STS 86-0302-2A

ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM (OSCRS)

FINAL REPORT
Volume II
STUDY RESULTS

(DRD-10)

Prepared for
the
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Lyndon B. Johnson Space Center

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March 1987 Revision A

Technical changes between this revision and the original release are denoted by a black bar along the text margin. Table and figure enhancements for legibility and correction of typographical or grammatical errors have not been high lighted with a change bar.

FOREWORD

This final report of the Orbital Spacecraft Consumables Resupply System (OSCRS) study was prepared by the Space Transportation Systems Division of Rockwell International for the National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas, in compliance with the requirements of Contract NAS9-17584, CDRL No. MA 1023T.

In response with the CDRL instructions, this report is submitted in three separately bound volumes:

Vol. 1. Executive Summary

Vol. 2. Study Results

Vol. 3 Program Cost Estimate

Further information concerning the contents of this report may be obtained from R. Bemis, Study Program Manager, telephone (213) 922-3805, Downey, California.

STATEMENT OF WORK TASK TO DRD-10
REPORT CROSS REFERENCE INDEX

The contract statement-of-work tasks were performed in general accordance with the study plan per STS-86-0109. Table A provides a cross-reference index between the S-O-W subtasks and the reporting paragraphs of this document.

TABLE A

STATEMENT OF WORK/DRD-10 REPORT
CROSS REFERENCE INDEX

S.O.W. Subtask		Description	DRD-10 Section No.
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2.1		Trade Studies	
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	c)	Docking Provisions	3.1.1.3
	d)	Automated vs. Crew EVA	3.1.1.4
	e)	Interface Requirements and Configuration	3.1.1.5
	f)	Data Management Optimization	3.1.1.6
	g)	System Design for Various Receiver Tanks	3.1.1.7
	h)	Instrumentation Requirements	3.1.1.8
	i)	Fluid Gauging Accuracy Requirements	3.1.1.9
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	a)	Hardware Availability	3.1.2.1
	b)	Fluid Capacity and Tankage Sizing	3.1.2.2
	c)	Quantity Gauging Techniques	3.1.2.3
	d)	Variable Supply Pressure vs. Flow Control	3.1.2.4
	e)	Pump vs. Pressure Fed Resupply	3.1.2.5
	f)	Receiver Propellant Tank Venting Techniques	3.1.2.6
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	h)	Thermal Control Techniques/Hardware	3.1.2.8
	i)	Optimization OSCRS Control	3.1.2.9
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2.1.3		Operational Trades	
	a)	Launch Site Operations	3.1.3.1
	b)	Landing Site Operations	3.1.3.2
	c)	GSE and Facility Operations	3.1.3.4
	d)	On-Orbit Operations	3.1.3.4
	e)	ASE	3.1.3.5
	f)	Contingency Planning	3.1.3.6

TABLE A
(continued)

STATEMENT OF WORK/DRD-10 REPORT
CROSS REFERENCE INDEX

S.O.W. Subtask		Description	DRD-10 Section No.
2.2		Preliminary System Design	
	a)	Structural Definition	3.2.1
	b)	Fluid System	3.2.2
	c)	Avionics Subsystem	3.2.3
	d)	Thermal System	3.2.4
	e)	Instrumentation and Signal Conditioning	3.2.5
	f)	Weight and Power Requirements	3.2.6
	g)	Subsystem Performance Predictions	3.2.7
	h)	Preliminary Safety/Hazard Analysis	3.2.8
2.3		Draft EIS/Program Plan/Cost Estimate	
2.3.1/4.2		Draft EIS	STS 86-0272
2.3.2/4.3		Draft Program Plan	STS 86-0271
2.3.3/4.4		Preliminary Cost Estimate	STS 86-0270
3.0/5.0		Conceptual Bipropellant System Design	4.0
3.1		Trade Studies	4.1
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3.3		Commonality Assessment	4.3
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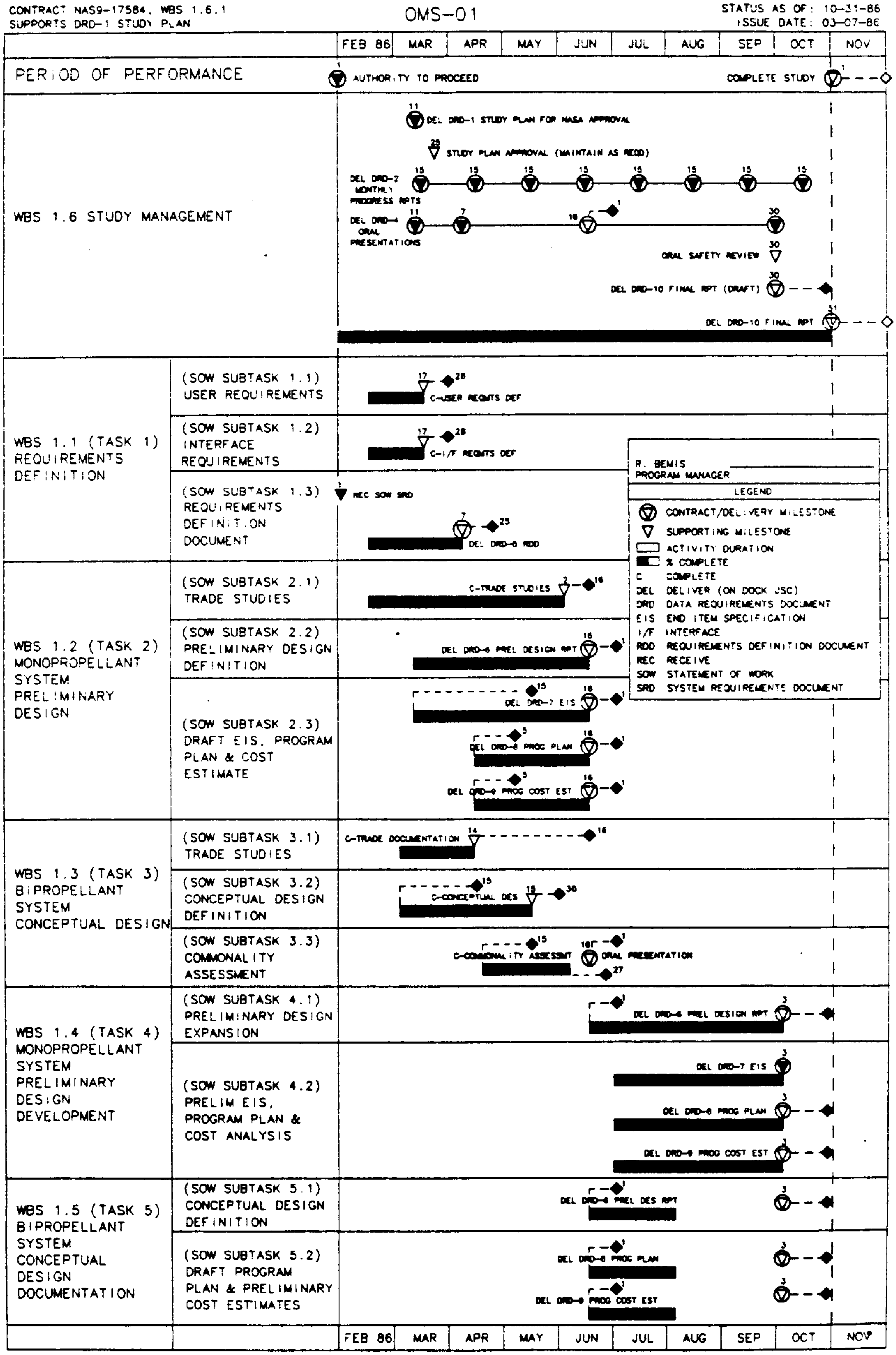
1.0 Introduction

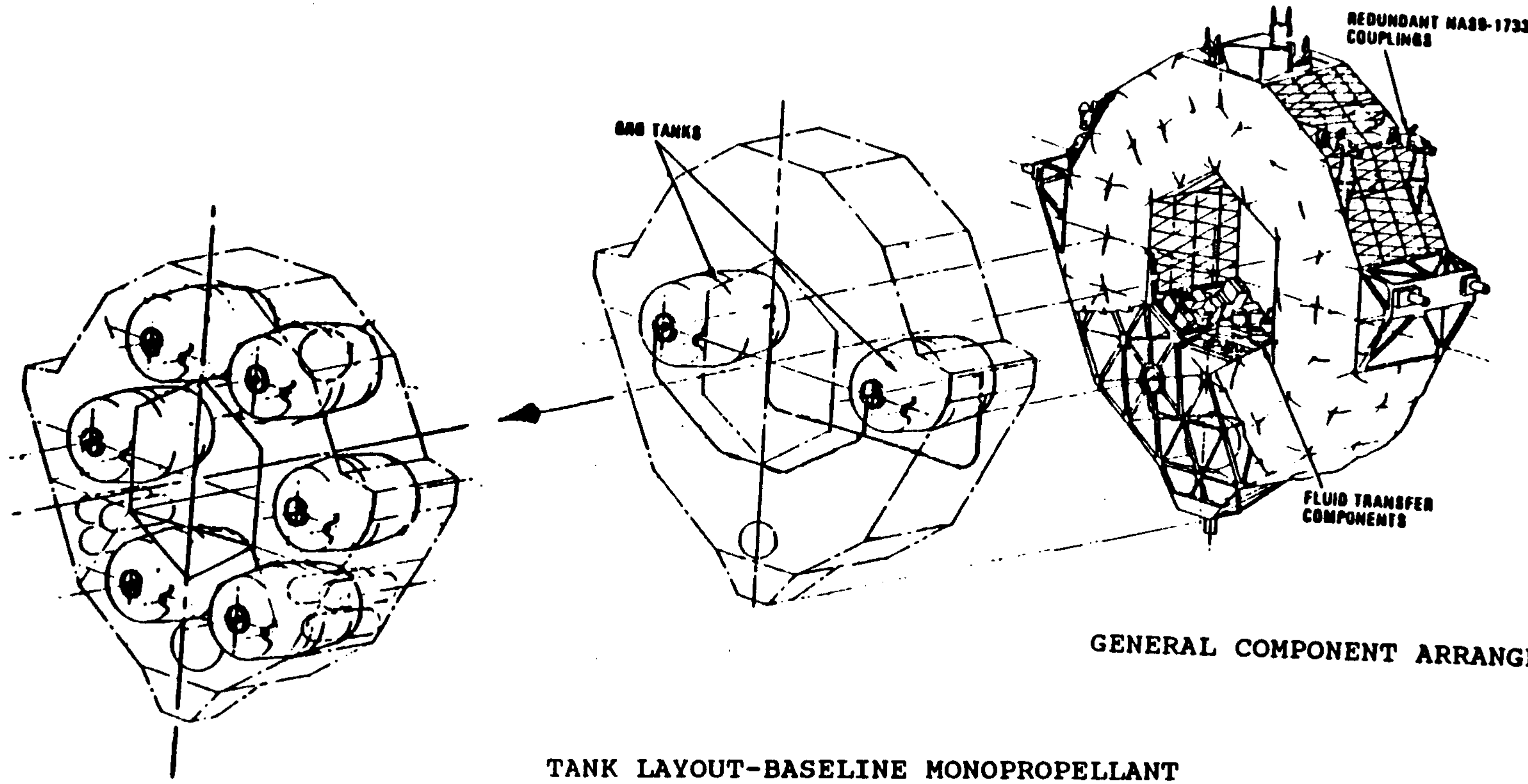
This report summarizes the results of the Orbital Spacecraft Consumables Resupply System (OSCRS) study performed by Rockwell International for the National Aeronautics and Space Administration (NASA) at Johnson Space Center (JSC) under contract NAS9-17584. The study was performed in accordance with the study plan contained in STS 86-0109 to the schedule depicted in Figure 1.0-1. The study consisted of two substudies which culminate in a monopropellant system preliminary design and a bipropellant system conceptual design.

This volume summarizes the primary conclusions resulting from the trade studies and analyses performed in three different categories. These categories were: System Requirements Trades; Hardware/Software Trades; and Operational Trades. The results of these trades define the concept of an earth-storable OSCRS tanker; provide recommendations for further concept development as well as development and fabrication of a production unit to be deployed; identify ground support equipment and facilities which are necessary to support the OSCRS resupply scenarios; define a preliminary monopropellant system design; document a conceptual bipropellant system design; and address the operational aspects of the GRO resupply mission.

The objective of this study was to establish an earth storable fluids tanker concept which satisfies the initial resupply requirements for the Gamma Ray Observatory (GRO) for reasonable front end (design, development and verification) cost while providing growth potential for foreseeable future earth storable fluid resupply mission requirements. The mutual achievement of these objectives becomes possible with development of a modularized tanker concept which is a hybrid of a dedicated GRO tanker and a generic earth storable propellant tanker. The hybrid concept is designed (sized) for the maximum foreseeable earth storable mission requirements but will be initially developed only for the GRO mission requirements. This keeps front end costs down while limiting the tanker weight penalty for low capacity resupply mission such as GRO to essentially primary structure weight differences. The concept which evolved is defined in Figure 1.0-2.

Figure 1.0-1
OSCRS
MASTER SCHEDULE
OMS-01





GENERAL COMPONENT ARRANGEMENT

TANK LAYOUT-BASELINE MONOPROPELLANT

TANK LAYOUT-BASELINE MONOPROPELLANT PLUS GROWTH
(SIX TANK MONO- OR BI-PROPELLANT TANKER)

FIGURE 1.0-2 HYBRID EARTH STORABLE PROPELLANT TANKER CONCEPT

2.0 Analysis/Trade Study Results

The OSCRS study consisted of five statement of work tasks. These tasks were performed in accordance with the study plan contained in STS 86-0109 to the schedule depicted in Figure 1.0-1. The five study tasks were interrelated as shown in Figure 2.0-1 to achieve a final objective of defining a cost and weight effective earth storable propellant tanker which can be used to resupply spacecraft into the 21st Century. The following discussions summarize the result and conclusions reached in each study task phase.

2.1 User Requirements Definition

User requirements were examined to determine the type and volume of OSCRS services required. Of 105 survey questionaires sent to potential users during May to November 1985, 36 responses were received of which 21 were positive. Of these 9 were U.S. Government users (4 from Goddard Space Flight Center, 4 from the U.S. Air Force, and 1 from Ames Research Center). Seven U.S. Companies and 5 foreign governments also responded positively. In addition, data from the existing Rockwell data base and business contacts with potential resupply candidates were used. The results are shown in Figure 2.1-1 and 2.1-2 and Tables 2.1-1 and 2.1-2.

The above resupply requirements indicate a need for a fully developed earth storable OSCRS by 1993. These requirements drive the design to a maximum of 7000 lbs of propellant.

The GRO is the only program currently committed to resupply, therefore, the initial tanker should be specifically developed toward satisfying the following GRO requirements:

- o Resupply up to 2484 lbs. of N2H4 using ullage recompression
  - o No pressurant resupply is required
- o Provide a berthing interface which is compatible with the Flight Support System (FSS) A' docking latch assembly
- o Use the GFE standard fluid interface coupling developed under Contract NAS 9-17333.

The initial OSCRS should be capable of growth to resupply hydrazine, pressurants and other fluids to spacecraft other than GRO. Early potential users include commercial, NASA and DOD satellites. The system should be capable of evolving to serve the requirements of the bipropellant user community also. The OSCRS fluid system must be adaptable to the various propellant management devices used in the variety of spacecraft needing resupply.

The above goals and mission model form the basic ground rules under which the system was developed.

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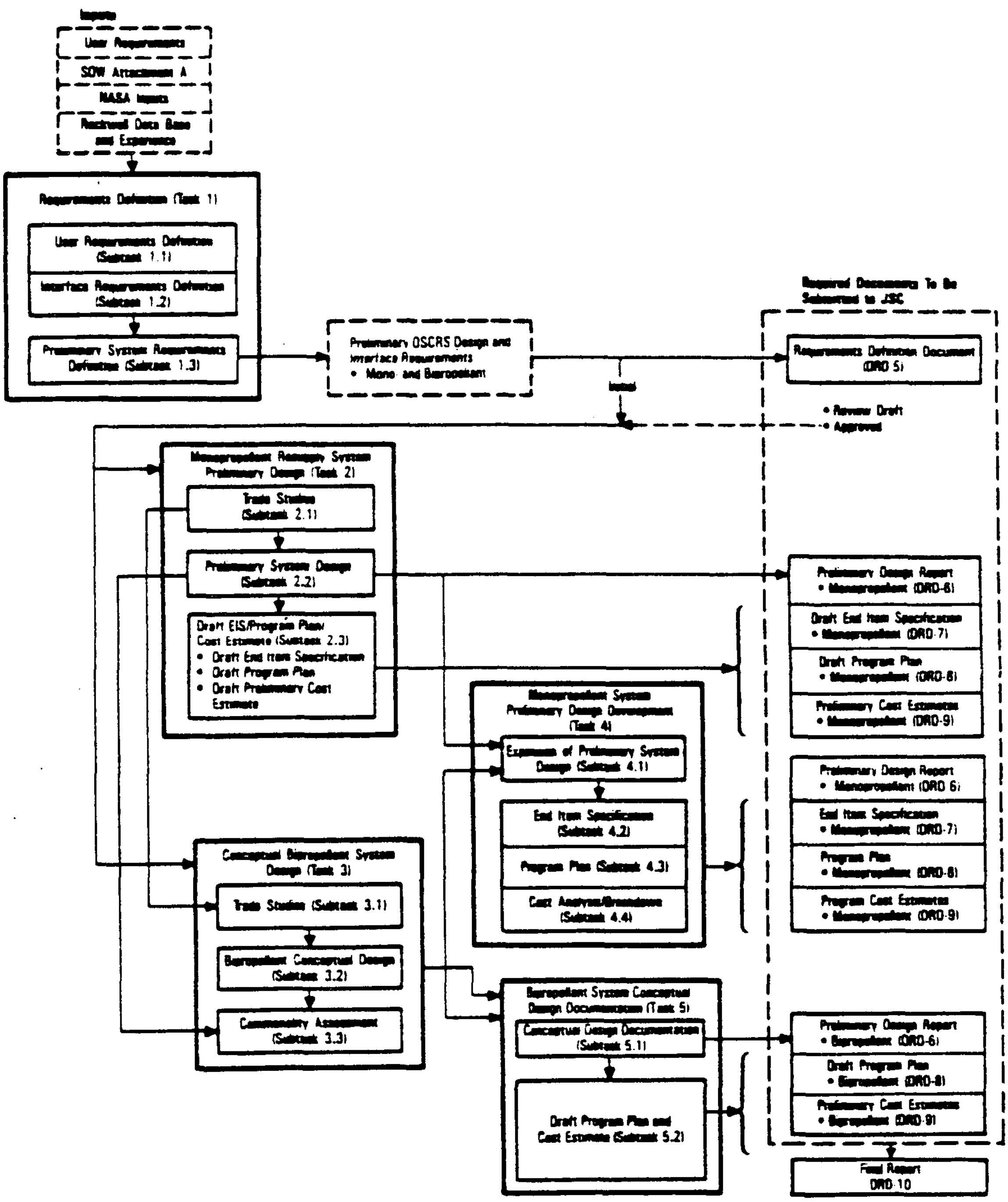
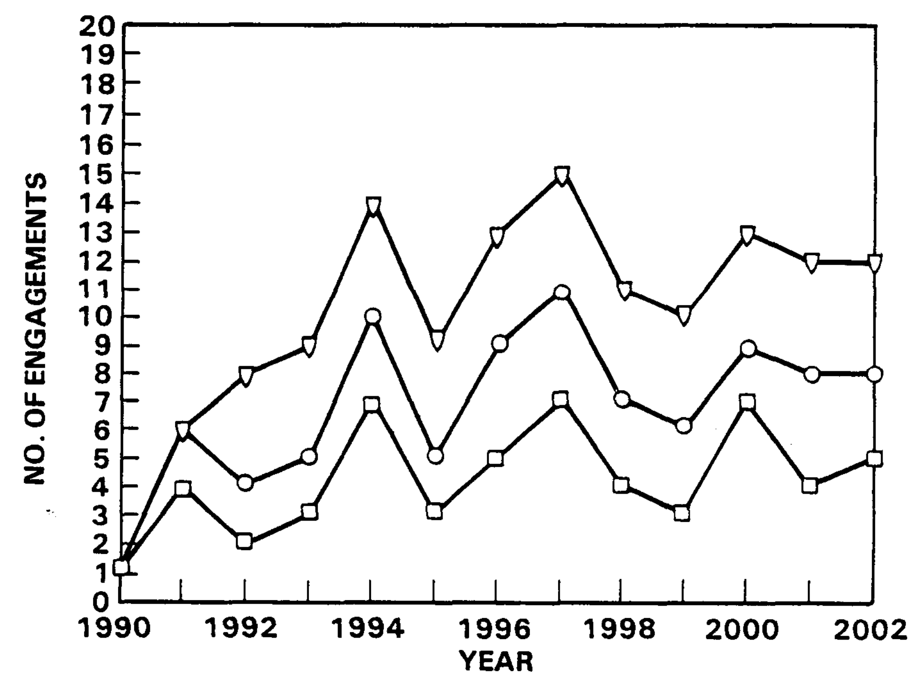


