-10, taken from the HH-M Customer Accommodations and Requirements Specifications (CARS).

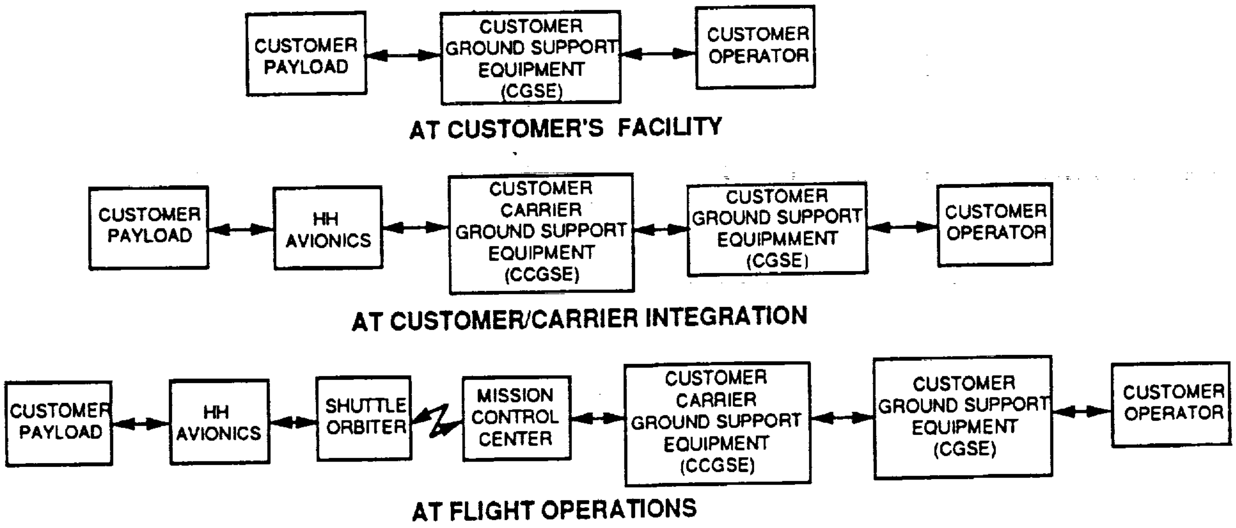


Figure 7-10, CONE End-to-End Communications Flow

The diagram shows generically how low and medium-rate commands and telemetry are generated, transmitted, and received. Since the CTCS is used for all operations, ground or flight, the operator interface at the TOCC or POCC is identical. The HH-M system is designed to be totally transparent to user, thus providing a transparent data system which facilitates successful mission operations.

7.2.2 Experiment Operations and Control

7.2.2.1 Experiment Scheduling

After thoroughly reviewing the technical and mission requirements for CONE, a mission schedule was developed which accomplishes all the technical objectives within a 7-day period and obviates the need for an extended-duration shuttle mission. Although CONE will require substantial shuttle interaction to provide settling maneuvers and liquid dumping periods, all of CONE's requirements can be accommodated during normal crew work periods.

Each technology area in the CONE experiment set was analyzed to predict system behavior, key parameters, fluid requirements, and test-time requirements. A spreadsheet model was developed to track fluid losses, thermal inputs and venting requirements, supply tank pressure and fill level, experiment power requirements, and pressurant consumption. Since each technology area required several tests at different fill levels and other key-parameter values, the tests were sequenced to accommodate mission priorities, shuttle and astronaut constraints, and logical ordering. Potential mission timelines were iterated with shuttle crew-sleep periods, fluid and power budgets, and overall mission duration until an acceptable timeline was developed. The spreadsheet model facilitated these iterations because of its flexibility and ability to propagate changes in operating timelines through the remainder of the mission.

The resulting mission schedule is shown in block form in Figure 7-11. The mission has two large periods of testing, one with the supply tank 90% full and the other with the tank 45% full. Active TVS tests have mission priority and will be conducted as soon as possible at each tank fill level. After launch, approximately 24 hours is required to stabilize the system and insure that all sensors and control loops are functioning properly. The first major test block consists of stratification (pressure rise) tests, followed by mixing and ATVS tests. These tests will be repeated with various parameter levels until all the high fill-level testing is completed. The first pressurized outflow series will occur on mission day 3 and will include two liquid outflow rates and the pressurant bottle recharge test. The long ATVS test in the middle of the mission will reduce the tank pressure to 15 psia for the 45% fill level testing. The first major test block at the lower fill level is similar to the stratification-mixing-ATVS tests conducted earlier in the mission. The last 45% fill level test will be the PTVS demonstration, which requires approximately 20 hours. The final outflow series will empty the supply tank, and the liquid residual will be measured by vaporizing and venting through a metered line. Return to earth will occur on mission day 7, and all CONE operations will be completed before the crew wakes up for the final day in orbit.

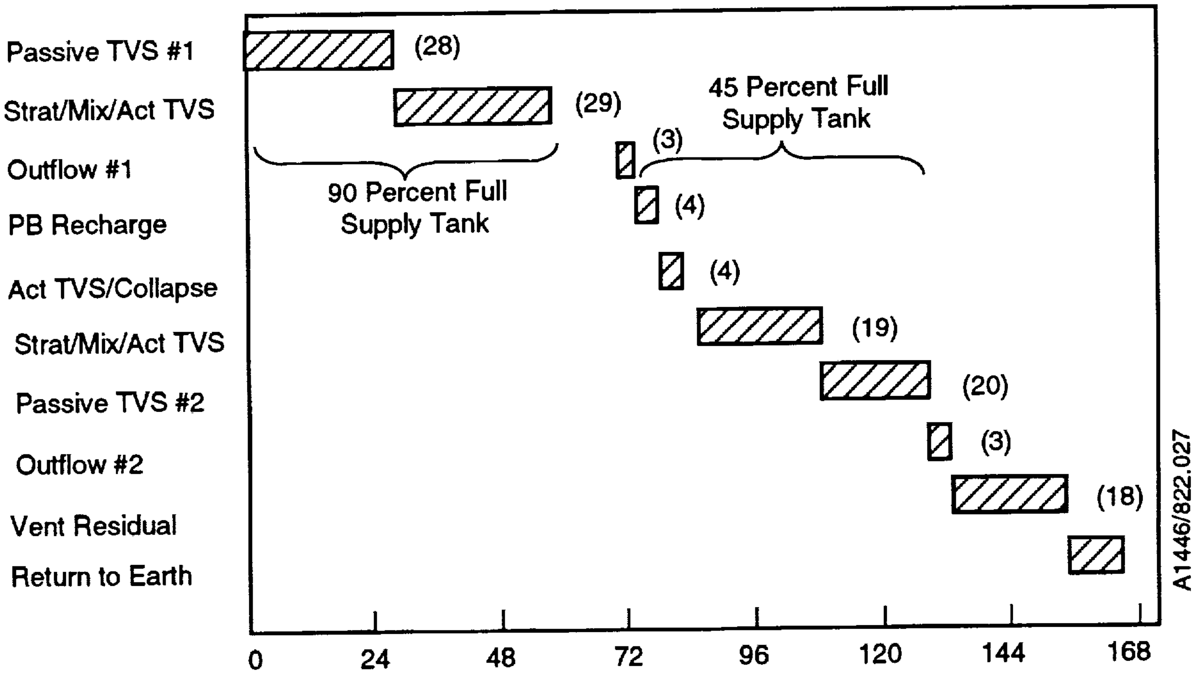


Figure 7-11, CONE Test Schedule Block Diagram

Figure 7-12 is a mission schedule which highlights required shuttle operations. All the key CONE maneuvers are scheduled during normal work periods, and the first two mission days do not require any shuttle maneuvers. The supply tank pressure and fill level are shown as a function of mission time in Figures 7-13 and 7-14. Most of the experiment blocks are labeled in the Figures for reference.

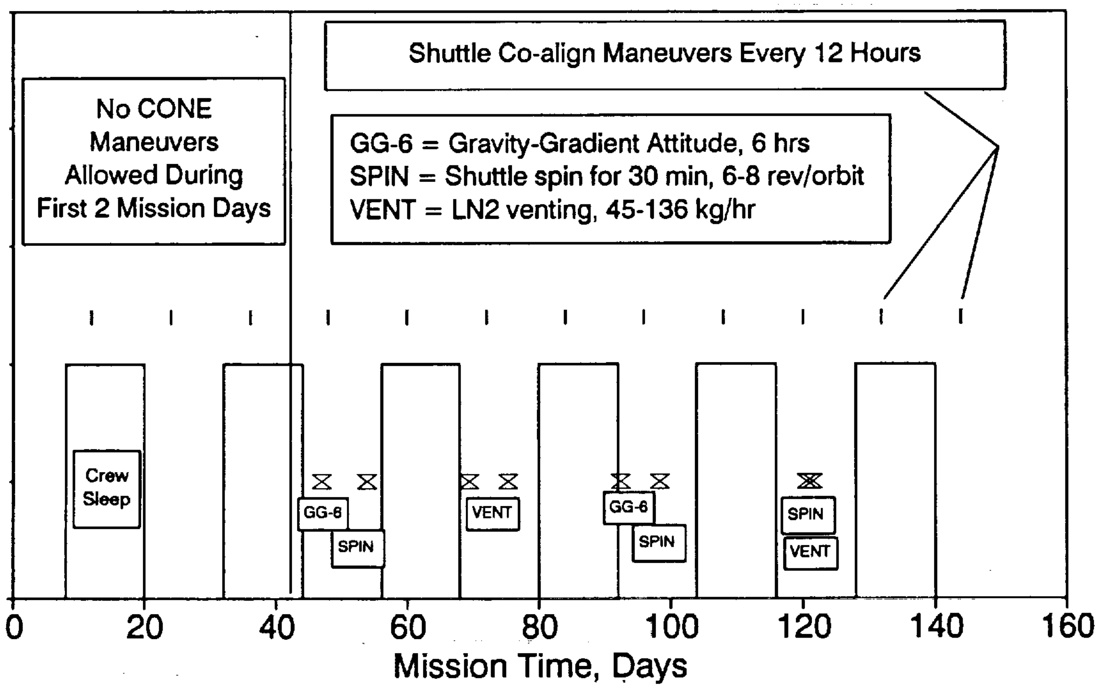


Figure 7-12, CONE Shuttle Events Schedule

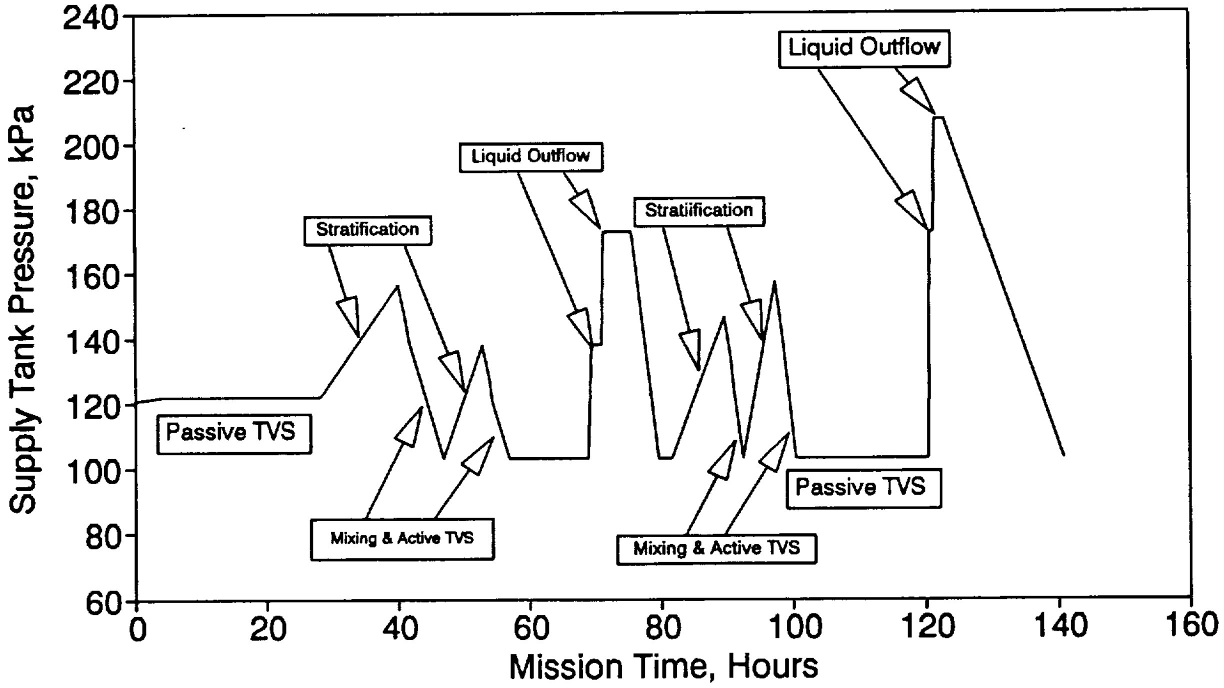


Figure 7-13, Supply-Tank Pressure Profile

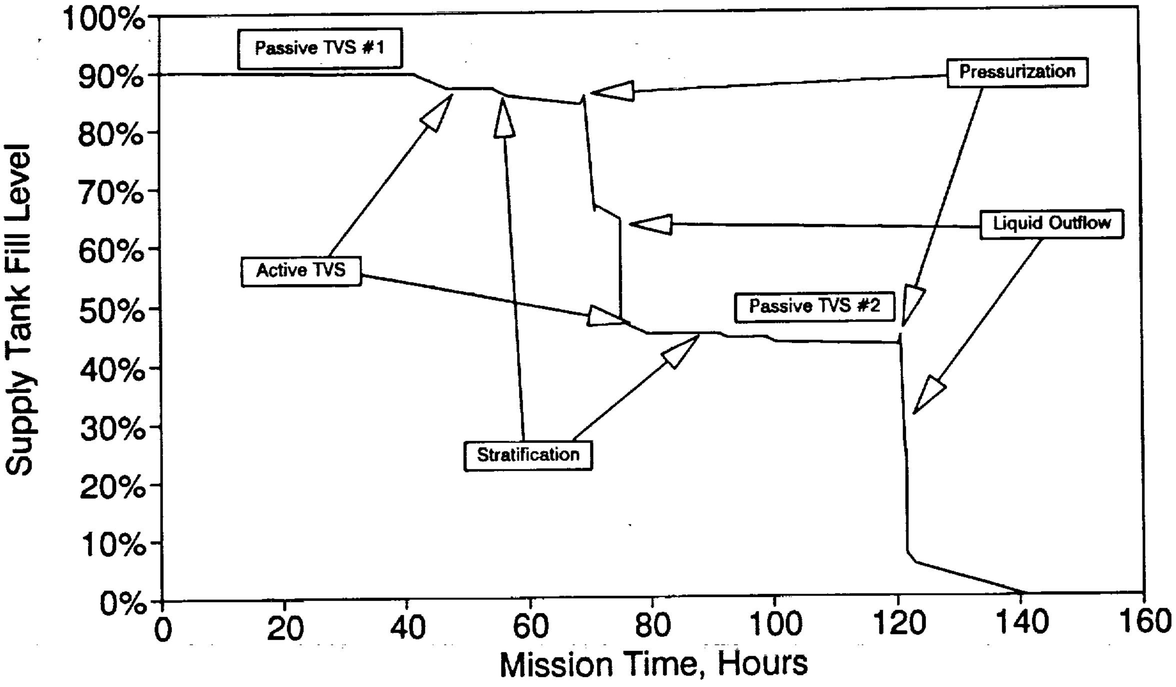


Figure 7-14, Supply-Tank Fill-Level Profile

7.2.2.2 Experiment Control

The CONE tests will be controlled from the ground using the on-board flight computer and electronics to actuate valves, heaters, and the fluid mixer. The ground team and the flight computer will monitor the experiment system at all times. Experiments will be initiated via ground commands, but the computer will have primary responsibility for terminating a test (or the entire system if a contingency condition arises). Ground control using a series of adjustable test parameters will provide maximum flexibility to modify the baseline experiment operating conditions or to accommodate workarounds in the event of a component failure. CONE will require several brief periods of induced g-level for fluid settling in the supply tank. These maneuvers will be coordinated with mission control and the astronauts. In addition, the astronauts will control overboard dumping of liquid nitrogen from the standard switch panel in order to insure that the bay doors are open and the shuttle attitude is acceptable.

CONE is a 7-day mission on a manned platform, and therefore, the flight control software should be of minimal complexity. Where ground-based decisions can substantially reduce software complexity, they are preferred over flight computer decisions. Simple monitoring and control features, such as actuating a valve sequence when pressure exceeds a particular value, are required for in-flight control, but more complex tasks which were part of the COLD-SAT control scheme were dropped from CONE. Since real-time coverage is less than 85% of mission time, the flight computer must be responsible for continuously monitoring the experiment and must make any decisions relating to limits or contingency situations which could arise during a test. Consequently, ground termination of a sequence or action cannot be the primary decision criteria governing an experiment, but ground initiation is preferable in most cases. Ground initiation of an action will occur when a series of conditions are met (including a sufficient real-time coverage window). Computer termination of any action allows for interrupts in the real-time data coverage as well as unexpected experimental behavior.

7.2.2.2.1 Active TVS Tests (Table 7-4).

These tests reduce the tank pressure from a high starting value to a lower value using a forced-flow heat exchanger coupled with the tank mixer. When the test begins, the tank contents will be mixed for 2 to 4 minutes to remove any stratification. After the tank is mixed, the heaters will be activated (if required by the test matrix) and the TVS vent line will be opened to begin reducing the tank pressure. Normally, the tests will be terminated when the target pressure is reached or the test time expires. If liquid appears in the vent line, the ground team will have the option of terminating the test, closing the TVS vent line, or allowing the test to continue. Excessive liquid overflow into the vent will require test termination, but the ground team will want to evaluate the data to be sure that the liquid signal was real and sustained (as opposed to a small pulse of liquid). Computer termination (or valve closure) based on liquid detection is more complex due to the uncertain nature of liquid/vapor sensors in the zero-gravity environment, and was therefore replaced by ground-based control.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