FIGURE 2.0-1 *OSCRS Study Task Flow Diagram*

TABLE 2.1-1 *Monopropellant user quantities and resupply engagements (1990-2002)*

Program	Nominal Life (yr)	Mass (lb)	Resupply Quantity (lb)	Fluid Type	Pressurant	Altitude (nmi)	Inclination (deg)	Access(1)	Year 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
GRO	2.25	33,000	2,484	N_2H_4	None	243	28.5	X	0	(1) 2,484	0	0	(1) 2,484	0	0	0	0	0	0	0	0
Space Station	N/A	TBD	2,300	N_2H_4	TBD	270	28.5	X	0	0	0	(U) 7,913	(U) 4,797	(U) 2,974	(U) 2,660	(U) 2,660	(U) 2,660	(U) 2,660	(U) 2,660	(U) 5,000	(U) 2,660
EOS	10	22,030	1,800	N_2H_4	GHe, GN_2	381	99.8	*	0	0	0	0	0	0	(1) 1,800	(1) 1,800	(1) 1,800	(1) 1,800	(1) 1,800	(1) 1,800	(1) 1,800
Eureca (ESA)	7	4-7,000	1,000	N_2H_4	None	160	28.5	X	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000	(1) 1,000
SMM	10	6,600 (with payload)	551	N_2H_4	None	216	28.5	X	0	0	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551	(1) 551
Landsat	3	4,400	510	N_2H_4	GN_2	381	98	*	0	0	0	0	(1) 510	0	(1) 510	0	(1) 510	0	(1) 510	0	(1) 510
Spot F/O (F)	6	4,000	500	N_2H_4	GHe	450	98.7	*	0	(1) 500	0	0	(1) 500	0	0	(1) 500	0	0	0	(1) 500	0
TOPEX	3-4	6,600	300	N_2H_4	None	720	63.4	*	0	0	0	(1) 300	0	0	(1) 300	0	0	0	0	0	0
ERS-1 (J)	2	3,100	200	N_2H_4	GHe	381	98.7	*	0	0	0	0	0	0	0	(1) 200	0	0	(1) 200	0	0
ERS F/O (ESA)	3	2,200	100	N_2H_4	None	450	98.7	*	0	0	0	0	(1) 100	0	0	(1) 100	0	0	(1) 100	0	(1) 100
N ROSS	3	10,000	70	N_2H_4	GN_2	450	98.7	•, *	0	0	0	(1) 70	0	0	(1) 70	0	0	0	0	0	0
DOD D	2-3	1,800	70	N_2H_4	GN_2	450	98.7	+, *	0	0	0	0	0	(1) 70	0	(1) 70	0	(2) 140	0	(2) 140	0

(1) Indicates STS accessibility as current vehicle is designed:
X — Accessible
* — Accessible with OMV
\+ — Accessible if vehicle lowers altitude with on-board propellant
Numbers in parentheses above propellant quantities indicate number of events per year; (U) indicates unknown



∇ SPACE STATION ○ DOD
□ CIVILIAN MAINTENANCE/CONT

Figure 2.1-1. PREDICTED EARTH STOREABLE PROPELLANT TANKER IN-BAY RESUPPLY ENGAGEMENTS BY COMMUNITY SEGMENT

TABLE 2.1-2 *Bipropellant user quantities and resupply engagements (1990-2002)*

Program	Nominal Life (yr)	Mass (lb)	Resupply Quantity (lb)	Fluid Type	Pressurant	Altitude (nmi)	Inclination (deg)	Access(1)	Time												
									1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
DOD A	1-2	25,000	7,000	N_2O_4 / A-50	Unknown	125	96.5	X	0	(2) 14,000	(1) 7,000	(1) 7,000	(2) 14,000	(1) 7,000	(1) 7,000	(1) 7,000	(1) 7,000	(1) 7,000	0	(2) 14,000	(1) 7,000
DOD C	3-5	32,000	7,000	MMH/NTO	Unknown	400	65	•,*	0	0	0	0	0	0	(1) 7,000	(2) 14,000	(1) 7,000	0	(1) 7,000	0	(1) 7,000
DOD B	2-3	25,000	6,000	MMH/NTO	Unknown	216	97	X	0	0	(1) 6,000	0	(1) 6,000	0	(1) 6,000	0	(1) 6,000	0	(1) 6,000	0	(1) 6,000
Radarsat (C)	5	5,300	4,000	MMH/NTO	GHe	540	99.5	*, +	0	0	0	0	0	(1) 4,000	0	0	0	0	0	0	0
Space Station	N/A	TBD	3,200	MMH/NTO	TBD	270	28.5	X	0	0					(1) 3,200	(1) 3,200	(1) 3,200	(1) 3,200	(1) 3,200	(1) 3,200	(1) 3,200
OMV (Low I)	N/A	N/A	4,900	MMH/NTO	GN_2	TBD	TBD	TBD	0	0	1,774	1,421	2,492	2,229	2,146	2,426	1,987	1,904	4,908	2,712	6,413
Polar Platform	N/A	N/A	6,400	MMH/NTO	TBD	405/216	98.25	+ (150 nmi)							(1) 6,400		(1) 6,400		(1) 6,400		(1) 6,400

(1) Indicates STS accessibility as current vehicle is designed:
X — Accessible
* — Accessible with OMV
+ — Accessible if vehicle lowers altitude with on-board propellant
Numbers in parentheses above propellant quantities indicate number of events; (U) indicates unknown

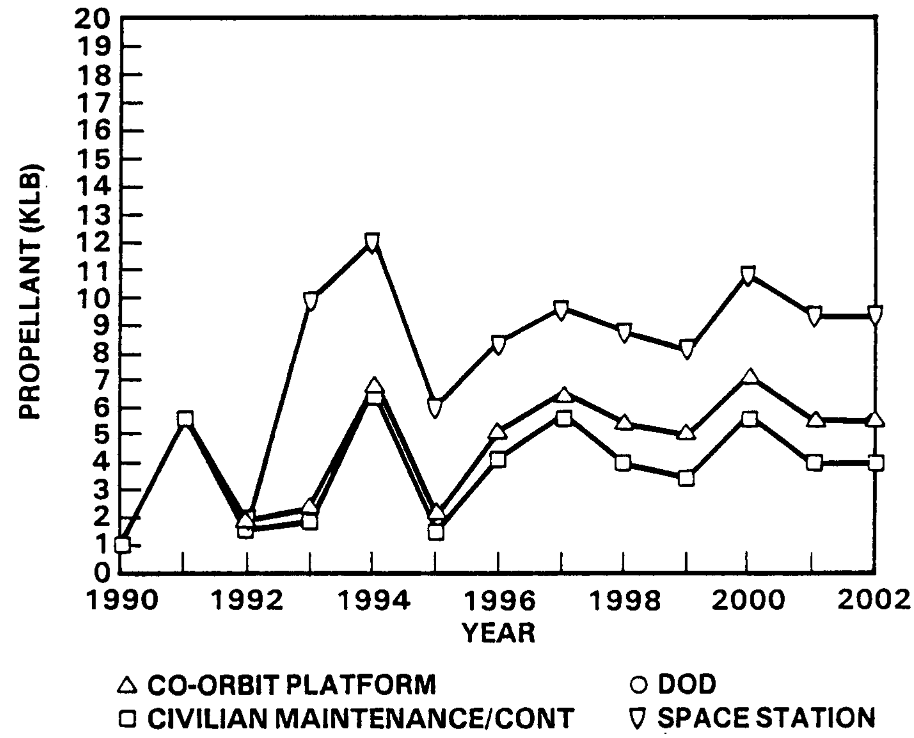


FIGURE 2.1-2 HYDRAZINE (N_2H_4) MONOPROPELLANT ORBITAL RESUPPLY REQUIREMENTS BY COMMUNITY SEGMENT

2.2 Orbiter/Ground Facilities/Crew Interface Requirements Definition

The Orbiter/ground facility/crew interface requirements definition is based on the results of the various trade studies discussed in paragraph 3.1 and subsequent. The interface requirements are defined in detail in the OSCRS End Item Specification, published as DRD-7 report number STS 86-0272.

2.3 Preliminary System Requirements Definition

The preliminary system requirements definition integrates user requirements definition and Orbiter/ground facilities/crew interface definition, to define and identify the following:

- The composite set of preliminary requirements
- Trade studies and analysis for generic monopropellant OSCRS
- Trade studies and analysis for generic bipropellant OSCRS
- Preliminary recommendations for future reservicing requirements and interface controls
- Design requirements that could impact system design (i.e., long lead times)
- Spacecraft elements for standardization
- Satellite certification and design requirements

The results of the preliminary system requirements definition were documented in accordance with the requirements of DRL T-2008 as DRD-5, Requirements Definition Document (RDD). The DRD-5 RDD was used as the basis for the development of the OSCRS End-Item-Specification discussed in paragraph 3.3 of this report.

3.0 Monopropellant Resupply System Preliminary Design

The development of the preliminary hydrazine monopropellant resupply system design includes incorporation of trade study results with initial system design considerations. Results of this preliminary design effort provide the basis for the development of the End-Item-Specification and Program Plan.

3.1 Trade Studies

Trade studies for the preliminary design are divided into three general areas. These are System Requirements Trades, Hardware/Software Trades, and Operational Trades. The results of these studies support the selection and optimization of the OSCRS monopropellant and bipropellant system characteristics, subsystems, components, software, and generic resupply operations.

3.1.1 System Requirements Trades

The trade studies in this area focus on design decisions and optimizations from a systems viewpoint. Emphasis is placed on system design features for accomplishing the GRO resupply mission while striving for growth potential as a major design objective.

3.1.1.1 Generic or Dedicated System Designs

An early study was made to determine if the tanker should be dedicated to a specific mission requirement (such as GRO) or generic to a variety of resupply mission requirements.

The study of the relative suitability of a dedicated or generic tanker shows that a hybrid concept is the most attractive (Figure 3.1.1.1-1). A hybrid tanker has the same structure as a generic tanker, and possesses the space attachment points required for the extra tanks and/or components desired in a generic tanker, but these components are not installed in the initial tanker system design. The components would be added as required for a particular mission or permanently attached for new growth user requirements. It also possesses a modular interface with the satellite that can be changed as required to interface structurally, electrically, and with the fluid disconnects of any satellite.

Justification for selecting a hybrid rather than a dedicated tanker stems from a large increase in propellant capacity, from 2450 lbs to 7000 lbs, for a small increase in structural weight and relatively low initial development, qualification and production costs to meet the GRO resupply mission requirements. The influence of added fluid capacity on basic structure weight was eventually shown to be as small as 87 lbs to increase the capacity from 2450 lbs to 8545 lb of resupply fluids (Table 3.1.1.1-1).

3.1.1.2 Redundancy Levels Required

Redundancy levels required for the monopropellant OSCRS are discussed in detail in paragraph 3.1.2.11 (Redundancy Management and Health Monitoring).

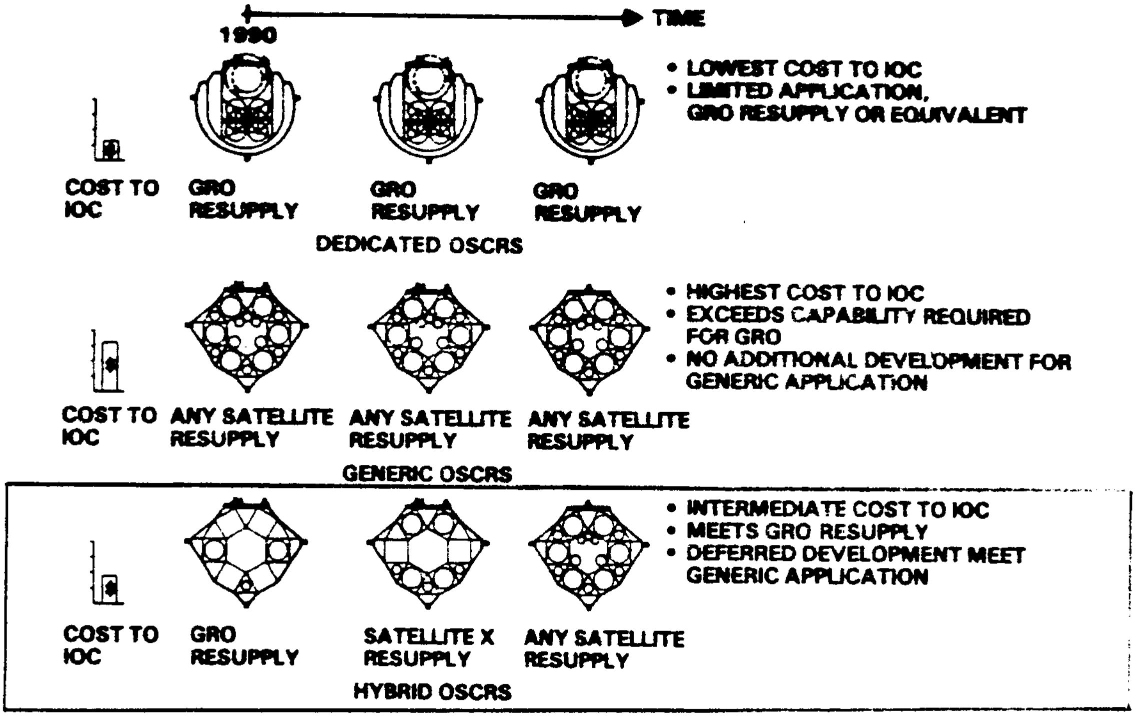


Figure 3.1.1.1-1 Hybrid OSCRS Concept

Table 3.1.1.1-1 Primary Structures Weight vs Fluid Carrying Capacity

TANKER CONFIGURATION	FLUID WEIGHT (LB)	STRUCTURE* WEIGHT (LB)	Δ WEIGHT (LB)
2 TANK MONOPROPELLANT	2,450	457	BASELINE
4 TANK MONOPROPELLANT	4,900	479	22
6 TANK MONOPROPELLANT	7,350	536	79
6 TANK BIPROPELLANT	8,545	544	87

*STRUCTURE WEIGHTS INCLUDE CRADLE, LONGERON, & KEEL SUPPORTS

3.1.1.3 Docking

For OSCRS operations, berthing (docking) is to be accomplished using the controlled rates of the Remote Manipulator System (RMS) assuring a soft initial interface contact with little or none of the kinetic energy absorption associated with conventional docking speeds and masses.

Although the Gamma Ray Observatory requires the use of the Flight Support System (FSS) latches (installed as shown in Figure 3.1.1.3-1), the latch interface must provide for attachment of future S/C berthing and further studies conclude that the concept of a flat unobstructed plane best satisfies this requirement. The recommended design of the GRO/OSCRS berthing interface (FSS latches) support structure provides a flat plane at location Z_O 475.141 and provides a simple, clean and convenient interface plane for attaching to different berthing concepts required by future S/C requirements.

As an aid in controlling the lateral displacement of the GRO spacecraft during the mating to the tanker FSS latches, a standard grapple target has been affixed to the mating side of the GRO. The target coordinates are: the target face (Z) GRO = -76.00; the target shaft centerline is Y = 21.54, X = 12.44. Using a mirror set at 45^o,adequate visual reference in the Z axis should be available via a CCTV to the RMS operator located in the aft flight deck (AFD), Figure 3.1.1.3-2. Operation of the Orbiter RCS system may be used to impart separation momentum without addition of redundant mechanisms. The incorporation of spring-induced separation forces may also be considered a viable emergency option although care must be taken to assure accuracy in the separation flight path to provide adequate spacecraft/Orbiter appendage clearances. Control of separation velocities to limit the "G" forces acting on spacecraft equipment must also be taken into account. In concert with NASA's wish to avoid using mechanisms to impart separation velocities between the spacecraft and OSCRS/Orbiter, use of the RMS or RCS, is baselined.

Further design studies included evaluation of pyro-actuated frangible bolts to secure each latch assembly to its mounting bracket. Presently envisioned is two frangible bolt assembles per latch assembly as shown in Figure 3.1.1.3-3.