Mix tank to eliminate stratification; record pressure history	Real-time command	Ready to start	
Calculate time, fluid losses based on P and fill level	Ground		These values are used for monitoring/control
Activate heaters, if req'd	Real-time command	Test matrix	Testing option
Open TVS vent line	Real-time command	Heater and mixer OK	2 valve actuations req'd
Monitor pressure, mixer condition, mass flow rate and quality	Ground and computer		
Close TVS vent line	Computer Stored command Computer Ground	1. P = Pfinal 2. Time = Endtime 3. Liquid in vent line 4. Ground command	1. Normal ending 2. Normal ending 3. Notify ground 4. Manual interrupt
Turn heaters off	Computer	Test ended	
Turn mixer off	Computer Stored command Ground	1. P = Pfinal 2. Time = Endtime 3. Ground command	1. Normal ending 2. Normal ending 3. Manual interrupt

Table 7-4, Active TVS Experiment Control

7.2.2.2.2 Stratification tests (Table 7-5).

As a precursor to mixing tests, the supply tank will be allowed to stratify (build up internal temperature gradients) from external heating. Two of the four planned stratification tests will require the shuttle to fly a gravity-gradient orientation for 4 to 6 hours to minimize g-level disturbances; astronaut coordination will therefore be required prior to heater activation. The pressure-rise rate in zero-gravity conditions is unknown, and consequently, experiment termination must be flexible to allow for several possible situations. A normal ending will occur when the experiment time expires without the pressure reaching the maximum allowable test value. If the tank pressure rises more rapidly than anticipated, two options will be available. The computer will terminate the experiment when the pressure is 14 kPa (2 psia) greater than the predicted test pressure. The ground team can then elect to continue the test, overriding the computer-set maximum, or they can mix the tank to return the contents to the starting point. Depending on the time remaining, an additional test could be initiated, or the next test in the sequence could be performed.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
Determine heat rate, time, max. allowable delta-P	Ground	1. Ready to start 2. Change parameters from default values?	Optional; use defaults if no changes required
Adjust shuttle attitude to gravity gradient	Astronauts	Ground communication	
Turn heaters on	Real-time command	Correct values uplinked	
Monitor pressure, heater condition	Ground		6 channels of data are required
Turn heaters off	1. Stored command 2. Ground 3. Computer	1. Time expired 2. Direct command 3. P > Pfinal + 14 kPa	1. Normal ending 2. Manual interrupt 3. Higher dP/dt than predicted
Notify ground @ P = Pfinal Ground continue or terminate test	1. Real-time command 2. Real-time command 3. Real-time command 4. Ground	1. Provide new Pfinal 2. Activate mixer 3. Terminate test 4. Continue to time-out	1. More pressure rise 2. Mix and resume 3. Results adequate 4. Normal ending OK
Terminate gravity-gradient attitude	Astronauts	Time or ground OK	

Table 7-5, Stratification Experiment Control

7.2.2.2.3 Mixing Tests (Table 7-6).

These tests will mix the tank contents using the fluid mixer and will follow all stratification tests and precede any active TVS tests. Since the mixer is variable speed, a value for the speed must be included in the "mixer on" command. Two of the four mixing tests which follow stratification will use shuttle spin to preferentially orient the fluid in the tank. For these tests, the astronauts will first rotate the shuttle to its desired spin rate, then notify the ground team that testing can begin. The ground team will then activate the mixer. Most mixing tests require 5 to 10 minutes for completion. The normal ending criteria is time, but the ground team can elect to terminate the test at any time and move on to the next test. Some tests are dual speed, and computer control would operate the mixer at a low speed for a certain time and then increase the speed to the next level.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
Spin shuttle to achieve induced g-field	Astronauts	Ground OK to spin	
Turn mixer on at desired speed	Real-time command	Correct values uplinked	
Monitor pressure, mixer condition	Ground and computer		6 channels of data are required
Turn mixer off	Stored command Real-time command	Time expired Direct command	Normal ending Manual interrupt
De-spin shuttle	Astronauts	Time or ground OK	

Table 7-6, Mixing Experiment Control

7.2.2.2.4 LAD Liquid Outflow Tests (Table 7-7).

Liquid outflow tests will demonstrate subcooled liquid delivery from the supply tank at two flow rates. Prior to liquid outflow, supply tank pressure will be raised to the appropriate level using mechanical regulators and the appropriate pressurization line. Liquid outflow tests using the subcooler will then open the subcooler TVS line to pre-cool the heat exchanger. After a pre-set cooling time has expired, the ready-to-dump signal will be given to the astronauts (a preliminary signal will be sent at the beginning of the tests when the tank is pressurized). The astronauts will then open the dump valve, and if possible, visually observe the liquid/solid nitrogen cloud from the experiment. The computer will terminate the liquid outflow after time expires or the mass totalizer indicates a satisfactory quantity of liquid has been expelled. The astronauts can also terminate liquid outflow from the standard switch panel. The final liquid outflow will break down the LAD and vapor will begin flowing from the tank (instead of liquid). The computer will detect this change and terminate liquid outflow.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
1. Determine mass out, set pressures, estimated outflow time	Ground	Ready to start; New values required?	
2. Open pressurant valve(s)	Real-time command		
3. Monitor pressure, mass flow (GN2)	Ground	Wait until P = Pdesired	
4. Open subcooler line	Real-time command	Test matrix	
5. Open outflow dump valves	Astronauts coordinated with ground team	P = Pdesired; cold subcooler	
6. Close outflow dump valves	1. Computer 2. Stored command 3. Computer 4. Ground/Astronauts	1. Mass out = mass reqd 2. Time expired 3. Vapor detect in LAD 4. Manual interrupt	1. Normal ending 2. Normal ending 3. LAD breakdown
7. Close subcooler valve	Computer/stored command	Outflow valves closed	
8. Close GN2 valve	Real-time command	Outflow series complete	

Table 7-7, LAD Outflow/Expulsion Experiment Control

7.2.2.2.5 Passive TVS (Standby) Tests (Table 7-8).

Passive TVS tests will demonstrate pressure control at two fill levels and will include two extended periods of operation as well as all standby periods during the mission. Time required for testing will be calculated from the total heat input required to demonstrate the successful operation of the system. If the total heat input is too low, the small rise in pressure which would occur could lead to a false conclusion regarding the TVS performance. The normal test ending is time expired, and liquid in the vent line is the most likely cause for premature termination. If the heat exchanger floods and pushes liquid into the vent system, then the remedy will be to close off the JT valves for a pre-set period of time and try again. Modulated operation of the passive TVS vent valve may be required for proper pressure control. A software routine for modulating the vent valve using a simple time-tagged sequence will be included in the software, but ground modulation could be required if the computer modulation scheme is ineffective.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
Determine test time, thermodynamic delta-P	Ground calculates default values for time	Ready to start	Optional
Open TVS vent valve(s)	Real-time command		
Monitor pressure, vent flow rate, vent flow quality	Ground Computer		6 channels of data are required
Close TVS vent valve(s)	1. Stored command 2. Computer/ground Gnd modulate valve 3. Ground	1. Time expired 2. Liquid in vent; wait TBD min. and reopen 3. Direct command	1. Normal ending 2. Flooding in HX requires valve mod. 3. Ground interrupt

Table 7-8, Passive TVS/Standby Experiment Control

7.2.2.2.6 Pressurant Bottle Recharge (Table 7-9).

A warm, partially full pressurant bottle must be chilled and partially filled with liquid nitrogen to demonstrate gaseous pressurant replenishment from liquid cryogen. Because of the sensitive timing required for some of the valve actuations, the computer will control all of the pressurant bottle recharge experiment, although the ground can interrupt the experiment at any time. All actions will be based on timed valve actuations (times will be developed during ground test), except for the final liquid fill which will use the liquid mass flow meter to measure the quantity of liquid introduced to the bottle. The large thermal mass of the bottle will require multiple chill cycles prior to reaching the ready-to-fill state. The ground team will activate the heaters on the bottle after they determine that a successful fill occurred.

Action / Sequence	Initiation or Execution	Decision Criteria	Comments
1. Evacuate PB to space	Real-time command	Ready to start	P < 14 kPa required
2. Hold for ground OK	Real-time command	OK to proceed	Allows go/no-go decision
3. Charge PB with liquid slug	Computer	TPB > Tprechill	Use timed valve cycle based on ground test
4. Hold for TBD time	Computer		
5. Open vent line	Computer	Hold time expired	Vent until P < 14 kPa
6. Go to step 2	Computer	TPB > Tprechill	Continue until cold
7. Hold for ground OK	Real-time command	OK to proceed	Allows go/no-go decision
8. Charge PB with fill mass (approx. 20% fill)	Computer	TPB < Tprechill	Fill rapidly to desired level
9. Close fill valve(s)	Computer	Mass in = mass desired	
10. Activate heaters on PB	Real-time command	Satisfactory fill	Go to step 4 if fill is unsatisfactory

Table 7-9, PB Recharge Experiment Control

7.2.2.2.7 Initial and Final Experiment Conditions

The conditions required prior to and at the end of each test are summarized in Table 7-10. In some cases, additional steps other than those listed in the preceding control tables may be required to properly configure CONE between tests.