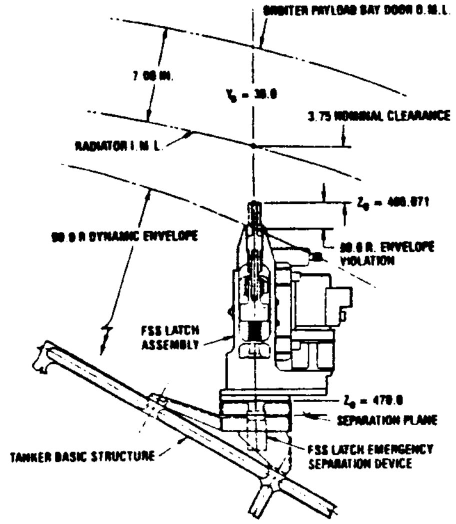
3.1.1.4 Automated vs Crew

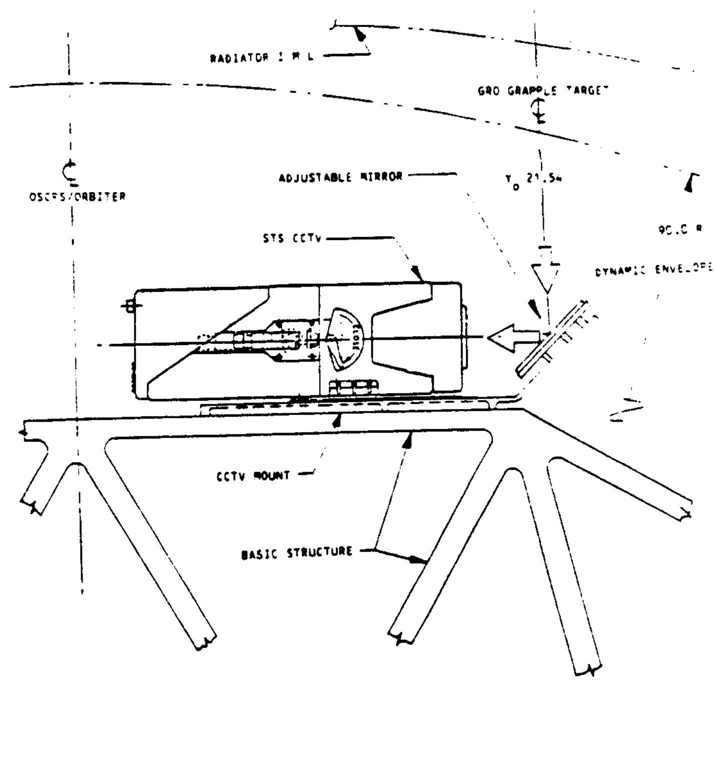
It has been dramatically demonstrated during the STS Orbiter operations that the capabilities and flexibility by the EVA crew were essential to the success of several satellite retrieval missions. When a critical function can be safely and dependably performed on-orbit without the risk and time delays associated with EVA activities, remote/automated functions should certainly be considered in their place.

EVA is particularly valuable in performing visual inspections for damage, leakage or malfunctions. The EVA crew can quickly and comprehensively assess the condition of hardware. However, EVA operations in space need not be expanded at the expense of developing remote, automatic equipment, specifically fluid/pressurant transfer (resupply) umbilicals. Functions that, while initially appearing to "require" EVA operations, can be developed to be performed automatically, either for the initial OSCRS concept or in future configurations.

FIGURE 3.1.1.3-1

FSS Latch/Payload Bay Door Clearance

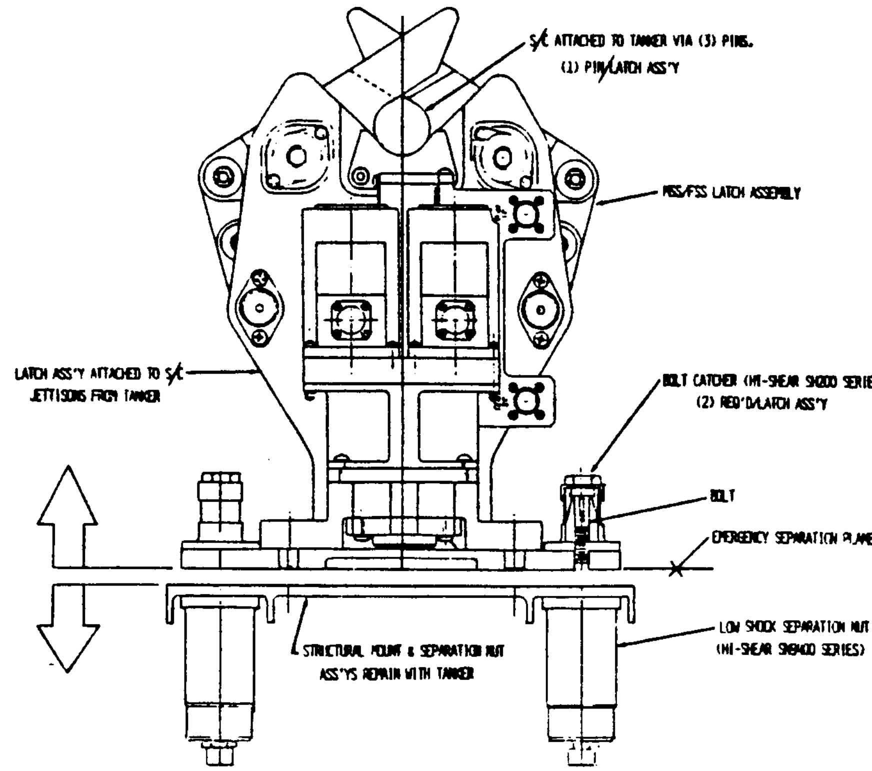


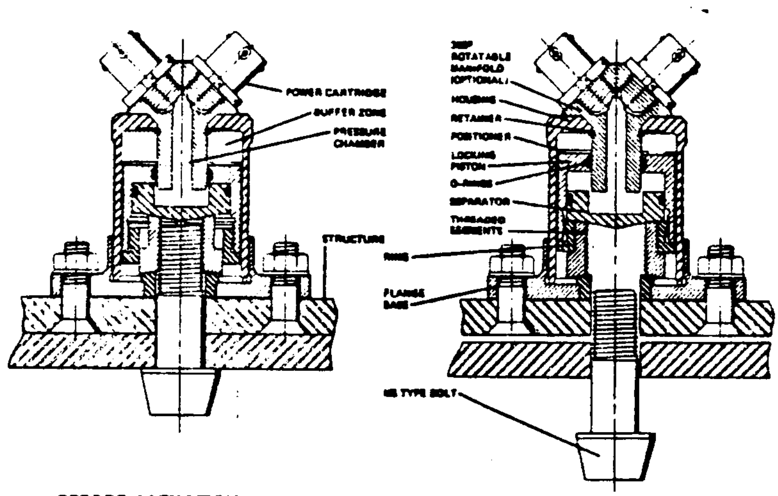


CCTV TRACKS GRO GRAPPLE TARGET

FIGURE 3.1.1.3-2

FIGURE 3.1.1.3-3 BERTHING LATCH ASS'Y EMERGENCY SEPARATION





BEFORE ACTUATION

1. Bolt is threaded fully into nut segments.
2. Nut segments are fully supported by locking piston.
3. Structure joint is clamped up to tension rating of bolt.

AFTER ACTUATION

1. Gas pressure acts on locking piston, moving it away from bolt to unlock threaded segments.
2. Segments displace radially away from bolt.
3. Bolt ejects and structure joint separates.

Aside from possible crew exposure to hazardous chemicals during preparations for and after propellant delivery, it seems to make the most sense to limit EVA activities to those functions that, after thorough study, mandate the presence of crew members. Where possible, automated fluid and gas umbilicals should be developed. Particularly in future resupply missions when transferring bipropellants will be required, EVA should be limited to supportive observation and contingency efforts only.

Man's proven ability in space to observe, assess, and improvise has been proven and needs to be utilized and expanded, but not extended to marginal or unduly hazardous operations that can be automated. Since the NAS9-17333 standard refueling coupling has been developed for the refueling of hydrazine for the GRO S/C, and since independent timeline operations have been identified as well within the six-hour time limit on EVA's (including contingency) the first usage of the OSCRS should include the EVA activities as planned. NASA should initiate development of a remote - automatic system as a standardized interface to deliver all future consumables.

3.1.1.5 OSCRS-To-Orbiter Avionics Interface

The avionics interfaces between the Orbital Spacecraft Consumables Resupply System (OSCRS) and the STS Orbiter must comply with applicable requirements of JSC 07700 Vol XIV "Space Shuttle System Payload Accommodations", and to Vol XIV attachment "ICD 2-19001, Shuttle Orbiter/Cargo Standard Interfaces".

The following paragraphs identify the key OSCRS Avionics/Shuttle Orbiter/Cargo Standard interfaces that will be applicable at the OSCRS module. These interfaces, which are shown on Figure 3.1.1.5-1, are also described in appendix A of the End Item Specification submitted under this contract.

AVIONICS COMMAND & DATA INTERFACES

The orbiter avionics system provides payload command and data interfaces that support requirements for transferring command data from the Orbiter to the OSCRS and for transmitting payload performance and status data to the orbiter for on-board use and/or relaying telemetry data to the ground.

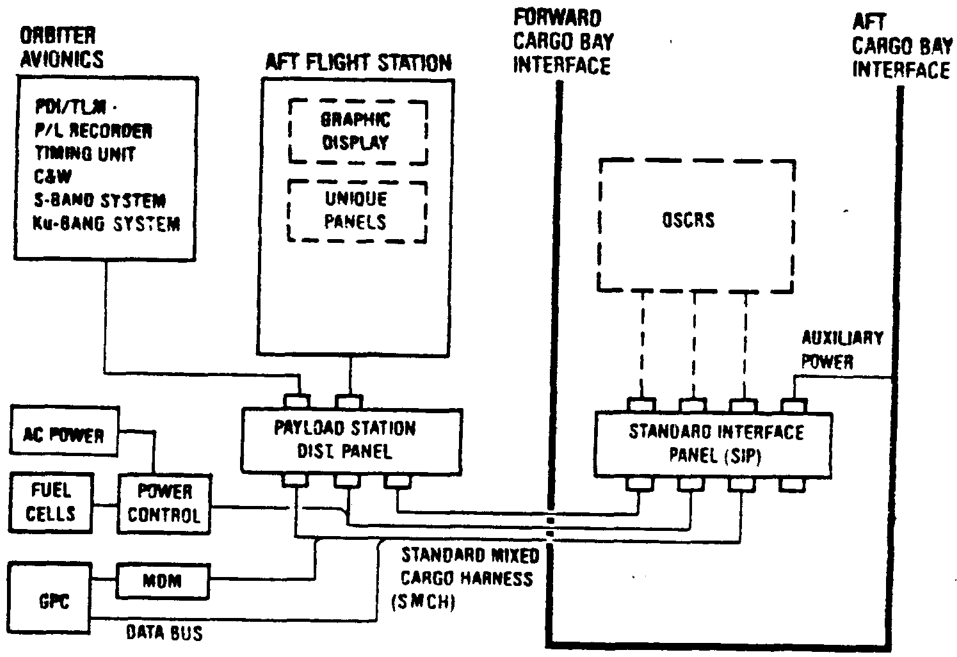
ELECTRICAL POWER REQUIREMENTS

The OSCRS shall require Orbiter-furnished DC and AC power during flight and ground operations. During flight, 28-volt DC power shall be furnished by the Orbiter fuel cell power plant system, and 400 Hz AC power shall be furnished by the Orbiter inverters.

The electrical power distribution and control concept shown on Figure 3.1.1.5-1B would be compatible with the orbiter power system, as required for an STS resupply system, and would utilize circuit and hardware concepts now employed on the orbiter in order to minimize development costs and risks on future resupply avionics system. Individual crew activated switches in the aft flight deck would be used to apply power to various boxes, using remote power controllers (RPC's) in the power control assembly (PCA) boxes. Rotary switches would be used for arming and safing circuits, as shown.

FIGURE 3.1.1.5-1A

OSCRS to Orbiter Avionics Interfaces

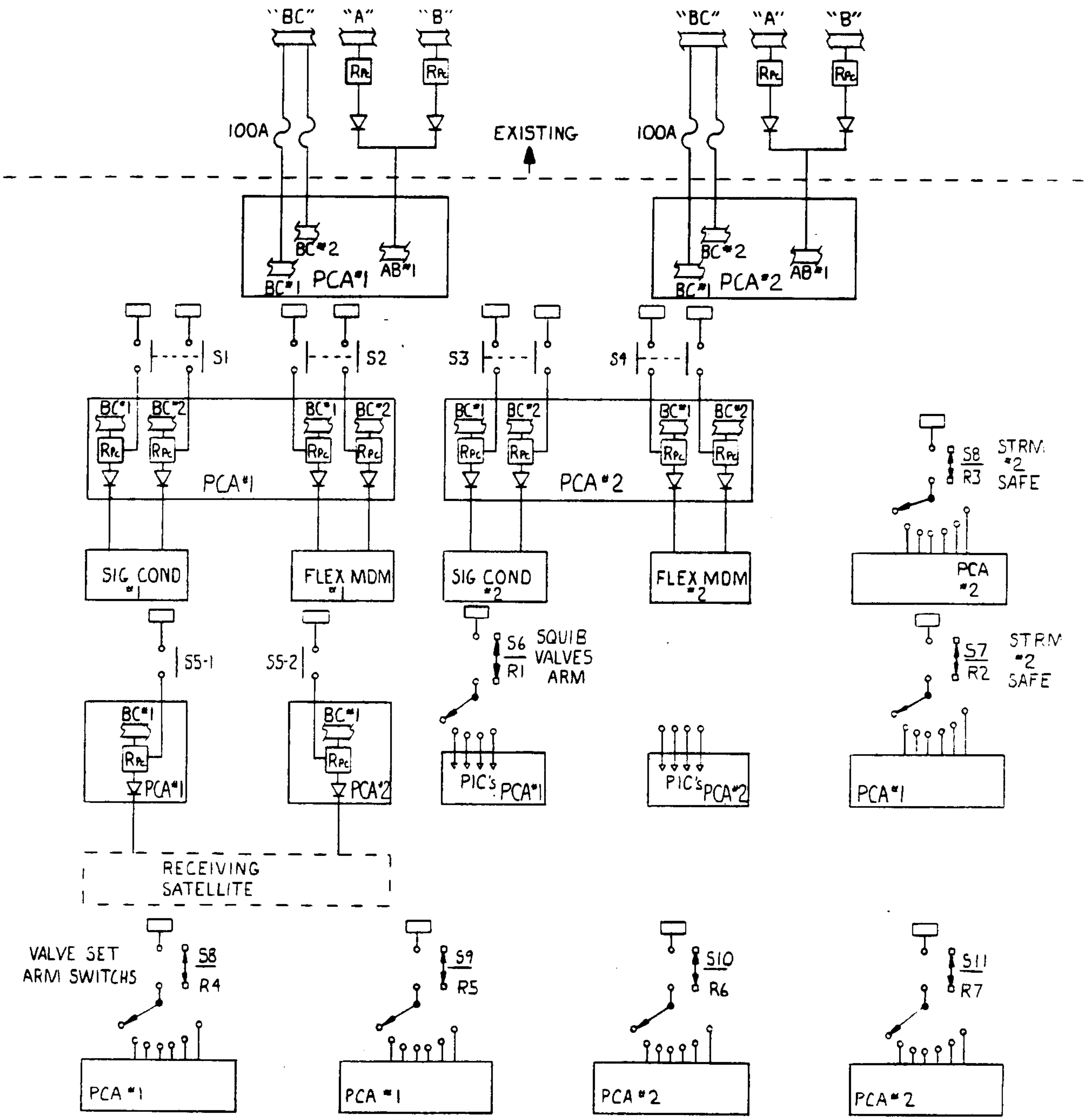


PHYSICAL INTERFACE (ELECTRICAL)

Standard payload electrical interface accommodations are available only at the cargo element end of Standard Mixed Cargo Harness (SMCH) cables in the cargo bay. Other electrical interfaces are not directly available to cargo elements, but non-standard cables to the cargo element(s) can be provided from these interfaces. Connector and pin assignments definition of the majority of these accommodations are given in Section 13.0 of ICD 2-19001.

Standard Interfaces Panels (SIP), located on the port and/or starboard sides of the Cargo Bay, will provide interface for the Standard Mixed Cargo Harness (SMCH), add-on black boxes, unique connector panels, structural support and clamps for cables. The relationship of the SIP to the cargo element within the Cargo Bay will be as defined in Section 13.0 of ICD 2-19001.

FIGURE 3.1.1.5-1B POWER DISTRIBUTION CONCEPT



AVIONICS SUBSYSTEM/COMPONENT INTERFACES

Orbiter avionics services that support OSCRS mission requirements for on-board control and data handling, and for command and data exchanges with the ground, include the following subsystem and component interfaces. These requirements are in addition to those for electrical power and the physical interfaces presented elsewhere.

- Payload Data Interleaver (PDI)
- Payload Recorder
- Data Bus
- Multiplexer/Demultiplexer (MDM)
- Caution and Warning System
- Master Timing Unit
- GPC Software

AFT FLIGHT DECK PAYLOAD STATION INTERFACES

A general arrangement of the aft flight deck paylaod station displays and controls is shown in Figure 3.1.1.5-2. The OSCRS dedicated display and control panels and GRID computer shall be installed as shown.

3.1.1.6 Data Management Optimization

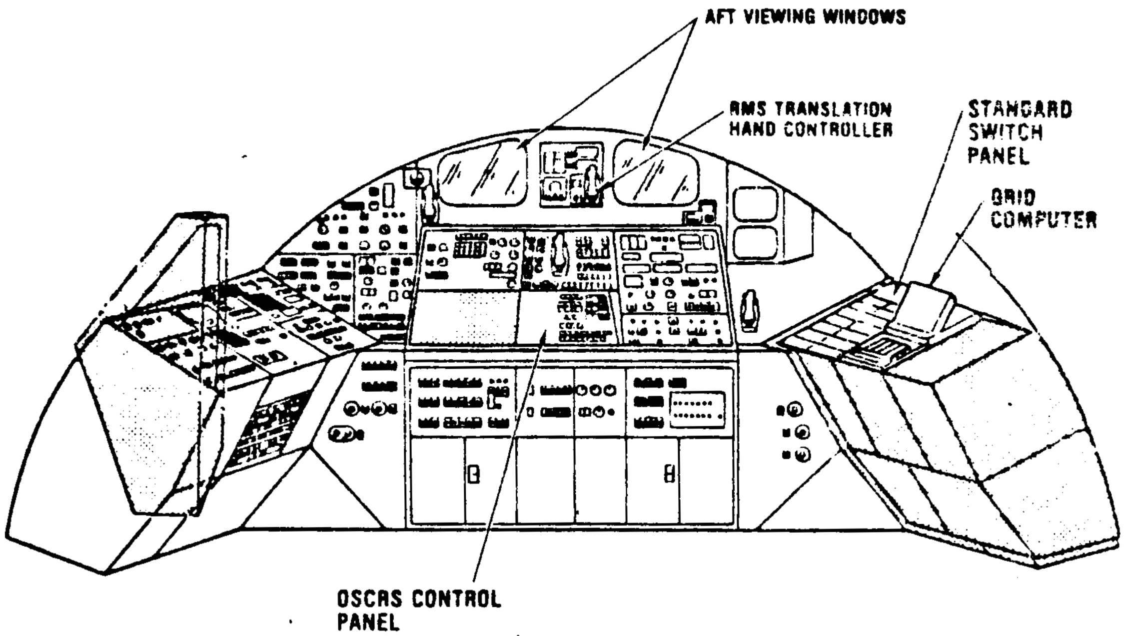
A study was conducted to define an optimized standard data management system concept that would accommodate the extensive data requirements changes that can be expected to occur when OSCRS mission objectives change from mission-to-mission. Such changes will include changes in fluid types and quantities, changes in tank and component configurations, different satellite interfaces and new procedures. The OSCRS data management concept must support incorporation of hardware and software changes with a minimum cost and schedule impact.