Experiment	Initial Conditions	Final Conditions
Active TVS	P = Phigh; unmixed	P = Plow; well mixed
Stratification	P = Plow; well mixed	P = Phigh; stratified
Mixing	P = Phigh; stratified	P = Plow; well mixed
LAD Liquid Outflow	P = Pexpulsion; Tank fill level TBD	P = Pexpulsion Tank fill level lower
Passive TVS	P = Pset; well mixed	P = Pset(?); stratified(?)
Pressurization	P = Plow	P = Pset
Subcooling	P = Pexpulsion; warm HX	P = Pexpulsion; cold HX
PB Recharge	Warm, empty (P < 14 kPa) GN2 bottle; Psupply = Pexpulsion	Cold bottle containing LN2; P < 350 kPa; Psupply = Pexpulsion

Table 7-10, Initial and Final Conditions for CONE Experiments

7.2.3 Contingency and Post-Flight Operations

Contingency flight operations; i.e. return to launch site (RTLS), abort once around (AOA), transoceanic abort landing (TAL), and abort from orbit (AFO), have been reviewed from impacts on the CONE design. The minimum time required to gain access to CONE from opening the payload bay doors is listed below for each of the contingencies:

RTLS	3 days
AOA	5 days
TAL	15 days
AFO	19 days

Assuming that the CONE mission has a successful completion and the primary or alternate end-of-mission (EOM) sites are used, there should be no non-standard payload bay access requirements for CONE. During a TAL or emergency landing site operation, it is possible to have the ferry flight back to KSC delayed up to 48 days. The current ground hold time for CONE is in excess of 30 days, and access to the payload bay will be available prior to venting of the tank. However, since this vent line is attached to the generic orbiter vent, even if the tank were to begin venting it would not pose any kind of safety hazard.

Optional access into the payload bay is through the crew compartment and airlock hatches. This option requires identification in the appropriate CONE PIP, and the CONE program would be required to provide any special access equipment . It is not anticipated that the current CONE design will require this option.

Section 8.0

SAFETY

This section discusses the various safety requirements for a shuttle payload. A preliminary safety meeting was held with NASA/JSC during Phase A of this study, and close coordination with the NSTS safety board will continue throughout the CONE program. A thorough understanding of all applicable safety requirements is essential for the success of CONE. Table 8-1 lists the safety documentation reviewed for CONE:

Document	Title
NSTS 1700.7, Rev B	Safety Policy and Requirements for Payloads Using the Space Transportation System
KHB 1700.7, Rev A	Space Transportation system Payload Ground Safety Handbook
MSFC-HDBK-505	Structural Strength Program Requirements
MIL-STD-1522, Rev A	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
NSTS 13830, Rev B	Implementation Procedure for NSTS Payloads System Safety Requirements
MSFC-HDBK-527, Rev F	Materials Selection List for Space Hardware Systems
MSFC-HDBK-1453	Fracture Control Program Requirements
NHB 8060.1	Flammability, Odor, and Off-Gassing Requirements and Test Procedures for Materials in Environments that Support Combustion
NHB 8071.1	Fracture Control Requirements for Payloads Using the National space Transportation System (NSTS)
MSFC-Spec-522, Rev B	Design Criteria for Controlling Stress Corrosion Cracking
NSTS 18798, Rev A	Interpretations of NSTS Payload Safety Requirements
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-1472, Rev C	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
NHB 1700.1 (V1-4)	Basic Safety Manual
NHB 1700.1 (V9)	NASA Safety Manual Fire Protection

Table 8-1, CONE System Safety Documents

The primary controlling safety document for the NSTS program is NSTS 1700.7B, Safety Policy and Requirements for Payloads Using the Space Transportation System. Additionally, several NASA Letter Interpretations have been generated and can be found in NSTS 18798 Rev. A, Interpretations of the NSTS Payload Safety Requirements. Since not all of these interpretations are applicable to CONE, those considered to apply are listed in Table 8-2. The design safety requirements derived from these two documents are given in Table 8-3.

Document Number	Title	Subsystem
ES52-87-238M	Pressure Vessel Safety in Abort Position	Fluid
TA-88-018	Monitoring for Safety	All
TJ2-87-136	Effects of Orbiter Ku-band Radiation	Electronics
TA-88-025	Rapid Safing	All
TA-88-074	Special Certification of Burst Disks	Fluid
ER-87-326	Payload Wire Sizing and Circuit Protection	Electronics
NS2/81-MO82	Ignition of Flammable Payload Bay Atmosphere	Electronics

Table 8-2, Safety Interpretations Applicable to CONE

8.1 HAZARD IDENTIFICATION

A safety analysis was completed on the CONE design which indicates that the following potential hazards may be considered credible (includes both ground and flight operations):

- Rupture of the cryogenic tank or pressurant tanks
- Venting of nitrogen vapor resulting in potential hazards to personnel
- Electrical shock
- Fire due to use of flammable materials, electrical malfunction, generation of ignition source
- Fire due to use of flammable materials in presence of ignition source, electrical failure, or electrical component
- Generation of electromagnetic interference in excess of allowable limits
- Exposure of personnel to sharp edges, corners, protrusions
- Exposure of personnel to toxic offgassing materials
- Structural failure of payload elements resulting in collision hazards

Reference to NSTS 1700.7B Paragraph	Requirement
200.4a Safe without services	Maintain fault tolerance or safety margins without NSTS services during ground and flight operations
205 Rapid safing for contingency return	(1) Within 20 minutes; zero-fault-tolerant safing system acceptable (2) Within 160 minutes; one-fault-tolerant safing system required
208.1 Structural design	(1) Ultimate factor of safety >1.4 for all NSTS mission phases except emergency landing (2) Verification per NSTS 14046 (3) Fracture control per NHB 8071.1 (4) Ultimate design load factors for emergency landing loads are TBD pending ICD completion
208.3 Stress corrosion	- Materials selected to resist stress corrosion cracking per MSFC-HDBK-527/JSC 09604 and MSFC-Spec-522 - Moderate- or low-resistance materials require NSTS approval
208.4 Pressure systems	- Pressure control shall be two-fault-tolerant from causing the maximum design pressure (MDP) to be exceeded - Pressure integrity shall be verified at the system-level proof test
208.4a Pressure vessels	Design per MIL-STD-1522A with modification per para. 208.4a of NSTS 1700.7B
208.4b Dewars	(1) Where possible leak before burst (LBB) designs should be used; non-LBB designs must employ a fracture mechanics safe-life approach (2) Relief devices must be sized for full flow at MDP (3) Vacuum jackets shall have pressure relief capability to preclude rupture (4) Pressure relief devices require certification (5) Worst-case venting in the cargo bay shall not affect structural integrity or thermal capability of the Orbiter (6) Proof test factor shall be a minimum of 1.1 times MDP; structural integrity for external load environments must be demonstrated in accordance with NSTS 14046
209.2 Flammable materials	- No uncontrolled fire hazards - Minimize flammable materials; determine flammability per NHB 8060.1 - Flammability assessment required
210 Pyrotechnic devices	"Locked Shut" safety demonstration required
213 Electrical systems	Faults internal to the payload shall not damage STS circuitry or create ignition sources

Table 8-3, Key Safety Design Requirements for CONE

The CONE safety review generated numerous hazard reports which were transmitted to NASA/LeRC during the System Design Review on July 9 and 10, 1991. Table 8-4 is list of the CONE hazard reports.