A key requirement driving the data management concept is that the OSCRS avionics system must be two failure tolerant to provide critical pressure, temperature, flow and valve position data to the crew. This requirement can only be satisfied by incorporating triple redundancy in the avionics data system. The data concept baselined by Rockwell for a three-string data system would satisfy the stated failure tolerance requirements.

The major challenge of the Data Management Optimization Study was to define the concept for preparing mission-unique software that must be developed and verified for each different resupply mission. Each new mission will have unique measurement requirements because of different fluids being handled, different valve and tank configurations, new receiving satellite interfaces and new sequences for the resupply mission and for contingencies, such as safing.

FIGURE 3.1.1.5-2

ORBITER INTERFACES LAYOUT OF AFD TO SUPPORT OSCRS OPERATIONS



An optimized concept was described in the study that features a modular software design that would permit individual payload contractors/customers to develop and verify their own mission-unique software that could then be efficiently integrated into the total flight software package for a particular resupply mission. This concept is shown in Figure 3.1.1.6-1.

The data management requirements significantly affect the avionics and software designs, and the recommendations for the optimized concept defined in the study must be implemented at the beginning of the design phase of the OSCRS program to achieve the required objectives.

3.1.1.7 Resupply Options for Various Receiver Propellant Tanks

The baseline OSCRS configuration was designed with the primary intent of resupplying the Gamma Ray Observatory (GRO) with hydrazine. The GRO spacecraft uses a propulsion system which operates in a blowdown mode starting from 400 psia and ending at 100 psia or less. For a system of this type, an ullage recompression transfer will be used (see Figure 3.1.1.7-1).

Ullage recompression is the simplest, and generally most efficient method of resupplying a satellite while on-orbit. First, the propellant transfer coupling is mated to the satellite, and the installation leak checks are performed. A flow restricting orifice controls initial propellant flow into the evacuated line until it is filled to equalized pressure. The coupling is then opened. Propellant transfer is initiated using the excess pressure in the supply tank. During this time the pumps are by-passed, and the flowrate is controlled by a flow restricting orifice. Once the pressures are equalized (or fairly close), the pumps are started and the flow is continued.

During the transfer, the receiver spacecraft's propellant tank ullage gas temperature will increase due to "adiabatic" compressive heating effects. A variable flowrate pump will be used to control the maximum ullage temperature within certain bounds as this occurs. Before the maximum allowable temperature is reached (Z 150°F), the flowrate is decreased as required. The flowrate at this point will be established such that the heat generated by compression is equal to the heat absorbed into the receiver propellant tank by radiation and conduction. This permits the fastest possible transfer, while maintaining adequate compression ignition safety margins.

Once the desired quantity of hydrazine has been transferred, the pumps are stopped; and the coupling closed, purged, leak checked, and disconnected.

Where applicable, this is the most efficient resupply method, since only one commodity need be transferred. Also, this transfer method has the advantage of minimizing the amount of pressurant gas desaturating during the fill process. The propellant supply tanks will be kept at low pressure (hydrazine vapor pressure Z 20 psia) during ground turnaround and launch. Immediately before the transfer commences, a separate ullage bottle will be used to pressurize the propellant tank. Since gas saturation of the propellant through the diaphragm is very slow, the propellant will remain unsaturated throughout the transfer. Some gas will effervesce in transit through the pump and at certain flow restrictions, but the total volume of free gas transferred to the receiver tanks (after being compressed to 300 - 400 psia) will be minimal. Since the transferred propellant was only saturated to 23 psia, this small amount of gas will all go back into solution.

FIGURE 3.1.1.6-1 SOFTWARE DEVELOPMENT FLOW FOR MISSION-UNIQUE MODULES

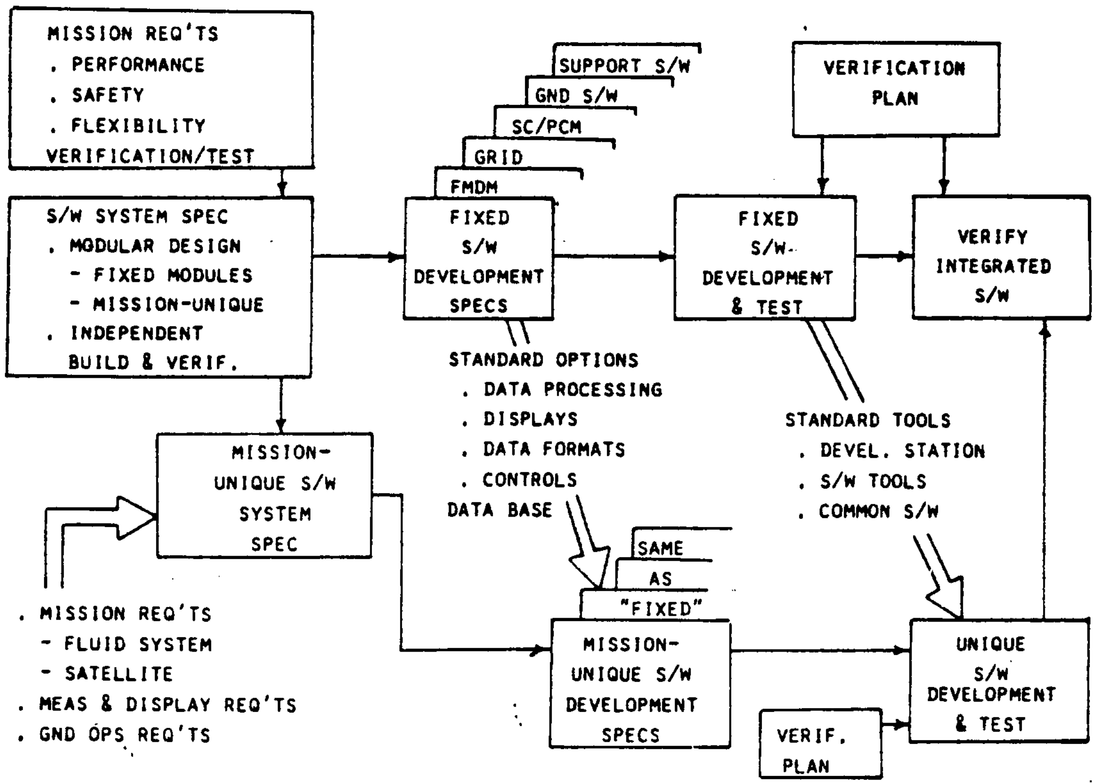
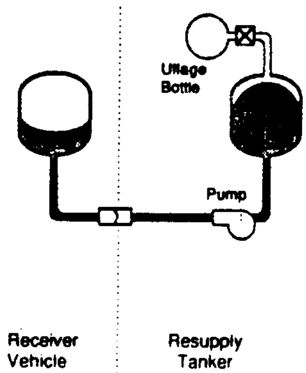
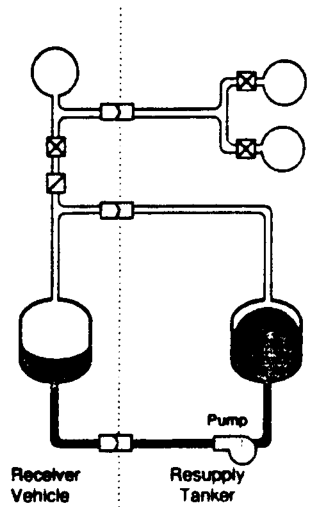


FIGURE 3.1.1.7-1 **ULLAGE RECOMPRESSION RESUPPLY METHOD**



- GRO Baseline resupply technique.
- Ullage in receiver tank is compressed to the spacecraft's BOL pressure.
- Separate ullage tank is used to maintain supply tank pressure above minimum pump inlet requirement.
- Propellant transferred by variable speed propellant pump.

FIGURE 3.1.1.7-2 **ULLAGE EXCHANGE RESUPPLY METHOD**



- Resupplies pressure regulated propulsion systems.
- As resupply propellant enters the receiver vehicle's propellant tank, ullage gas is displaced.
- Displaced ullage gas is transferred into the OSCRS' propellant tank.
- Pressure regulated propulsion systems require pressurant resupply.

At the present time, all of the identified monopropellant spacecraft resupply candidates either have a diaphragm-type propellant tank, or require ullage recompression. The baseline system will therefore satisfy all foreseeable monopropellant needs without modification. When alternate resupply methods are required (with bipropellants for example), the system is easily adapted with the addition of specific modules.

By adding ullage and pressurant transfer modules, ullage exchange resupply of pressure regulated systems is also possible (see Figure 3.1.1.7-2). In this resupply mode, three transfer couplings are required; one for propellant, one for pressurant, and one to transfer the ullage. Using ullage exchange, the receiver satellite's pressurant tank is first isolated from the propellant tank ullage. As fluid enters the receiver propellant tank, ullage gas is displaced out the ullage return line. This displaced ullage gas is thereby transferred into the OSCRS propellant tank. Pumping energy required is very small, since the delta pressure is minimal, and there is essentially no heating of the receiver propellant tank.

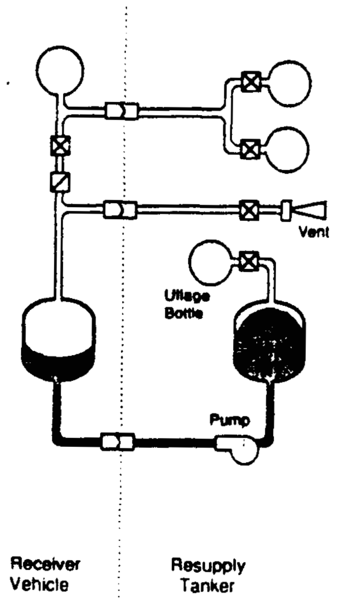
It should be noted however, that a liquid/gas separation device would be required in the spacecraft's propellant tanks without diaphragms. This is necessary to prevent propellant from inadvertantly being transferred back into the OSCRS through the ullage return line. Spacecraft which use diaphragm propellant tanks would be candidates for ullage exchange. No other spacecraft currently have the gas/liquid separation capability.

In parallel with the propellant loading, pressurant is also transferred to the spacecraft. A "cascade" method of pressurant resupply will be used. See paragraph 3.1.2.13 (Pressurant Transfer System) for more details on pressurant resupply.

Ullage exchange resupply will require more time to complete than ullage recompression due to the additional operations that must be performed, but since there is no practical method of returning the pressurant in the ullage to the pressurant tank, it is the preferred resupply mode for pressure regulated systems.

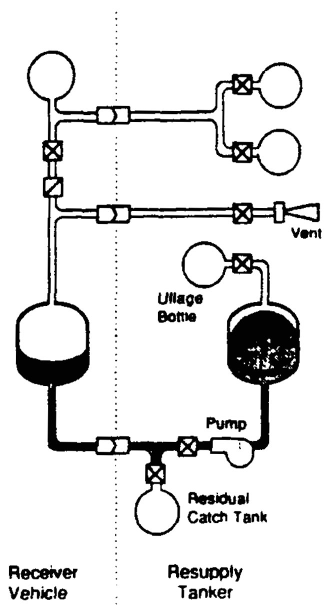
With the addition of pressurant transfer and vent modules, ullage vent/repressurization resupply is also possible (see Figure 3.1.1.7-3). This type of transfer is required for pressure regulated satellites that do not have liquid/gas separators. The approach is very similar to the ullage exchange transfer, but in this case, the receiver tank is first vented to slightly above the propellant vapor pressure. Propellant vapors in the ullage are vented overboard after first being converted into harmless gases with the use of a catalytic bed. The transfer of propellant and pressurant occurs as before, and when complete, the receiver propellant tank is pressurized to its BOL pressure.

FIGURE 3.1.1.7-3 **ULLAGE VENT / REPRESSURIZATION RESUPPLY METHOD**



- Resupplies pressure regulated propulsion systems.
- Receiver tank is vented to vapor pressure before transferring propellant.
- Propellant transferred by variable speed propellant pump.
- Receiver tank is then pressurized, collapsing trapped propellant vapor bubbles.
- Pressure regulated propulsion systems require pressurant resupply.

FIGURE 3.1.1.7-4 **RESIDUAL REMOVAL / ULLAGE VENT / REPRESSURIZATION RESUPPLY METHOD**



- Resupplies pressure regulated propulsion systems.
- Reciever tank is drained of residual propellant.
- Receiver tank is vented to vapor pressure before transferring propellant.
- Propellant transferred by variable speed propellant pump.
- Receiver tank is then pressurized, collapsing trapped propellant vapor bubbles.
- Pressure regulated propulsion systems require pressurant resupply.
- Receiver vehicle has a screen or other complex PMD design.

Some satellites may require that before any transfer is initiated, the propellant residuals be removed from the propellant tank(s). Draining of the tanks could be prompted by several factors. Lack of knowledge concerning flight residuals could require draining of the tank to establish a known level prior to resupply, or perhaps a lengthy on-orbit stay could cause concern about contamination of the propellant. Also, it may not be convenient to wait until a satellite has completely depleted its propellant load to begin resupply, and large residuals (perhaps 40%) may still be on-board. In this case, large residual quantities may need to be off-loaded before venting can occur. A complicated propellant management device (such as a baffle used in an oxidizer tank) may require complete evacuation to the propellant vapor pressure to assure that no bubbles are trapped in the baffle structure.

A residual drain/ullage vent/repressurization resupply technique can be used for these customers with the addition of a residual drain tank module (see Figure 3.1.1.7-4). Prior to initiation of resupply, the propellant tank residuals would be drained into a catch tank on the OSCRS for later removal during ground turnaround activities. In the case of large residuals, the propellant could be filtered and returned to the spacecraft. With residual propellant removed, the transferred propellant quantity (which is measured by the OSCRS) could be used to establish the spacecraft's baseline propellant mass.

Overall, the baseline blowdown pump-fed resupply system chosen is seen to provide an efficient resupply system that is capable of servicing the GRO; and, with the capability to add pressurant transfer, ullage exchange, and residual drain modules as required, is seen to provide a resupply system that is capable of handling all possible monopropellant and bipropellant satellite resupply requirements. At the same time, this system will be of light weight (since modules are only added as required), and of low cost (since module development and fabrication are deferred until a specific need arises).

3.1.1.8 Instrumentation Requirements

The different types and quantities of instrumentation required to safely and effectively monitor system status for general health, loading/resupply operations, and fault detection are discussed in detail in paragraph 3.2.5.

3.1.1.9 Fluid Quantity Gaging Accuracy Requirements/Techniques

The fluid gauging accuracy requirements incorporate influences associated with satellite resupply requirements and those associated with the OSCRS design. These include the requirements for the determination and control of the quantities of fluids transferred during a resupply and for the determination of fluid quantities remaining in the OSCRS tanker tankage.

Spacecraft requirement assessments have bracketed the need to determine the quantities of N_2H_4 transferred during a resupply to accuracies ranging from 1 to 5 percent. Tanker/spacecraft interface pressure accuracy measurement of 0.5% and/or gas mass transfer accuracy of 2% are the pressurant transfer's most stringent requirements. The maximum quantity of N_2H_4 to be transferred is 7440 pounds (including growth capability) at flowrates ranging up to 10 gpm.

Indirect techniques and direct techniques were evaluated for their ability to fulfill the accuracy requirements and for complexity, inherent reliability, safety, cost, weight, development, and adaptability to the tanker design and spacecraft needs. The indirect techniques are those that determine an ullage volume by existing classical techniques or that measure the input/output flow rates of the liquid. These techniques require computation of the fluid mass in the tank from gas laws or outflow rates and require that the initial tank quantity be known. Direct gauging techniques are those wherein the mass of medium in the tank is determined by measuring the influence of the medium's parameters on an energy field or beam used to interrogate the tank's volume.

Examples of indirect and direct concepts are as follows:

INDIRECT GAUGING TECHNIQUES	DIRECT GAUGING TECHNIQUES
1. Pressure-Volume-Temperature (PVT)	1. Radio Frequency
2. Flowmeters	2. Nucleonic
	3. Sonic
	4. Optical
	5. Capacitance

The use of indirect gauging techniques is considered the most viable approach for OSCRS (Table 3.1.1.9-1). The use of flowmeters provides potentially the most accurate method for controlling and determining the amount of propellant transferred during a spacecraft servicing operation. Present state-of-the-art flowmeter accuracies of ±1/2% are common. Probably the greatest contributor to flowmeter inaccuracy is the effects of two-phase flow. These effects can be minimized by minimizing the amount of gas entrainment in the liquid being transferred. Even though it can be assumed (or decreed) that liquid flow during a transfer shall be single-phase, the use of a flowmeter whose operational principal lends itself to being used under single and two-phase flow application would be highly desirable.

The following conclusions have resulted from this evaluation:

1. The use of flowmeters is a viable approach for determining and controlling the quantities of fluid transferred during space reservicing operation.

2. Determination of the amount of fluid transferred to an accuracy of ± 1% is considered attainable with available state-of-the-art ground type flowmeters; however, some development for flight application may be required.

3. It is recommended that three flowmeters be used in series to provide redundancy and health monitoring capability.

4. A PVT gauging technique which utilizes the pressure and temperature data generic to the fluid system design can provide a reliable backup to the flowmeter system. PVT gauging accuracies of ± 3 to 4% are attainable with generic state-of-the-art instrumentation and could be improved to an anticipated ± 2% with advanced state-of-the-art instrumentation (pressure measurement accuracy of ± 0.5%), and with a temperature probe in the propellant tank ullage space.

• GAUGING OPTIONS	PVT	FLOWMETER	DIRECT
• ACCURACY CAPABILITY			
• TANKER QUANTITY	± 3 TO 4	± 1%	± 2 TO 5%
• TRANSFERRED QUANTITY	± 4 TO 6	± 1%	± 3 TO 7%
• DEVELOPMENT RISK	NONE	SLIGHT	HIGH
• WEIGHT	LOW	MODERATE	HIGH
• COST	LOW	MODERATE	HIGH

RECOMMEND TURBINE FLOWMETER USAGE WITH PVT AS BACKUP TO MEET ACCURACY REQUIREMENTS WITH MINIMAL RISK.

FIGURE 3.1.1.9-1 FLUID QUANTITY GAGING SELECTION

Based upon the results of this evaluation it is recommended that a three flowmeter system be baselined for use in the OSCRS to determine quantities of propellant transferred during a reservicing operation. In addition, it is recommended that a PVT gauging system using state-of-the-art instrumentation be used as a backup to the baseline method.

3.1.1.10 Envelope Studies

The Gamma Ray Observatory (GRO) being the first committed user of an OSCRS resupply has a significant influence on the monopropellant tanker baseline design. Use of the GRO propellant tanks for OSCRS was baselined and established a basic structural configuration characteristic. Figure 3.1.1.10-1 shows the major interfaces which influenced the ultimate structural configuration.