Supply Tank (Dewar)	CO-1-01 Rupture of cryogen tank (structural failure)
	CO-1-02 Rupture of cryogen tank (overpressurization)
	CO-1-03 Venting of liquid nitrogen
Pressurant Module	CO-2-01 Rupture of pressurant tank (structural failure)
	CO-2-02 Rupture of pressurant tank (overpressurization)
Centrifugal Pump	CO-3-01 Failure of centrifugal pump
Electronics	CO-4-01 Electrical shock
	CO-4-02 Generation of ignition sources
	CO-4-03 Exposure of STS electrical systems to EMI
Human Factors	CO-5-01 Exposure of personnel to sharp edges, corners, or protrusions
	CO-5-02 Exposure of personnel to extremely cold temperatures
Materials	CO-6-01 Offgassing of toxic materials in habitable area
	CO-6-02 Use of flammable materials
Plumbing	CO-7-01 Rupture of cold valve box
	CO-7-02 Rupture of line, fitting, valve, or component
Structures	CO-8-01 Structural failure of payload element

Table 8-4, CONE Hazard Reports

8.2 SAFETY DESIGN PHILOSOPHY

The Ball CONE design philosophy to meet the NSTS safety requirements is to minimize credible failures and to be passively tolerant to failures.

The fault tolerance approach for CONE is two-fault tolerance for catastrophic hazards, single-fault tolerance for critical hazards, and zero-fault tolerance for mission success. The mission success requirement allows the fluid system to tolerate a single failure with some mission degradation.

8.3 SYSTEM DESIGN FEATURES

The CONE design is compliant with NHB 1700.7B and considers failures of structure, non-vacuum jacketed fluid lines, and fittings to be noncredible failure modes. The only credible fluid-system failure modes are overpressurization of the pressure vessel, leak of the pressure vessel into the vacuum space, overpressurization of the pressurant bottles, and leak of fluid lines within the CVB. Passive redundant vent systems which accommodate the anticipated vent rates have been incorporated into the tank vent system, the vacuum shell of the supply tank, the pressurant bottle manifold, and on the vacuum shell of the CVB.

A major design objective is to passively control the pressure and venting of the CONE fluid systems. For all potential fluid path (both liquid and gaseous) leakage, there are three separate barriers to flow (two-fault tolerance). The maximum design pressure (MDP) is stated to be the "highest pressure defined by maximum relief pressure, maximum regulator pressure, or maximum temperature." For CONE, the MDP is shown below in Figure 8-5.

System Element	Maximum Design Pressure		Limit Feature
	MPa	psi	
Supply Tank	0.345	50	Burst Disc
Cold Valve Box	0.207	30	Relief Valve
Pressurant Bottles	23.4	3400	Relief Valve
Vacuum Shell	0.207	30	Relief Valve

Table 8-5, CONE Maximum Design Pressure

The loss of guard vacuum is one of the most complex CONE safety issues to analyze. This is a pre-flight ground operations concern in which the guard vacuum around the pressure vessel is lost, creating extremely high boiloff rates, a large pressure excursion, or both. The largest unknown during vacuum loss is the exact amount of heat added to the fluid. Investigations at NASA/JSC[1] and elsewhere established that vent rates are dependent upon the fluid stored, the configuration of the storage vessel (i.e. use of vapor cooled shields, number of layers of MLI, etc.), and, pressure vessel wall thickness and material. Some attempts have been made to determine if adding a low-conductivity barrier such as a closed-cell foam will aid in controlling vent rates or fluid pressure excursions. In conversations, with P. Mason of NASA/Ames, the improvements obtained by adding these barriers are marginal, particularly when the fluid has a high heat capacity (such as nitrogen). Consequently, no foam barrier was added to the CONE supply tank.

8.4 OPERATIONS PROCEDURES

All safety critical operations will be annotated as such in procedural documents and will be referenced to Appendix Z of that procedure. Appendix Z is the location of all emergency procedures and will instruct the operations crew as to the steps to "safe" the system.

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[1] BR #16425, Loss of Vacuum Test, Date March 20, 1987, performed for NASA/JSC by Beech Aircraft Co.

Section 9

RELIABILITY

9.1 RELIABILITY GUIDELINES

The CONE reliability guideline is to complete the experiment set in a seven-day mission on three flights with an overall reliability of at least 0.95, assuming the orbiter, payload operations center, and ground segment have a reliability of 1.0. Because the overall mission duration is short, the addition of redundancy was primarily driven by safety considerations and not by reliability constraints. In a few cases, single-point failures in the experiment subsystem were eliminated where the cost was minimal and the experiment data concept was enhanced. This category of redundancy included additional temperature sensors, valves, and flow meters so that the loss of one of these components would not appreciably degrade the mission.

9.2 SYSTEM RELIABILITY

The CONE reliability analysis relied heavily on COLD-SAT heritage (Reference 9.1) for reliability numbers associated with various subsystems. No redundancy was required to meet the CONE reliability goal of 0.95, and therefore, the reliability analysis was quite straightforward. Figure 9-1 summarizes the CONE reliability analysis. The overall system reliability of 0.99399 is a product of the four major subsystem reliability values.

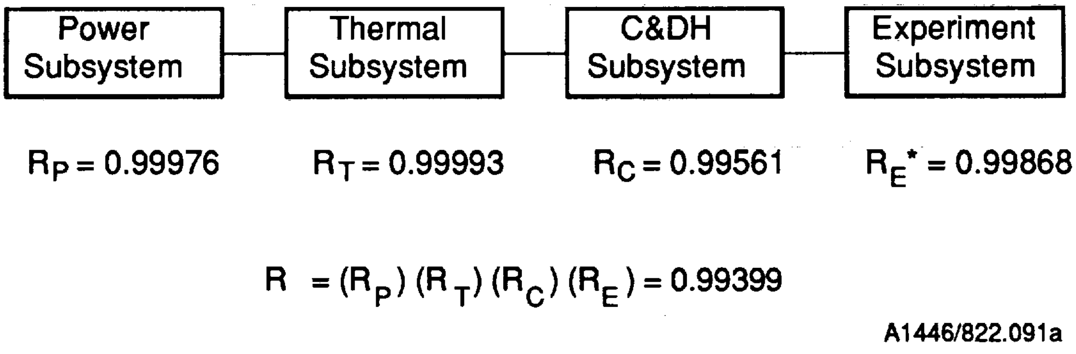
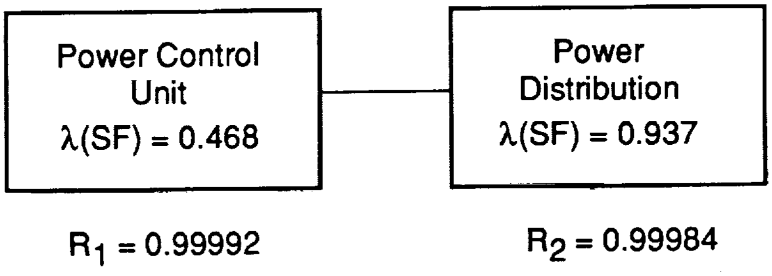