The OSCRS configuration was established from past IR&D studies and the GRO interface/resupply requirements. A goal was to establish a single basic structure configuration for both the monopropellant and the bipropellant tankers which is cost and weight efficient. This objective can be achieved for a small weight penalty (87 lbs) on the baseline 2500 lb monopropellant tanker.

Two of the three MMS/FSS latch assemblies are located at Y_0 = 18.0. If an adjacent payload outside envelope matches this Y_0 location on OSCRS then an added 10.0 inches must be added to the manifesting separation of 24 inches. Since no bipropellant berthing interface exists at this time no judgment can be made as to whether a greater or smaller clearance is required during a mixed cargo manifesting using other than MMS/FSS latches.

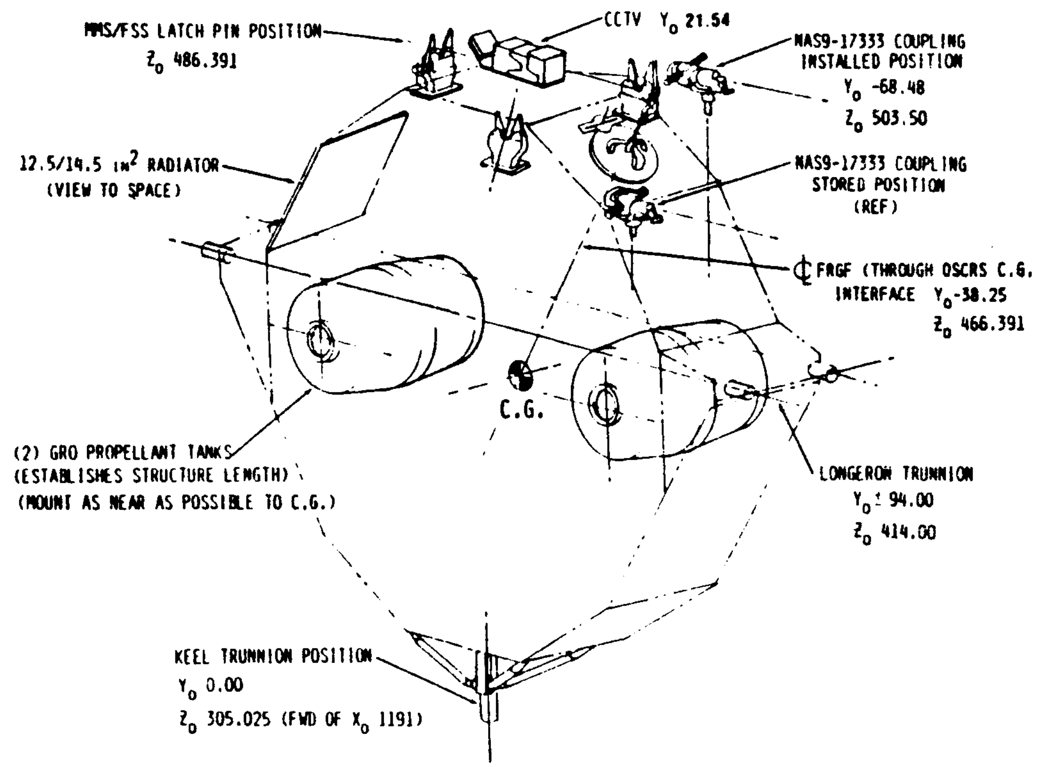
Location of the Flight Releasable Grapple Fixture (FRGF) is identical on both monopropellant and bipropellant tankers. They have no impact on cargo manifesting. The location of the NAS9-17333 fluid coupling on monopropellant tanker occupies a space in the upper port side to match the refueling interface on GRO. A bipropellant refueling interface/requirement has not been established. Consolidation of the refueling umbilicals to one specific area of the S/C and tanker would be beneficial in simplifying the bipropellant umbilical mechanical/structural support system.

3.1.1.11 Optimize System Weight

The initial structure selection was based on a GRO resupply quantity of approximately 4,300 lbs of N_2H_4, stored in four GRO-type propellant tanks mounted in the OSCRS. Subsequently, the GRO resupply quantity was reduced to 2,450 lbs. This latter quantity can be stored in two GRO type propellant tanks. Growth beyond the GRO resupply requirements is considered a major characteristic of the OSCRS tanker.

A NASTRAN finite element model (Figure 3.1.1.11-1) of the growth configuration (4,300 lbs of propellant) was developed. This permitted quick and efficient evaluation of the structural impact (static and dynamic) of various propellant weight and tankage configurations. Both the static and dynamic (normal modes) analyses were performed using the MacNeal-Schwendler Corporation (MSC) program.

FIGURE 3.1.1.10-1 INTERFACES ESTABLISH GENERAL STRUCTURE ENVELOPE



Dynamic Analysis MSC/NASTRAN Model

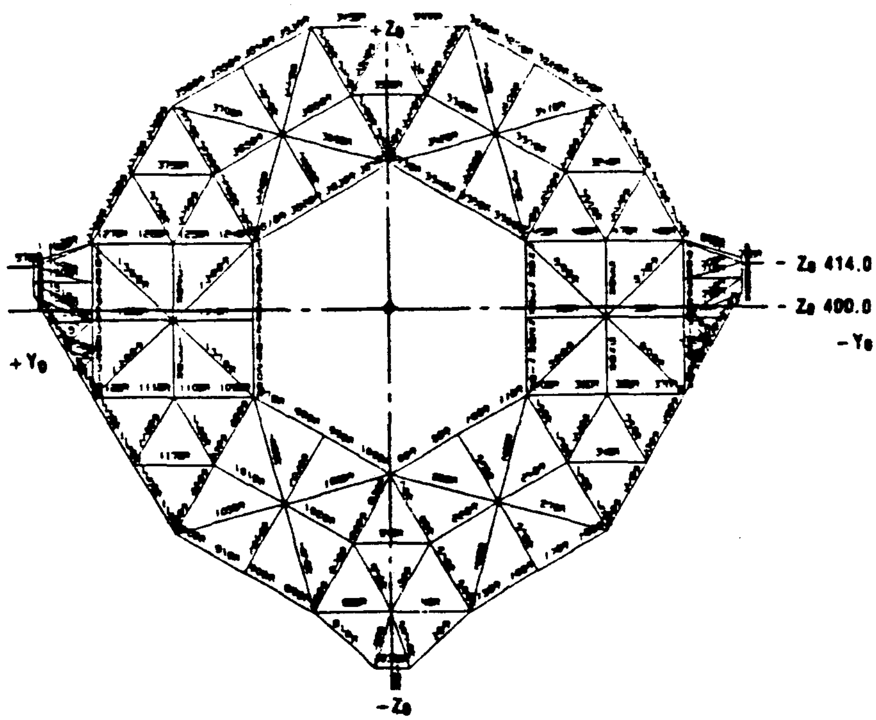
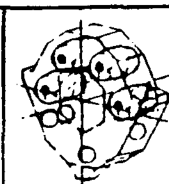
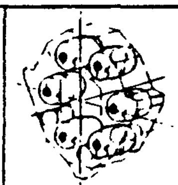


FIGURE 3.1.1.11-1

TABLE 3.1.1.11-1

CONFIGURATION WEIGHT SUMMARY

	TANKER CONFIGURATION				
	NO. OF TANKS	2	4	6	6
	PROPELLANT SYSTEM	MONOPROPELLANT GRO	MONOPROPELLANT GROWTH	MONOPROPELLANT MAXIMUM	BIPROPELLANT BASIC
	PROPELLANT WEIGHT DELIVERED (LBS.)	2481	4959	7443	8545
①	BASIC STRUCTURE WEIGHT	457	479	536	544
②	SUBSYSTEM WEIGHT	1914	2187	2625	2787 ③
	SYSTEM LIFTOFF WEIGHT	4852	7625	10,604	11,876
	FREQUENCY (H_z)	8.47	6.5	6.33	6.41

① BASIC STRUCTURE INCLUDES TRUNNION & SUPPORTS

② (DRY) INCLUDES COMPONENTS & SUPPORT STRUCTURE

③ LESS FSS BERTHING LATCHES, CCTV, & NAS9-17333 COUPLING

The minimum member stress sizing was based on an estimate of realistic minimum manufacturing/machining and handling dimensions. Several heavier members were also used for primary load paths. With the initial sizing, a static stress distribution was calculated, using MSC/NASTRAN for the transient lift-off and landing cases, which were deemed critical. An existing in-house program was used to search the element member stresses and print out only those elements that exceed predefined compression and tension stress allowable limits. Based on the element cross section and length, column allowables were developed. The column allowables were calculated using standard aircraft analysis methods that account for the interaction of Euler column failure with local buckling failure.

After an acceptable static stress sizing was established, constrained natural frequencies (first eight modes) were calculated using the MSC/NASTRAN modes analysis. The four tank configuration (4,300 lbs propellant) structure (477 lbs) analysis was performed and a minimum constrained frequency of 6.29 Hz was obtained and was considered an acceptable frequency for use in defining basic structural cross sections. The minimum required constrained frequency for a payload less than 45,000 lbs is 6.33 Hz (39.75 radians/second). A second run was made employing the above structural configuration with six tanks (6450 lbs). The resulting constrained frequency was 6.11 Hz. A static stress model was run and the maximum element stress search conducted. A minimum of structural beef-up was required. Structural beef-up was made in the area on the trunnion backup structure and a third run was made. From this run the frequency was 6.60 for a 7 lb increase in structure weight to 484 lbs.

Utilizing the four-tank structure sizing of 477 pounds, a MSC/NASTRAN model analysis produced a frequency of 10.34 Hz indicating some reduction in structural weight was available for a dedicated two-tank system (baseline GRO tanker).

To provide a more accurate weight and dynamic response of the actual proposed trunnion support structure, the baseline NASTRAN model was modified in the local area of trunnion and trunnion backup structure.

Since the six-tank configuration met the established compression and tension allowables, selective structural beef-up was initiated to increase the constrained frequency to the minimum allowable of 6.33 Hz.

After several iterations, sufficient structural beef-up (increased member area and plate thickness) was made in the trunnion structure area to achieve the required constrained frequency of 6.33 Hz. The resulting weight of a six tank structure was 536 lbs. versus 457 lbs for the baseline two tank structure, or a delta weight of 79 lbs. The four-tank configuration was handled in a similar manner, resulting in a structure weight of 479 lbs, a delta weight of 22 lbs. over the basic two tank structure. Table 3.1.1.11-1 compares the various configurations (including a 6 tank bipropellant structure) and provides a quick-look at delta weights.

3.1.1.12 Nominal & Emergency S/C Demate

Spacecraft on-orbit resupply operations require berthing the spacecraft to the OSCRS interface and connecting the fluid, gas, and electrical/avionics umbilicals, permitting the transfer of consumables to the spacecraft. In the baseline monopropellant tanker delivery system, all umbilical connections are manually mated and demated utilizing EVA crew activity.

The requirement for redundant couplings (i.e., NAS9-17333) will necessitate redundant transfer line/coupling assemblies. At this point in the design the choice of using redundant coupling/line assembles provides clear design and operational advantages over a single line, redundant coupling replacement concept:

- o EVA operational safety and simplicity
- o Lower overall cost
- o Maintenance of all electrical and heater element connections

The added requirement of emergency demate, during consumables transfer, without benefit of EVA activity, adds system design and component complexity to the fluid umbilical interface.

The emergency separation device shown in Figure 3.1.1.12-1 has been examined in detail for use within the tanker structure. This design is more attractive than one located close to the NAS9-17333 coupling attachment on the GRO since it eliminates any requirement for remote/automatic re-stowing mechanisms to reposition the extended transfer hose from outside of the payload bay doors to the vicinity of the tanker structure.

Emergency demate at the FSS latch interfaces is covered in Section 3.1.1.3, docking provisions.

During an emergency demate, in the event the RMS is unavailable to provide the separation forces necessary, the Orbiter RCS system can be used to provide the separation forces.

Electrical/Avionics connectors (for use in the spacecraft umbilical interface) to satisfy both EVA and emergency demate requirements are available as qualified components.

The total subject of emergency spacecraft separation deserves more detailed technology development in consonance with remote/automatic spacecraft berthing and hookup.

3.1.1.13 Added Propellant Storage

As the need for additional on-orbit propellant increases with the maturity of the Space Station and other orbital operations, tanker delivery capability may have to be increased. A planned growth from the baseline two tank to a maximum of six tanks has been recommended. This growth can be accomplished with a minimum of re-qualification testing and least impact on the baseline system.

FIGURE 3.1.1.12-1 FLUID TRANSFER EMERGENCY DISCONNECT SEQUENCE

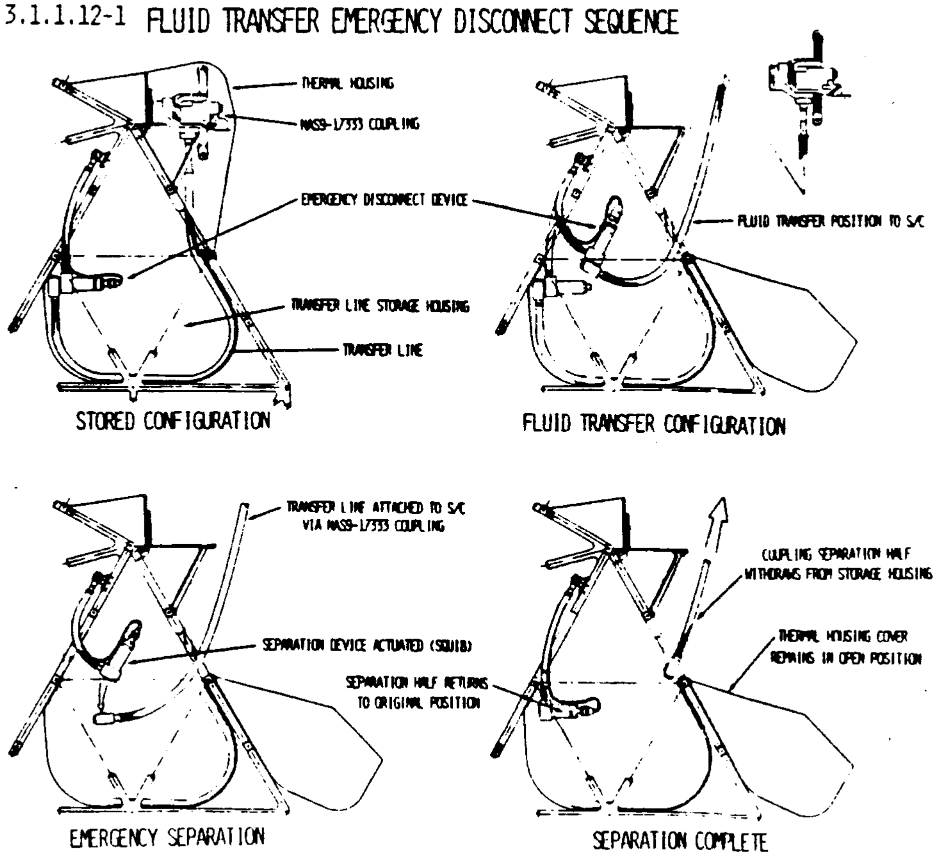
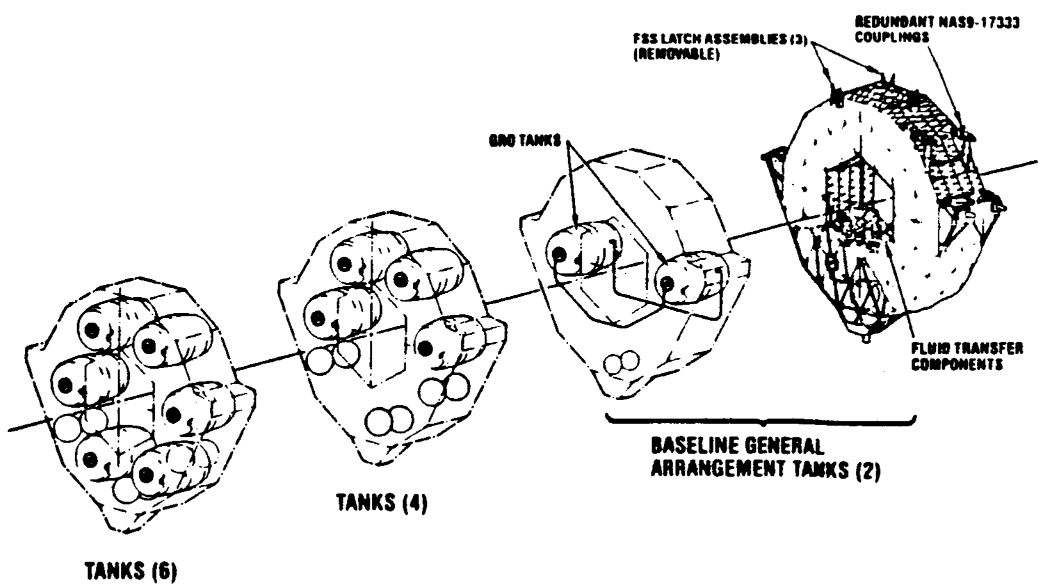


FIGURE 3.1.1.13-1

Monopropellant Tanker Growth



From the selected baseline structural arrangement, a simple, logical growth in propellant loading can be accommodated. Fuel tanks and pressurant bottles identical to the baseline configuration can be installed in the open chambers incorporated into the basic cradle structure. This planned, step growth concept is depicted in Figure 3.1.1.13-1.

Provisions incorporated in the structural arrangement of the baseline monopropellant system readily provide for propellant capacity growth. Almost no structural system weight penalty is incurred. Propellant tanks and pressurant bottles and their installation are identical to those components in the baseline tanker and can be modularly added or removed with minimum scar weight impact.

From a baseline propellant load of six tanks for near-term space operations a growth to (12) tanks capable of carrying up to 18,000 lbs has been developed. Using the several elements of structure, propellant tanks, and pressurant bottles of the baseline tanker, various configurations for this growth have been reviewed.

Growth of the bipropellant system from the six-tank baseline to the 12-tank system can be readily accomplished in a logical evolution. The structural concept developed for the baseline greatly facilitates this growth. Several conceptual approaches have been identified for future evaluation.

A simple, cost effective arrangement has been defined to provide additional propellant (for example, bipropellant). Six baseline fuel tanks can be installed in the six chambers of the basic monopropellant tanker structure and six oxidizer tanks can be installed with "A" frame supports, cantilevered externally to the structure assembly. This configuration is shown in Figure 3.1.1.13-2.

Another expanded propellant capacity scheme utilizes two nearly identical structural assemblies as shown in Figure 3.1.1.13-3. The arrangement incorporates two basic structure assemblies bolted together to produce a double-length structure similar to the technique employed by the STS Space Lab pallet.

3.1.1.14 OSCRS Relocation

To provide the maximum manifesting capability, the tanker may be required to occupy a launch and/or entry payload bay location other than that required to interface with a particular spacecraft (S/C) for any given mission. After other payload deployment, the tanker may be required to be relocated in the bay.

The OSCRS structural envelope and location of the grapple fixture were designed to assist in on-orbit relocation so that the number of payload bay (PLB) relocations will not be limited by RMS excursion limits. Limitations do result from: (a) the trunnion centerline-to-centerline span chosen consistent with bridge fitting limit loads at any one X_o station (the shorter this span, the more relocations available if single bridge fittings are used) and (b) the decision of whether or not to use dual bridge fittings to support relocation.

Added Propellant Storage

"A" FRAME MOUNTED "CANTILEVERED" OXIDIZER TANKS ARE WEIGHT EFFECTIVE FOR MAXIMUM (18,000 LB) BIPROPELLANT TANKER CONFIGURATION

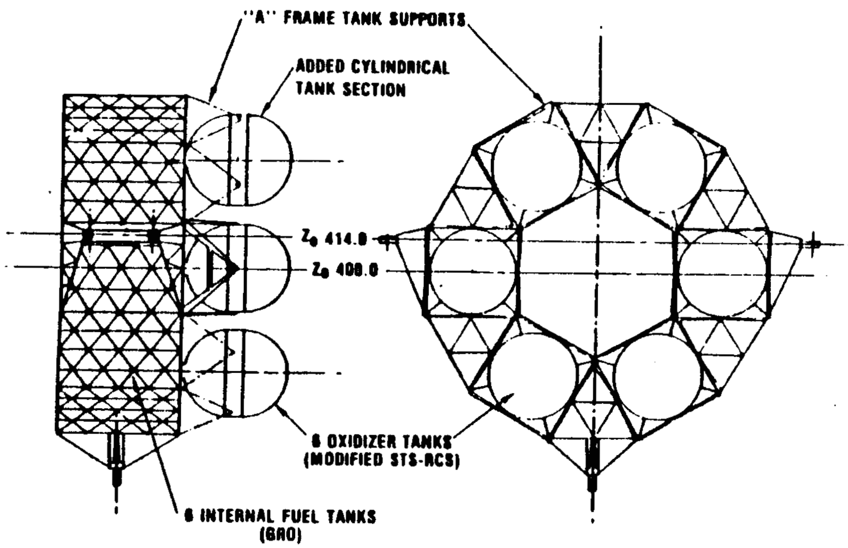
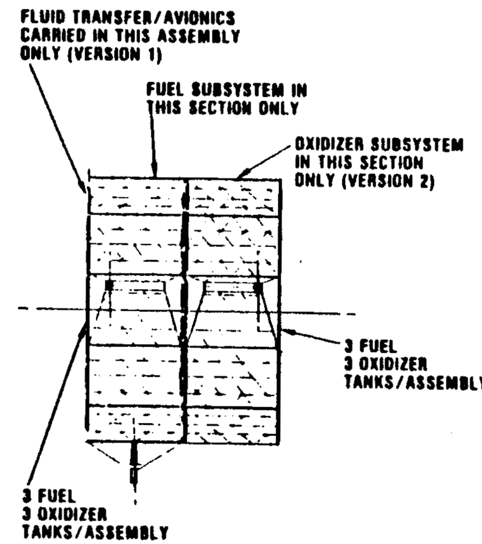


FIGURE 3.1.1.13-2

Added Propellant Storage



BACK TO BACK ASSEMBLIES COULD BE COST EFFECTIVE

FIGURE 3.1.1.13-3

To minimize weight, tanker trunnions should require only one set of bridge fittings. Standard bridge fittings weigh from 131 pounds each in Bay 1 to 195 pounds each in Bay 3. Active (deployable) retention fittings are required and add 77 pounds to each bridge fitting. (Keel bridge fitting weights include the active retention fitting weight.)

The final design of the tanker must reconcile its trunnion centerline-to-centerline span to the limit load it imposes on any bridge fitting and the minimum span that the payload ground handling mechanism (PGHM) can accommodate with the Orbiter in the vertical (launch) position. If a span shorter than that which the PGHM can accommodate is desirable, then modification to the PGHM must be considered. A 27.53 inch span is the minimum span that the PGHM can accommodate with the Orbiter in the vertical position. Using a 27.53 inch trunnion span provides a maximum of 9 payload bay locations (Bays 4, 5, 6, 7, 8, 9, 10, 11, and 12) when utilizing two sets of longeron bridge fittings.

Baseline payload retention system and deployment clearances require payloads to be manifested so that a 2-foot clearance is maintained until the trunnions enter the guides, which are 24 inches high. This clearance can be decreased uniformally to a minimum of 6 inches when the trunnions are fully seated in the latches. A cargo element with remote manipulator system (RMS) deployable payloads must provide either the clearances described above or be designed to safely withstand 1.1 feet per second contact velocities between components. If the RMS auto trajectory system is utilized, the minimum clearance increases to 5 feet from any part of the Orbiter, including other payloads. The OSCRS interface control document (ICD) should stipulate maintenance of a minimum of two feet of cargo-to-cargo clearance during prelaunch cargo manifesting. Tanker relocation operational procedures and timelines should not utilize the RMS auto trajectory mode.

Figure 3.1.1.14-1 illustrates the maximum X_0 forward and aft positions available to a berthed Gamma Ray Observatory (GRO) spacecraft given the Orbiter to S/C minimum clearances and drift angles shown. The trailing high gain antenna need not be returned to its original launch/stowed position but the antenna dish must be rotated to its maximum angle of 110°. The tanker structure is outlined and illustrates its relative position to the GRO.

3.1.1.15 Optimization of Avionics Subsystem

Control & Data System Optimization

The objective of this study was to define a basic avionics control and data system concept that would satisfy the critical two-failure tolerant safety requirement, plus other stated requirements for the OSCRS.

In the study the following design requirements were established. Redundant avionics strings are required to satisfy the two-failure tolerance safety requirements. Dedicated computers are needed because of the requirement to operate independently of the orbiter GPC's, and the requirement to ultimately support remote operations establishes that the OSCRS microprocessors should be located on the Tanker Module in the payload bay. The requirements to minimize cost and technical risk by utilizing proven systems and technologies were combined with the recognition of the importance of providing an effective friendly interface with the crew on the aft flight deck to define a system that employed extensive crew participation in all critical functions.

On-Orbit Relocation

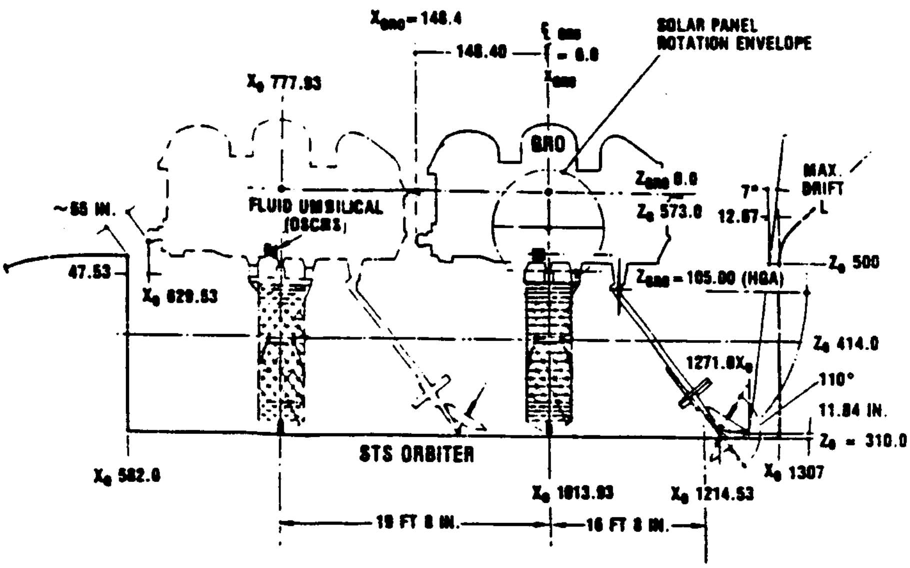
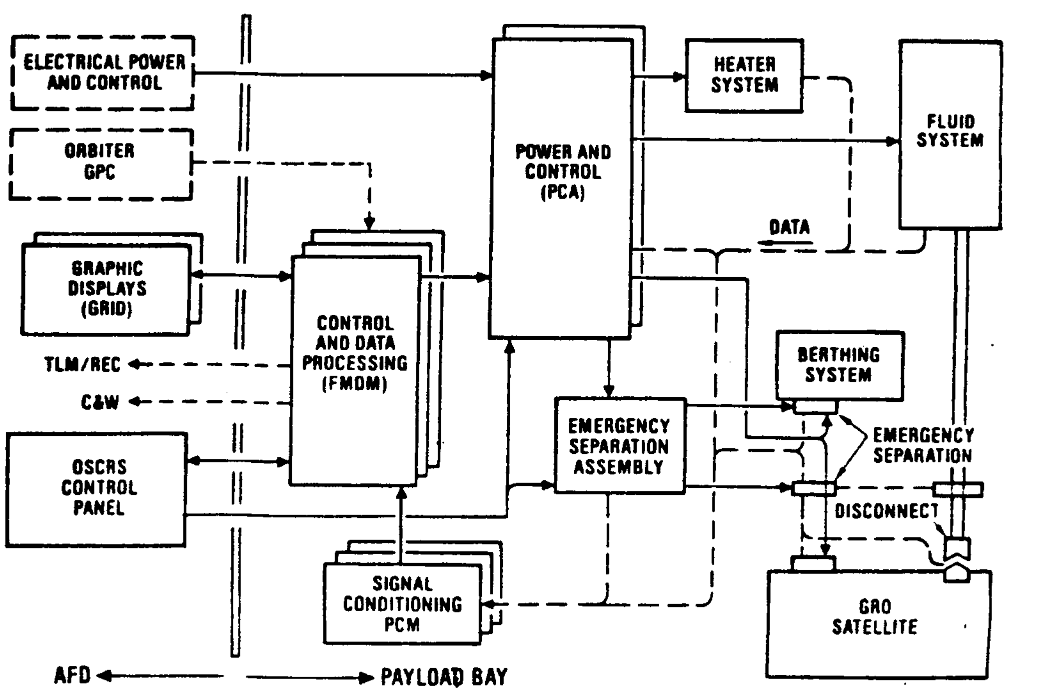


FIGURE 3.1.1.14-1

FIGURE 3.1.1.15-1 OSCRS AVIONICS SYSTEM BLOCK DIAGRAM



The avionics system concept defined is shown on Figure 3.1.1.15-1 "OSCRS Avionics System Block Diagram".

Control and Data Processing Requirements Analysis, and FMDM Selection

A key analysis in the OSCRS avionics definition studies was the identification of the functions to be performed by the control and data processing avionics located on the OSCRS Tanker Module and the definition of proven designs and systems that would accomplish the required computational and data processing functions.

Most of the FMDM modules are developed and have flight history. The Decom module is in the conceptual design stage but is considered fairly straight forward and will fit well into the FMDM system with no significant anticipated problems expected.

The MCV version of the FMDM (MCV is the concept adopted for OSCRS and flew on flight 51B in April of 1985) contained 32K of PROM and 16K of RAM. The EEPROM version of the memory module fits into the same slot occupied by the above memory and has 8K of PROM, 24K of EEPROM and 40K of RAM. This quantity of memory is believed to be sufficient for the required tasks.

Examination of the requirements clearly shows that a complex, carefully integrated system will be required to perform the OSCRS control and data processing functions. The necessity of using existing space-proven systems and components to minimize development costs and risks on the OSCRS program limits the selection to only a few alternatives.

One design concept that appears to satisfy the functional and physical OSCRS requirements, and which is the concept recommended by this study, is the Sperry Corp FMDM. The FMDM design is based on the proven Orbiter MDM's, used on all STS flights to date, with no in-flight failures. The FMDM, developed specifically to support Orbiter payload operations, is shown in Figure 3.1.1.15-2.

No other avionics design concept has been identified that provides the required capabilities in a single integrated package, as does the FMDM. Other avionics concepts that could possibly be integrated into an OSCRS avionics system that were evaluated during the trade study were:

- o Gulton Industries T^2 C^2 System
- o Fairchild STACC System, and other modular systems

Power and Control System Analysis

The power and control system analysis addressed the requirements for developing adequate avionics system output commands to control critical valves and other fluid system components that must satisfy the two-failure tolerance safety requirements.

Two alternatives evaluated for satisfying the power and control requirements, which are virtually the same as the requirements imposed on critical STS valve control circuits which must meet two-failure tolerance requirements, were:

- o Utilize circuits employing multiple individual power driver circuits and diodes to control each component in response to redundant input commands, as is done on Orbiter control circuits

FIGURE 3.1.1.15-2 OSCRS FMDM

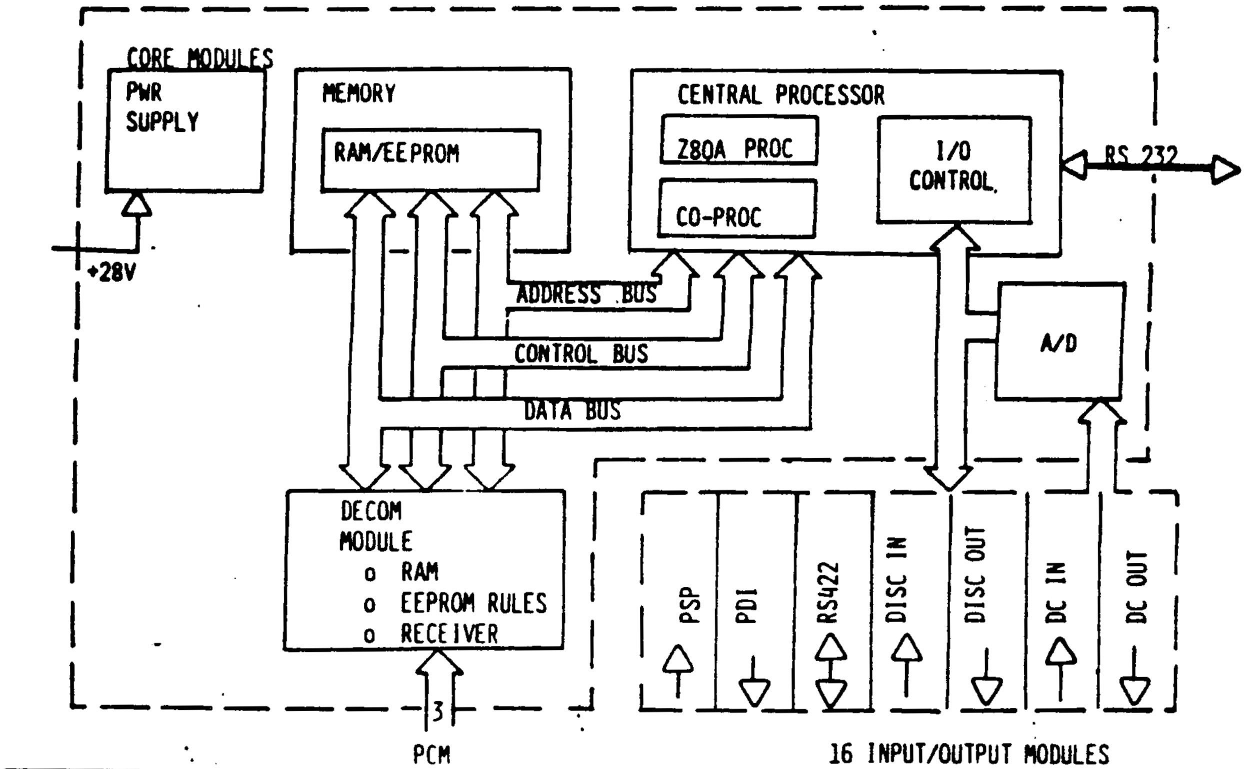
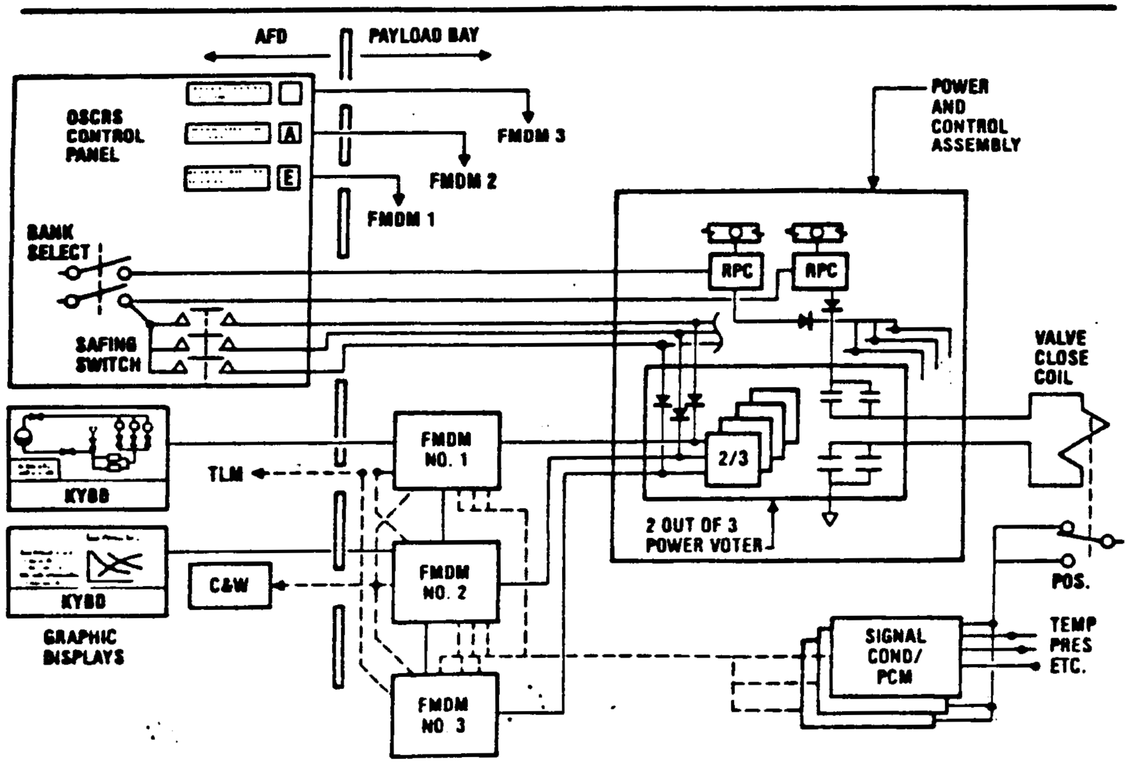


FIGURE 3.1.1.15-3 AVIONICS CONTROL CONCEPT



- Utilize a 2-out-of-3 power voter module that incorporates all required logic and power switching on a single 2-inch by 2-inch module

The 2-out-of-3 power voter, as shown in Figure 3.1.1.15-3 was selected for the OSCRS application. The newly developed Rockwell voter module will permit a three to one reduction in the number of components required, plus reductions in size and in circuit complexity over a design using the current Orbiter control concepts. This design is a derivative of the single driver modules currently used on STS, and has been developed by the same designers.

A control circuit for the coil to close a critical valve is shown in Figure 3.1.1.15-3. The redundant low level commands from the three FMDM's are shown as inputs to the logic which, with correct inputs, activates power circuits to close the valve. Crew activated switches for selecting one group of valves to be powered up, and safing switches to bypass the logic and close the valve in the event of an avionics system failure, are also shown.