Figure 9-1, Overall CONE System Reliability Diagram

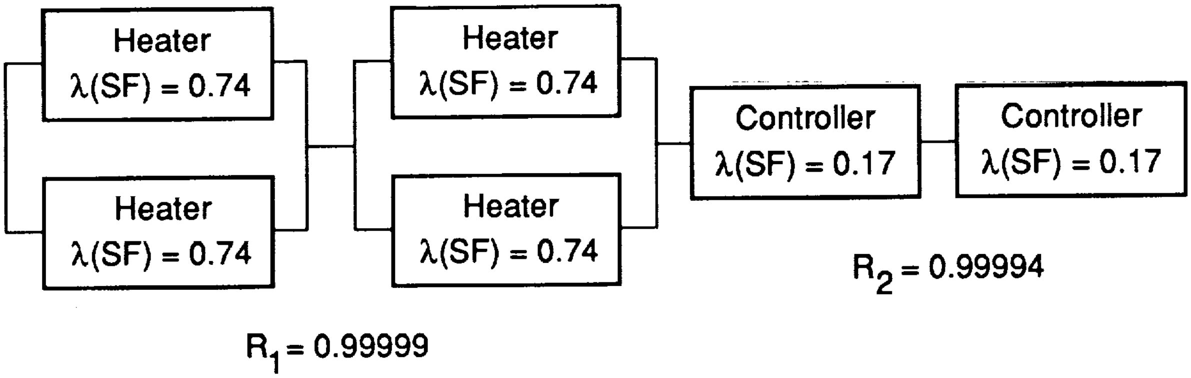
Figures 9-2 through 9-4 derive the reliability of the power, thermal, and C&DH subsystems. Each box indicates the failure rate (λ(SF) = failure rate during orbital operation). The C&DH subsystem is the only subsystem area which has less than 0.999 reliability due to the failure rates of the computer and the tape recorder. No reliability improvements are required at this time, primarily because of the short CONE orbital life. Although thermal analysis showed that heaters are not required for the expected orbital environments, they were included in the reliability analysis on the assumption that they might be added during phase C/D.



$$R_P = (R_1)(R_2) = 0.99976$$

A1446/822.088

Figure 9-2, Power Subsystem Reliability Calculation



$$R = (R_1)(R_2) = 0.99993$$

A1446/822.089

Figure 9-3, Thermal Subsystem Reliability

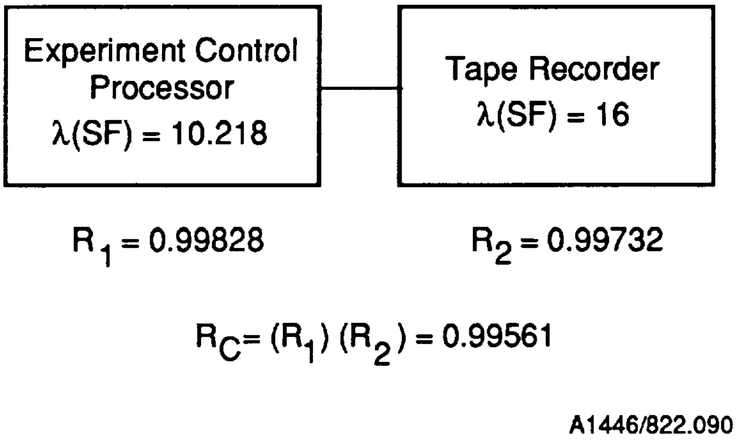


Figure 9-4, C&DH Subsystem Reliability

The experiment reliability consists of valve, heater, and mixer actuations which are similar (although much less complex) than those required for COLD-SAT. Consequently, the COLD-SAT experiment reliability was used directly for CONE as a conservative estimate of CONE experiment subsystem reliability.

9.3 REFERENCES

9.1 "Feasibility Study for a Cryogenic On-orbit Liquid Depot-Storage, Acquisition and Transfer (COLD-SAT) Satellite," NASA CR 185248, August, 1990.

Section 10

PROJECT PLANNING

This section addresses the programmatic issues associated with the implementation of the CONE program. These issues include the technological risks involved with project implementation, unique personnel and facility resource requirements, system testing philosophy, and overall program schedule.

10.1 TECHNOLOGICAL RISK

An assessment of the state of technology for the various elements of our CONE design was made and assigned risk categories A through D according to the following criteria:

A. Those elements for which existing hardware or qualified designs may be used.

B. Those elements requiring new designs but for which existing, proven design techniques are available.

C. Those elements requiring new designs and are at or near the state-of-the-art for the technical discipline involved.

D. Those elements requiring new design which are beyond the current state-of-the-art for the technical discipline involved.

A numerical risk factor between 0 and 10 was also assigned to each element. Zero indicates no-risk, ten indicates the highest degree of risk, requiring major breakthrough for accomplishment. Correlation between the numerical risk factor and risk category is as follows:

Category A:	0, 1
Category B:	2, 3, 4
Category C:	5, 6, 7
Category D:	8, 9, 10

Table 10-1 outlines the technological risks associated with the Experiment Subsystem. As indicated in the figure, there are no components identified as Category D. Note that the only Category C item is the two-phase flow meter. All other components are Categories A or B.

Item	Category				Risk Factor
	A	B	C	D	
Accelerometer	X				1
Disk, Burst	X				0
Expander, J-T	X				0
Flowmeter, 2-Phase			X		6
Heat Exchanger		X			2
LAD		X			4
Pump, ATVS Mixing		X			3
Regulator	X				0
Sensor, Temperature	X				1
Sensor, Differential Temp.		X			3
Sensor, Liquid/Vapor	X				1
Sensor, Pressure	X				0
Tank, Supply		X			4
Tank, Pressurant	X				1
Valves, Check	X				0
Valves, Warm, Solenoid	X				1
Valves, Cold	X				1
Valves, Cold, Hi-Pressure		X			2
Valves, Manual	X				0
Valves, Relief	X				0

Table 10-1, Experiment Subsystem Technological Risk

New design items are concentrated in the cryogenic fluid section. The supply tank and LAD are new designs. The subcooler and ATVS heat exchangers are also new designs, but based upon well proven methodology. The ATVS mixing pump is also a new design based upon current pump design practice. Finally, the differential temperature sensor arrays are new designs, but derive from proven solutions to gradient measurement applications.

The pressurization subsystem operates in the ambient temperature range and uses components similar to many pressurization systems which have previously flown. Therefore, it is a Category A subsystem.

The technological risk associated with the support support subsystems is shown in Table 10-2.

Item	Category				Risk Factor
	A	B	C	D	
AVIONICS:					
Experiment Control Processor			X		5
Data Storage Unit	X				1
Valve/Mixer Driver		X			2
Power Distribution Unit		X			2
Harness		X			2
STRUCTURE:					
Primary		X			2
Secondary		X			2
THERMAL CONTROL:					
MLI		X			2
Heaters	X				0
Paint	X				0

Table 10-2, Support Subsystem Technological Risk

The experiment control processor uses an 80386/80387 chipset and is considered to be a Category C component due to the current state of hardware design. It is an upgrade of a flight processor used on the SP-18 program which was based on an 80C86 microprocessor. Other vendors are also developing 80386 based machines, leading to the use of the lowest risk factor allowed for a Category C device. The structural components are Category B with extensive design heritage and use of proven materials. Thermal control components such as finishes and heaters are catalog items. The MLI is a Category B component, indicating that particular attention must be paid to the manufacturing and assembly processes. The data storage unit is an off-the-shelf design which should be revisited during Phase C/D since solid-state memory devices will be available with potential cost savings and reliability improvement. The valve/mixer driver and power distribution unit are new designs using existing technology and components. The electrical harness uses standard design practices, but is, of course, a new design.