Because of the manual sequences required to enable each FMDM, it will probably be necessary to use value position feedback to terminate coil power. (Otherwise command could be terminated before power is applied.) This would naturally (time) limit applied coil power. A secondary timeout may also be used to limit the consequence of value position feedback failure.

The baseline avionics concepts will satisfy the critical OSCRS two-failure tolerant safety requirements while also satisfying program requirements for minimum development cost and risk, and satisfy flexibility and growth requirements.

3.1.1.16 Limitations for On-Orbit Venting

Presently defined contamination limitations are for quiescent operation of space-based facilities or for maximum exposure limitations of ground personnel in a normal working environment. These limitations as applied to an on-orbit hydrazine transfer must be considered as a starting point in venting limitations until actual data is available for more realistic limitations.

Results of laboratory tests and flight data strongly indicate that the venting of hydrazine through a catalyst bed (using a judicious vent direction) will not adversley affect the orbiter, Space Station, or receiver vehicle. Laboratory tests under vacuum conditions have shown that hydrazine decomposition products do not collect on surfaces at temperatures above -50° F in the absence of chemical or space environmental effects such as UV radiation and solar wind induced particle bombardment. Flight data from two quartz crystal microbalance detectors (one at -40°F and the other at -150°F) on board the SCATHA satellite were analyzed to determine if firing the light hydrazine motors (six - 0.23 lbm, two - 6.5 lbm) resulted in measurable contamination at the sensors. No measurable contamination was attributed to a multitude of firings of the SCATHA RCS hydrazine thrusters over a period of 10 months.

It is recommended that the receiver vehicle shield sensitive cold areas (less than -50°F) during the venting and transfer process. It is assumed that the receiver vehicle will move out of the created molecular vent cloud after the transfer is complete.

Two other alternatives were examined for venting propellants from the receiver vehicle: (a) Residual containment in waste tanks for post-landing disposal, and (b) Cold trap subsystem to decontaminate vent gas. Both alternatives were rejected in favor of a simpler venting system -- use of a catalyst bed with nonpropulsive vents. Alternative (a) was rejected because of the massive waste tank volumes necessary (about 10 times the receiver tank volume). Alternative (b) was rejected due to system complexity and the concern that slugs of propellant would not be removed completely from the vent gas.

3.1.2 Hardware/Software Trades

The studies in this area perform design optimization trades on hardware and software. These studies resolve design related issues, identify cost and schedule drivers which influence selection of hardware and software designs.

3.1.2.1 Hardware Availability

The assessment of the hardware required to satisfy the OSCRS tanker monopropellant resupply system design requirements had as a goal the use of previously space qualified hardware/concepts where possible. The hardware availability list presented in Tables 3.1.2.1-1 through 3.1.2.1-3 identifies the degree of qualification or technology status, the recommended supplier, the quantity required on the baseline tanker (GRO) and the weight and power requirements where applicable.

3.1.2.2 Fluid Capacity and Tankage Sizing

The selection of a propellant tank is an important step in the design of a low-g propellant transfer system, such as the OSCRS Tanker. In many cases the propellant acquisition device/tank design will constrain the operational capabilities of the transfer system, such as the transfer flowrates and system's operating environment. The selection of a tank also helps determine the design of the rest of the tanker systems, including pressurant subsystem sizing, heater control, power requirements, and structural configuration.

Two state-of-the-art low-g propellant acquisition device (PAD) designs were identified as possible candidates for the monopropellant hydrazine tanker. These PAD designs are 1) surface tension devices, and 2) positive expulsion devices.

Due to the complexity of the screen tank's design, the weight and cost of a propellant transfer system using this type of tank would be higher, in comparison to less complex tank designs, such as surface tension vanes, or positive expulsion diaphragms. Shuttle Orbiter on-orbit station-keeping acceleration levels, due to vernier thruster firings, achieve values as high as 3×10^{-4} g's in the payload bay. Acceleration levels of this magnitude will not allow the use of large scale vane tanks in the orbiter environment, therefore surface tension devices are not appealing candidates.

The most feasible tank/PAD design for the tanker is the positive expulsion diaphragm. Positive expulsion devices, such as the polymeric diaphragm, have received wide use throughout the industry in monopropellant hydrazine propulsion systems. Examples of hydrazine systems currently employing diaphragms include the TDRSS and the Space Shuttle Orbiter's Auxiliary Power Units (APU). Both the TDRSS and APU propellant tanks have demonstrated the ability of diaphragm tanks to withstand STS launch loads. The major

TABLE 3.1.2.1-1 GRO MONOPROPELLANT TANKER FLUID SYSTEM COMPONENT LIST

COMPONENT	QTY	WEIGHT/UNIT (LBS)	RECOMMENDED MANUFACTURERS	DEVELOPMENT STATUS
ULLAGE TANK	1	25.0	ARDE/BRUNSWICK	T
QD CO TANK	1	5.0	ARDE	T
PROPELLANT TANK	2	99.0	PSI/TRW	Q
FLOWMETER	3	7.0	QUANTUM DYNAMICS	T
ISO VALVE (GAS)	8	2.3	WRIGHT COMPONENTS	Q
ISO VALVE (PROP, W/ RELIEF)	10	2.0	PARKER HANNIFIN	T
ISO VALVE (PROP)	10	2.0	CCC	T
MANUAL ISO VALVE (GAS)	1	2.7	FUTURE CRAFT	T
PRESSURE REGULATOR	2	1.5	STERER ENG.	T
FILL/DRAIN COUPLING (GAS)	2	1.4	FAIRCHILD	Q
FILL/DRAIN COUPLING (PROP)	1	2.2	FAIRCHILD	Q
FILTER	3	1.0	VACCO	T
EMERG'Y SEP DEVICE	2	5.0	PYRONETICS/CONAX	T
TEST POINT COUPLING	5	0.2	J.C. CARTER	Q
FLEXLINE	2	1.4	METALBELLOWS/RESISTOFLEX	T
PUMP ASSEMBLY	2	15.0	PNEU DEVICES/SUNDSTRAND	T
CAT BED/NONPROP VENT	1	6.0	HAMILTON STANDARD	T
PROP TRANSFER COUPLING	2	20.1	GFE	Q
ORIFICE	2	0.3	CCC	Q
MECHANICAL DISCONNECT	4	0.2	RESISTOFLEX	Q

LEGEND: Q - QUALIFIED
T - CURRENT TECHNOLOGY
N - NEW TECHNOLOGY

TABLE 3.1.2.1-2 THERMAL CONTROL SUBSYSTEM EQUIPMENT LIST (GRO)

COMPONENT	RECOMMENDED MFGR	POWER	QTY	DEVELOPMENT STATUS
• PANEL HEATERS	TAYCO, WATLOW, COX	34.2 W. EA.	(18)	T
• WIRE HEATERS OR	COX	1.1+ W./FT.	(2)	Q
• TAPE HEATERS	TAYCO, WATLOW	1.1+ W./FT.	(2)	T
• PATCH HEATERS	TAYCO, WATLOW	5 W. EA.	(8)	T
• THERMOSTAT SWITCHES	ELMWOOD, SUNDSTRAND	--	(16)	Q
• SENSOR/CONTROLLER SYSTEMS	TAYCO/MARQUARDT	--	(4)	T
• MLI, RADIATOR SURFACE MATERIAL		--	--	Q

WEIGHT SUMMARY

INSULATION SYSTEM	102 LBS.
RADIATOR PANEL	26 LBS.
HEATER SYSTEMS	22 LBS.
TOTAL	150 LBS.

TABLE 3.1.2.1-3 AVIONICS EQUIPMENT LIST (GRO MISSION)

COMPONENT	QUANTITY	SUPPLIER/ PART NUMBER	WEIGHT (LB)	POWER (WATTS)	QUAL NEEDS
TANKER MOUNTED AVIONICS					
FLEX MULTIPLEXER - DEMULTIPLEXER (FMDM)	3	SPERRY CORP	40	70	MINOR DELTA QUAL
POWER CONTROL ASSEMBLY (PCA)	2	ROCKWELL	50	40	FULL QUAL
SIGNAL CONDITIONER/ PULSE CODE MODULATION UNITS (SC/PCM)	3	GULTON	25	30	DELTA QUAL
EMERGENCY SEPARATION CONTROLLER ASSEMBLY	1	ROCKWELL	25	5	NONE
AFT FLIGHT DECK MOUNTED AVIONICS					
GRID COMPUTER	3	GRID SYSTEMS	10	60	NONE
OSCRS CONTROL PANEL	1	ROCKWELL	5	5	FULL QUAL

advantages of employing diaphragm tanks in the tanker include: high expulsion efficiency; independence of expulsion to spacecraft accelerations; light weight design; and a definite boundary between ullage and propellant.

The baseline monopropellant OSCRS design is for resupply of the GRO with a resupply quantity requirement of 2450 lbm of hydrazine. For growth capability, the design must permit interconnection of multiple OSCRS or supplemental propellant modules to the primary tanker to achieve increased propellant quantity transfer up to 7400 lbm.

To maximize the propellant capacity of the propellant tank designs identified in Table 3.1.2.2-1 a minimum tank ullage needs to be identified for these tanks. If the propellant tank ullage volume is sized too small, thermal expansion of the ullage gas, due to a 2-3 degree rise in tank temperature, could cause the pressure level within the tank to exceed safe operating limits. Minimum ullage volume was sized to accommodate a maximum thermal excursion of +5 psid/deg. F, at nominal tank operating pressures. Table 3.1.2.2-2 defines the usable propellant capacity of the Shuttle APU, TDRS, and GRO tanks in the OSCRS applications.

A 2 GRO tank propellant transfer system design would have a propellant resupply capacity of 2472 lbs of hydrazine. A propellant resupply system using the TDRS propellant tank would require 3 tanks (2880 lbs) to meet the GRO 2450 lb transfer capacity requirement. A propellant resupply system using the APU tank would require 7 tanks (2730 lbs) to meet the GRO transfer capacity requirement.

Significant parameters in the selection of a preferred propellant transfer subsystem design were system weight and operating pressure. An estimated delta weight analysis of the propellant transfer subsystem designs (not including any structural support weight) reveals the 2 GRO tank design to be lighter than the 3 TDRS tank design (by approximately 25 lbs). In addition, the operating pressure of the 3 TDRS tank design (339 psia) is significantly lower than the 2 GRO tank design (400 psia). Since the baseline user of the OSCRS vehicle, the Gamma Ray Observatory, operates at a beginning-of-life pressure of 400 psia, a higher operating pressure capability for the tanker propellant transfer subsystem is considered a significant system design feature. The 7 APU tank design is the least desirable, due to the large number of tanks, high system weight, and low operating pressure.

Based on this evaluation, the 2 GRO diaphragm tank propellant transfer subsystem design is the best suited for the OSCRS monopropellant tanker.

3.1.2.3 Quantity Gauging Techniques

The quantity gauging techniques for OSCRS were evaluated and discussed in detail in paragraph 3.1.1.9. The use of flowmeters was determined to provide the most accurate method for controlling and determining the amount of propellant transferred during a spacecraft servicing operation. Turbine flowmeters were selected as the most accurate system over the broad flowrate range required for OSCRS operations. Three turbine flowmeters used in series will provide for redundancy and health monitoring.

Quantum Dynamics has developed and supplies such a flowmeter for measuring mass flows of cryogenic fluids. This design enables determination of two-phase mass flows to accuracies of 1/2%. Mass flow determination of the tanker propellants is considered state-of-the-art for their flowmeter concept.

TABLE 3.1.2.2-1 Diaphragm Propellant Tank Characteristics

	Diaphragm Propellant Tanks		
	Shuttle APU	TDRS	GRO
Nominal Size (inches) (dia. x length)	28 (1)	40.2 x 31.8 (2)	36 x 47 (3)
Volume (cu. in.) (total usable)	11,350	28,144	36,626
Weight (lbs.)	43	76	99
Operating Pressure (psia)	340	338	400
Burst Pressure (psia)	1070	676	800
Operating Temp. (deg. F)	45 - 125		
Operating Acceleration Level (g's)	0 - 5		
Expulsion Efficiency (%)	98.7		97.6 (4)
Expulsion Rate (cu.in./sec)	24		
Manufacturer	TRW/PSI	TRW/PSI	TRW/PSI

Notes: (1) - spherical shape
(2) - oblate spheroid shape
(3) - conoellipsoid shape
(4) - pre-qualification estimate

TABLE 3.1.2.2-2 Diaphragm Tank Propellant Volume

	Diaphragm Propellant Tanks		
	Shuttle APU	TDRS	GRO
usable internal volume, cu.in. (prop. + ullage)	11,350	28,144	36,626
minimum ullage volume, %	4.25	4.25	5.00
maximum propellant volume, cu.in.	10,868	26,948	34,798
maximum propellant mass, lbs. (N2H4=62.8648 lbm/cu.ft.)	395	980	1,266
residual propellant mass, lbs.	5	20	30
transferable propellant mass, lbs.	390	960	1236
multiple tank system resupply mass, lbs.	2,730 (7 tanks)	2,880 (3 tanks)	2,472 (2 tanks)

3.1.2.4 Variable Supply Pressure vs. Flow Control

This task compared a propellant transfer system that used an electronically controlled pressure regulator with a fixed orifice, versus a variable orifice flow control device with a set pressure regulator. The electronically controlled pressure regulator was found to be the preferred option for the following reasons:

1. A variable regulator is able to deliver relatively gas free propellant to the receiver vehicle as compared to a variable orifice flow control device. The effervesced gas volume using a flow control device could be as high 88 in^3 (using GN_2) at the completion of a 2500 lbm hydrazine transfer. This quantity of pressurant and the time required for redissolution are not acceptable conditions to impose on the receiver vehicle.

2. Greater versatility of the variable pressure regulated system can be achieved using a pump as the flow control device. With a pump, the tanker will be able to perform an "ullage transfer" spacecraft reservicing.

3. An electronically controlled pressure regulator as a developed technology will also be beneficial for applications in a pressurant transfer subsystem.

The advantages and disadvantages of the two systems are summarized in Tables 3.1.2.4-1 and 3.1.2.4-2.

3.1.2.5 Pump versus Pressure Fed Supply

A tradeoff of the blowdown pump-fed propellant transfer system and the pressure-regulated pressure-fed system was performed to identify the best system option for a 2500 lb hydrazine (N_2H_4) transfer system. The two resupply options are presented in Figure 3.1.2.5-1. Table 3.1.2.5-1 presents the delta weight, delta cost, and system comparisons, respectively. Final system selection was based on the following evaluation criteria: weight, cost, safety, versatility, complexity, and the ability of the system to accommodate all spacecraft propellant feed systems.

Table 3.1.2.5-1 presents a weight comparison of the two propellant transfer systems for the transfer of 2500 lbs. of hydrazine. The table includes only the differences between the two schematics. Therefore, the total weight values are to be used as comparative values, not as total system values. The lightest system is clearly the blowdown pump-fed system using Orbiter power. The total weight is 62 lbs. compared to 247 lbs. for the pressure-fed system.

The cost shown is not the total system cost but an estimated delta cost between the differences in the system components (based on supplier data and similarity to Shuttle component costs). As can be seen the pressure-fed system will cost about 1.2 million dollars more than the blowdown pump-fed system. The major-cost driver in the pressure-fed system is the large number of components that are required for this system.

Table 3.1.2.4-1 - Advantages and Disadvantages of an Electronically Controlled Pressure Regulator for a Propellant Transfer System

Advantages

1) Several different receiver tanks can be resupplied
   a) At different BOL requirements (same or different missions).
   b) With different PMD's.
   c) Direct resupply methods include: ullage recompression and ullage vent/repressurization. Ullage transfer can be performed if a pump is part of the system.

2) Propellant transfer can be flow controlled by varying pressure inlet valves.
   a) Initial flow rate can be ramped (no slam starts) to required flow rates. This will also allow initial tanker/receiver pressure equalization before flow commences.
   b) Final flow rates are controlled by maximum tank operating pressures and/or are limited by maximum ullage temperature. (Regulating pressure set point changes with external signal input).
   c) Very accurate control through a wide range of flows (regulated pressure variation of less than 1%).

3) Pressurant dissolution into propellant can be minimized.
   a) Start BOL Tanker conditions at minimum pad pressure.
   b) Use BOL receiver tank pressure requirements as the final pressure between transfers on a multi-receiver propellant transfer mission.

Disadvantage

1) Component does not exist, but is under development from flight qualified components.

Table 3.1.2.4-2- Advantages and Disadvantages of a Variable Orifice Flow Control Device for a Propellant Transfer System with a Fixed Pressure Regulator

Advantages

1) Several different receiver tanks can be resupplied.
   a) At different BOL requirements (same or different missions).
   b) With different PMD's.
   c) Direct resupply methods include: ullage recompression and ullage vent/repressurization.

2) Propellant transfer can be flow controlled by changing orifice size.
   a) Initial flow rates are controlled by maximum orifice size and/or fixed point regulated pressure.
   b) Final flow rates are controlled by decreased orifice size determined by receiver tank pressure and/or maximum allowable ullage temperature.
   c) Very accurate control through a wide range of flows.

3) System is a proven concept with low technical risk. Slight system adaptation development is required on control software and hardware.

Disadvantages

1) Dissolved pressurant will effervesce from propellant upon passage through the flow control device.
   a) Even if tanker BOL pressure is at pad pressure (100 psia or less) sufficient pressurant volume will effervesce to create problems.
   b) For transfers between multi-receiver systems during the same mission, pressurant dissolution into the propellant will be at a maximum for the maximum BOL resupply requirement.

2) The ullage transfer method requires a pump for transfer. In a growth scenario a pump would be the flow control device.