10.2 PERSONNEL RESOURCES

The types of personnel required by CONE encompass the normally available range of engineering trades, from cryogenics to spacecraft subsystem design, generally available in the aerospace community. Cryogenics engineers with flight hardware experience are not as prevalent as spacecraft subsystem engineers, but are present in a number of organizations. However, the ability to assemble a management and engineering team experienced in high-performance, low cost, cryogenic flight hardware design and low cost spacecraft implementation is not so common. BASG is one of the few aerospace organizations having access to all of the required talents required for a low risk, low cost CONE program. Mission specific requirements analysis and specialty items such as liquid acquisition devices which are outside our areas of expertise will be provided by our team members MDAC.

10.3 KEY FACILITIES REQUIRED

Key facilities required for the CONE program are shown in Table 10-3.

Preliminary analyses of CONE facility requirements reveal that most can be satisfied by resources readily available in the aerospace community with two key exceptions:

- A large thermal vacuum chamber capable of accommodating the fully assembled CONE payload.

- A large acoustic chamber capable of accommodating the fully assembled CONE payload.

Item	Location	Unique Facility
Static Load Modal Survey Facility	BASG	
100 K Cleanroom	BASG	
EMI Facility	BASG	
Vibration Table (to handle supply tank)	BASG	
3 x 6.7 m Thermal Vacuum Chamber	BASG	X
Nitrogen Test Facility	BASG	
Acoustic Chamber	MMC/GSFC	X

Table 10-3, CONE Key Facility Requirements

BASG has a large NSTS class thermal vacuum chamber (BRUTUS) that has a working space of 5.5 m (18 ft) diameter by 7.3 m (24 ft) high which can accommodate the CONE payload for thermal/vacuum and thermal balance testing.

The large acoustic chamber required to verify CONE structural integrity is located at Martin Marietta Corporation (MMC) approximately 40 miles from BASG, and is readily available. This acoustic chamber has been used on past BASG programs and all of the required interfacing and contractual infrastructure between the two companies is in place.

10.4 PROGRAM SCHEDULE

As shown in Figure 10-1, CONE is scheduled as a three year program from authorization to proceed (ATP) to launch on the NSTS. The schedule is predicated on the use of the requirements and concept designs that result from this CONE Phase B study. This "running start" enables SRR and PDR to occur three and six months after ATP. In addition, the Phase B data enables the initiation of long-lead item component procurement approximately six months into the program.

The proposed schedule is consistent with past BASG projects of similar complexity and scope.

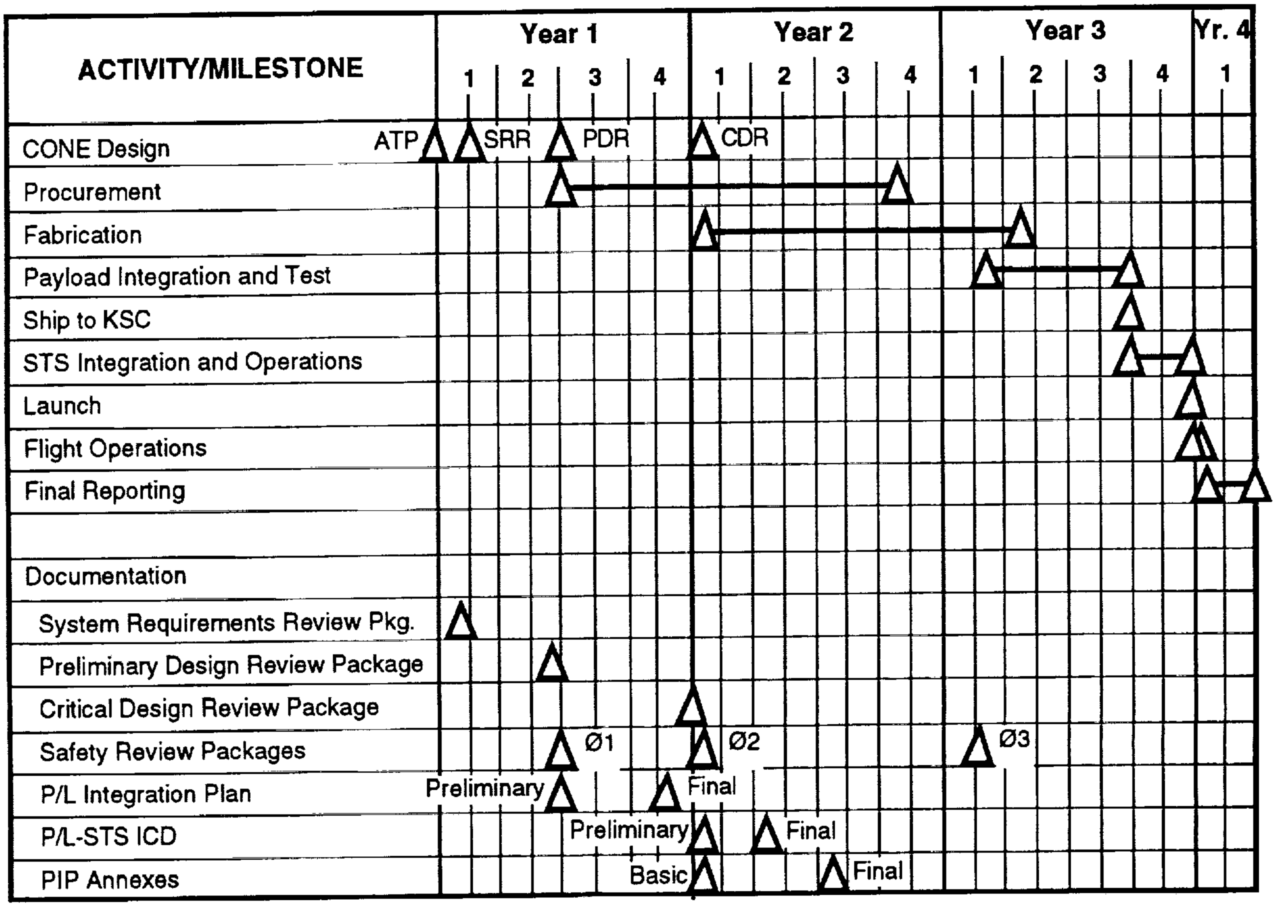


Figure 10-1, CONE Program Schedule

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16. Abstract

An improved understanding of low-gravity subcritical cryogenic fluid behavior is critical for the continued development of space-based systems. Although early experimental programs provided some fundamental understanding of zero-gravity cryogenic fluid behavior, more extensive flight data are required to design space-based cryogenic liquid storage and transfer systems with confidence. As NASA's mission concepts evolve, the demand for optimized in-space cryogenic systems is increasing. Cryogenic Orbital Nitrogen Experiment (CONE) is an attached shuttle payload experiment designed to address major technological issues associated with on-orbit storage and supply of cryogenic liquids. During its 7-day mission, CONE will conduct experiments and technology demonstrations in active and passive pressure control, stratification and mixing, liquid delivery and expulsion efficiency, and pressurant bottle recharge. These experiments, conducted with liquid nitrogen as the test fluid, will substantially extend the existing low-gravity fluid database and will provide future system designers with vital performance data from an orbital environment.

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