FIGURE 3.1.2.5-1 **GRO RESUPPLY OPTIONS**

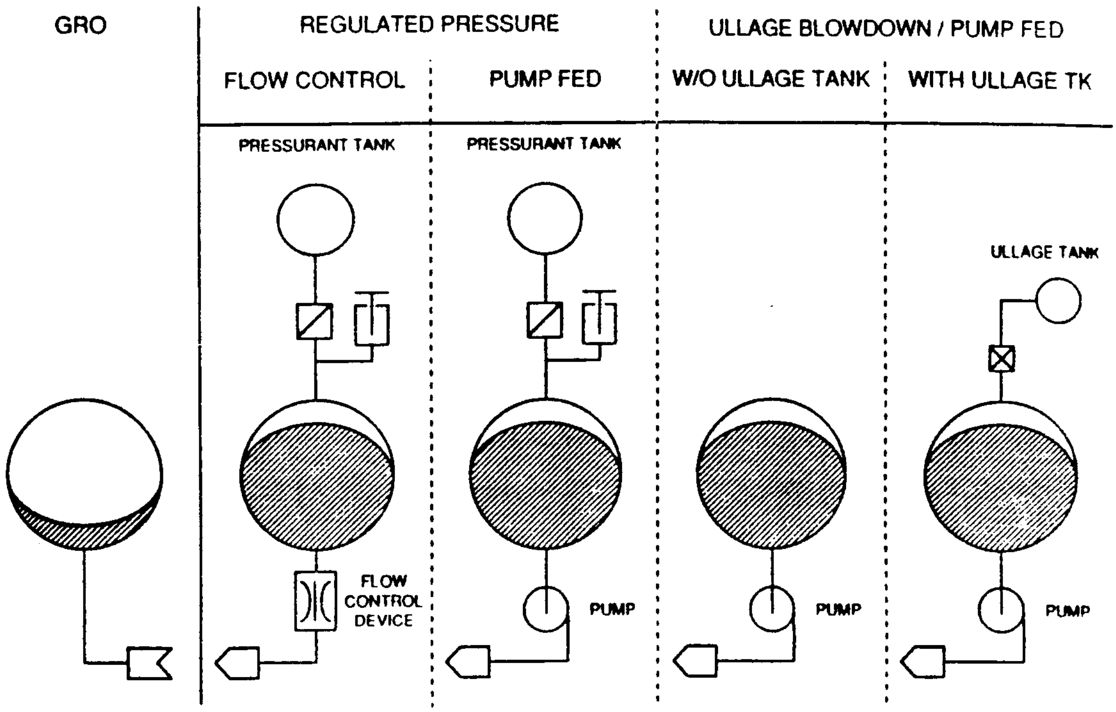


TABLE 3.1.2.5-1 GRO PROPELLANT RESUPPLY SYSTEM COMPARISON

FEED SYSTEM CONCEPT	TRANSFER METHOD ACCOMMODATED	TIME TO RESUPPLY	DEGREE OF VERSA-TILITY	WEIGHT (LB.)	COST (K$)
BLOWDOWN PUMP-FED	ULLAGE TRANSFER ULLAGE RECOMPRESSION ULLAGE VENT RESIDUAL REMOVAL	2.0 AT 2.5 GPM 1.4 HR. USING DUAL FLOWRATE	HIGH	62	1857
PRESSURE-REGULATED PRESSURE-FED	ULLAGE RECOMPRESSION ULLAGE VENT	1.7 HR.	LOW	247	2946

RECOMMEND BLOWDOWN PUMP-FED PROPELLANT RESUPPLY SYSTEM DUE TO LOWER WEIGHT AND COST, AND GREATER VERSATILITY.

The blowdown pump-fed system accommodates all methods of propellant transfer, it costs and weighs less (for Orbiter supplied power), and has a greater versatility than the pressure-fed system. Safety considerations rate the two systems about the same. Disadvantages of the pump-fed system include a small increase in resupply time and complexity when compared to the pressure-fed system.

This system evaluation shows that the blowdown pump-fed propellant transfer system is favored over the pressure-fed propellant transfer system. The pump-fed system is lower in cost and weight (with Orbiter power), more versatile, and it can accommodate all methods of resupply.

3.1.2.6 Receiver Propellant Tank Venting Techniques

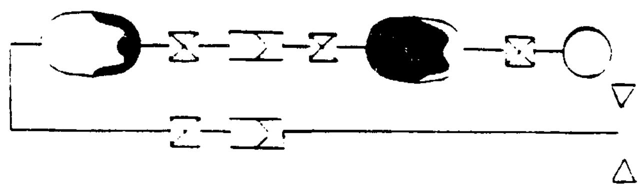
Identified spacecraft requiring hydrazine resupply fit into two general pressurant system categories. The first system type is a blowdown system. The blowdown system will be resupplied by the method of ullage recompression and therefore no venting is required. It should be noted that almost all hydrazine spacecraft that require resupply from the Orbiter fit into this category. The second type is a pressure regulated system. Since the pressure of the propellant tank is maintained at a fixed pressure, resupply can be performed by two methods: ullage exchange or by ullage vent followed by subsequent repressurization (this will require a pressurant transfer). For ullage exchange no venting is required (Space Station may be a potential candidate due to strict contamination limits). For ullage vent followed by subsequent repressurization, venting is obviously required. One potential resupply candidate that may fit into the category is the Space Station.

There are several conceptual methods of ullage venting that can be applied to hydrazine users as shown in Figure 3.1.2.6-1. Figure 3.1.2.6-1a represents a nonpropulsive dumping of unreacted hydrazine vapor/liquid overboard from either the Orbiter or during a more remote transfer (such as Space Station). This method is not considered to be a routine method for ullage venting since the unreacted hydrazine has the potential of damaging the Orbiter, user, and OSCRS over extended periods of time.

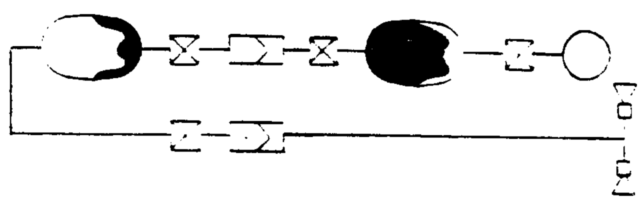
The method of venting by non-propulsive vents through a catalyst bed is illustrated in Figure 3.1.2.6-1b. Hydrazine decomposes primarily into ammonia, nitrogen, and hydrogen gases; all of which are considerably less corrosive than hydrazine. The quantity of hydrazine that is expected to be vented is about 3.6×10^{-3} lb per cubic foot of ullage for a diaphragm tank. Safety problems associated with the method of non-propellant venting through a catalyst bed come as an outgrowth of defining the catalyst bed as a thruster. NHB 1700.7A states that for a "10 pounds or less thrust, the minimum safe firing distance following deployment is 200 feet from the Orbiter". The major problems that a thruster can cause to the Orbiter result from impingement and heat damage from a thruster directed toward the Orbiter (or satellite). OSCRS can be designed so that this should not present a problem by selective directional venting and reducing the size of the thruster (a 0.1 lb thruster is allowed within 30 ft of the Orbiter).

FIGURE 3.1.2.6-1 - VENTING TECHNIQUES

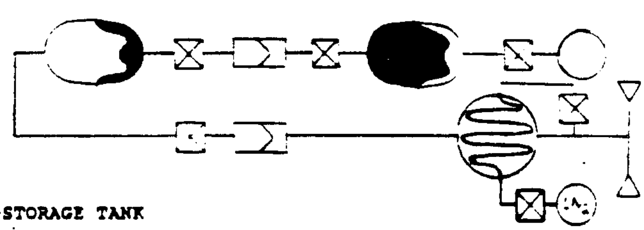
1a-NONPROPULSIVE-NONCATALYTIC



1b-NONPROPULSIVE-CATALYTIC



1c-NONPROPULSIVE-COLD TRAP



1d-STORAGE TANK

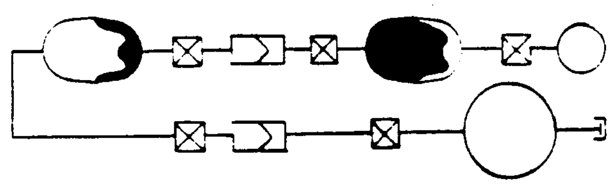


TABLE 3.1.2.6-1 RECEIVER TANK ULLAGE REMOVAL TECHNIQUES

VENTING TECHNIQUES	DEGREE OF CONTAMINATION			DEGREE OF COMPLEXITY			SAFETY CONCERNS			WEIGHT			COST		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
NONCATALYTIC NONPROPULSIVE	X					X	X					X			X
CATALYTIC NONPROPULSIVE		X				X		X				X			X
COLD TRAP		X		X				X			X		X		
STORAGE TANK			X		X				X	X				X	
ULLAGE EXCHANGE			X			X			X			X			X

ULLAGE EXCHANGE IS THE PREFERRED ULLAGE REMOVAL TECHNIQUES FOR RECEIVER TANKS WITH ULLAGE CONTROL.

IF OVERBOARD VENTING IS REQUIRED, USE A CATALYTIC NONPROPULSIVE VENT.

A third method is to use a cold trap to remove the liquid/vapor propellant from the ullage gas to be vented (Figure 3.1.2.6-1c). The "cleaned" ullage would then be vented nonpropulsively. By reducing the temperature of the ullage to about -60°F one can remove a maximum of 99.8% of the propellant from the ullage. To accomplish this goal it was assumed that the cold plate operated as a heat exchanger with LN_2 as the coolant. If 4 GRO tanks were to be vented, about 0.3 lbs of hydrazine and and 24.0 lbs of He must be cooled to -60°F. This will require a mass ratio (LN_2 to N_2H_4) of about 160 or about 50 lb of LH_2 just to cool the ullage down. The coolant nitrogen will require nonpropulsive vents as its temperature increases to -60°F.

Safekeeping of spacecraft tank ullage in waste storage tank(s) is represented in Figure 3.1.2.6-1d. In a pressure-fed system that also has a diaphragm/bladder tank, transfer of the ullage is a simple matter of displacing the ullage as the spacecraft tank is filled. For a pump-fed system this would be even simpler by performing an ullage exchange with the OSCRS propellant tank. The diaphragm/bladder allows complete separation of the ullage from the bulk propellant during the transfer without the need to vent or carry along a waste storage tank. If the spacecraft tank contains a screen or vane then a cascaded ullage transfer must be performed. The ullage is transferred to one of four tanks in succession each time reducing the ullage pressure almost in half. This requires a total waste tank volume that is over 4 times the size of the transferred ullage volume.

Table 3.1.2.6-1 presents a comparison of the five venting methods. Nonpropulsive dumping of hydrazine may be the simplest, have the lowest cost and weight, of the four methods; but presents the greatest degree of contamination of the four methods. It was rejected on this basis as a viable method except in an emergency situation. Venting through a catalyst bed is the second simplest method, it also has a low weight (3-5 pounds for the catalyst bed and one set of valves), is a developed technology is low cost and has a greatly reduced contamination problem (since only by-products are vented). The safety problems associated with a thruster can be solved by establishing the impingement and heat effects to the Orbiter, user, and OSCRS. Using a cold trap device to capture and retain hydrazine vapor/liquid from the ullage gas will result in a more complex, heavier, and more expensive method than the two methods mentioned above. The minimum hydrazine concentration will be the reduced vapor pressure. A storage tank system to capture the ullage will have the least amount of contamination and the greatest safety of any of the methods, but for a pressure fed system it is also the heaviest. If a pump fed system is used and an ullage exchange is performed, then this method would not only be the safest and have the lowest contamination potential, but it would also have the lowest weight and be simple to perform. Cost though would be strongly dependent on pump development.

The discussion up to this point has considered only venting from hydrazine tanks in which the liquid propellant and the ullage could be separated during the venting process. If the propellant tank does not have this capability, then the propellant should be removed as a first step, followed by the recommended venting techniques. The removal of residual propellant is discussed in a separate section.

There are two recommendations that have been produced by this study.

1) Since the spacecraft will contain an ullage transfer quick disconnect to return ullage to the OSCRS tanker for disposal, ullage exchange is the preferred method for diaphragm tanks. This indicates a need for a pump-fed propellant system.

2) If venting is required and ullage exchange is not possible then using a catalyst bed to decompose the hydrazine is the suggested approach.

3.1.2.7 Residual Spacecraft Propellant Disposal Techniques

The removal of residual propellant from the spacecraft may be necessary for three reasons. One reason would be to enable an accurate propellant quantity determination by filling the spacecraft's propellant tanks from the empty state. The removal of residual propellant from the spacecraft will allow the quantity of propellant added to the spacecraft to be accurately determined by OSCRS tanker flowmeters. The second reason for removal of residual propellant may result from contaminated propellant due to long-term storage on orbit. The last reason occurs when venting is required and the receiver propellant tank does not have a propellant/ullage separator. The removal of residual propellant in this case would minimize the quantity of vented by-products by removing most liquid propellant from the receiver tank before venting.

Two methods of propellant disposal techniques are considered viable options for the tanker. The first method would involve the dumping of residual propellant through a nonpropulsive vent system after passing through a catalyst bed. The second method would involve the storage of residual propellant in storage tanks or the tanker propellant tanks.

The removal of residual propellant from the spacecraft by dumping through a catalyst bed may be a viable option in specific cases, but is not considered to be a viable option in general. The venting of by-products in the vicinity of the Space Station is banned in the quantities considered as residual propellant. The quantities of residual hydrazine may be as high as 200 lbs or more. Specific cases where venting may be allowed: 1) for small residual quantities transferred at the Orbiter, 2) the removal of contaminated propellant at the Orbiter, and 3) the emergency removal of propellant.

The second viable method is to store the residual propellant in a storage tank (this includes the tanker propellant tanks). The removal of propellant from a diaphragm/bladder acquisition tank will present no removal problems and will be the best type of tank for propellant removal (most potential users fit in this category). Hydrazine removal from a vane acquisition device should be as simple as from a diaphragm tank except that the flowrate must be tailored to the capability of the vane tank. Removal of hydrazine from a screen acquisition tank will require one more step. The screen must be either completely wet or completely dry for an effective resupply to occur since ullage trapped inside the channel will limit the acquisition device's ability to deliver gas free propellant to the thrusters. The removal of all propellant to vapor pressure can be accomplished by first using the storage tank to remove as much residual propellant as possible and then venting the remaining propellant through the catalyst bed. An advantage to using the storage tank method over the venting method is that the stored propellant can be reused in specific cases to resupply the spacecraft.

There are three recommendations that have been produced by this study.

1) Usage of residual storage tanks to remove and store residual hydrazine is the best option. It will minimize any problems of contamination or safety, with small penalties for weight and cost. The residual storage tank could be an extra propellant tank or a planned volume of a required propellant tank.

2) Catalytic venting of hydrazine is a secondary option of residual propellant removal and disposal. It is best applied to small quantities of residual propellant.

3) A pump transfer system will allow more versatility in the options of residual removal and storage.

3.1.2.8 Thermal Control Techniques/Hardware

A comparison of heater types (i.e., component vs. area) was performed. IR&D studies completed under projects 85250 and 85208, prior to the OSCRS contract, indicated that power requirements of insulated component heaters are lower than for area heaters, and showed technical problems associated with each type. Under contract, further investigation relating to costs, ferry flight, safety and other issues was conducted. A panel type heater system was selected on the basis of safety, with advantages for redundancy, repair, installation, and convenience of tank changeout as secondary considerations. Costs also favor panel heaters, although the advantage is small compared to program cost.

Analysis of in-bay ferry operations indicated that for a monopropellant tanker long distance ferry transportation is not a reliable possibility without heating of OSCRS components, which is presently not possible. Transportation from DRFC to VAFB can be accomplished if the smaller fluid lines are insulated. An improved understanding of Orbiter payload bay ferry conditions would allow better analysis of this mission phase.

Hot case entry and postlanding conditions, particularly for NTO, were analyzed under IR&D Project 86210.

It was found that under the worst possible conditions, overtemperatures could occur after landing. This is at variance with Orbiter fluid line experience under nominal conditions. It is concluded that conditions leading to overtemperatures are unlikely and can be prevented procedurally. Insulation of very small lines is recommended. It was shown that results for NTO are conservative for hydrazine.

Several studies of the fluid transfer coupling and line were accomplished. It is recommended that a removable insulation system, installed following coupling deployment, be used in conjunction with patch and wire heaters to maintain the assembly in the required temperature range under design and failure conditions. Based on conservative assumptions, a maximum of 21 watts peak power should be applied to the coupling and about 20 watts for the fluid line.

Avionics thermal control was investigated for a varying avionics heat load under IR&D Project 86210, for a bipropellant design producing 195 watts. This analysis resulted in a louvered radiator design. Under contract, a continuous 380 watt avionics heat load was analyzed. The contract analysis more closely models current OSCRS design conditions. It was determined that an internally and externally radiating flat panel (nonlouvered) radiator is adequate for all flight conditions. An outer surface area of 12 ft^2 to 14.3 ft^2, with an effective inner surface area of 14 ft^2, is required, depending on flight conditions.

To support OSCRS avionics design, temperature instrumentation ranges were established for each instrument location.

Studies of temperature sensor requirements were carried out under IR&D Project 85208 (monopropellant-1985) and 86210 (bipropellant-1986). A final monopropellant study was done under contract. For the monopropellant OSCRS, about 102 temperature sensors (65 for thermal control and 37 for other purposes) are required. About 155 sensors are required for the growth design. Following the hardware test and analysis program, a potential reduction of about 26 sensors (baseline) to 31 (growth) exists. Table 3.1.2.8-1 lists the instrumentation applications.

3.1.2.9 Optimization of OSCRS Control

The objective of this study was to develop an optimized control system for a monopropellant orbital consumables resupply system. The optimized control system defined by the study features a user friendly man/machine interface and satisfies resupply system failure tolerance requirements.

The functions to be controlled by the OSCRS control system were identified in the study described in 3.1.2.12. Table 3.1.2.9-1 identifies these functions and also indicates whether the functions should be controlled by hardwired commands from the Orbiter aft flight deck or be controlled automatically by the Flex Multiplexer Demultiplexer (FMDM) units on the tanker module.

The control concept developed under this study includes a dedicated OSCRS Control Panel, located on the AFD as shown earlier on Figure 3.1.1.15-1. The GRID computers, also shown on the figure, operate in conjunction with the OSCRS Control Panel to provide the man-machine interface between the crew and the OSCRS. The dedicated OSCRS Control Panel, shown in Figure 3.1.2.9-1, provides dedicated switches to control bank select, valve safing, berthing latches, emergency separation functions, and power ON/OFF control of electronics and heaters. The panel also includes the Crew Control/Status Panel, which provides redundant, dedicated control and status paths to each FMDM.

All automatic sequences performed on a resupply mission will be controlled by the FMDM software. This software will consist of programs for a large number of sequences, such as opening a valve, that could either be run individually or as a series of events in a resupply mission. These critical FMDM sequences can only be initiated by crew activation of the ARM/EXECUTE switches on the Crew Control/Status Panel.

TABLE 3.1.2.8-1 TEMPERATURE INSTRUMENTATION (ALL SUBSYSTEMS)

	2 TANK GRO		6 TANK MAXIMUM	
	TCS	OTHER	TCS	OTHER
FLUID SUBSYSTEM				
TANKS, VALVES, PUMPS, LINES, FLOWMETERS	7	33	15	49
TRANSFER LINES, COUPLING CHECKOUT COMPONENTS, CAT/VENT	14	3	14	3
ULLAGE TRANSFER & PRESSURANT	0	0	34	0
MISCELLANEOUS	4	1	2	0
HEATER DEDICATED	12	0	12	0
AVIONICS & RADIATOR	20	0	24	0
STRUCTURE				
BERTHING SUBSYSTEM	2	0	2	0
FIRST FLIGHT TEST	6	0	0	0
	65	+ 37 = 102*	103	+ 52 = 155**

POTENTIAL FOR REDUCTION FOLLOWING TEST AND ANALYSIS PROGRAM: *26, **31

TABLE 3.1.2.9-1

Automated vs Crew Controlled Functions

FUNCTION	NUMBER GRO	NUMBER GROWTH	CONTROL HARDWIRE	CONTROL FMDM (AUTO)
POWER ON/OFF	8	8	X	
HEATER POWER	5	5	X	
BANK SELECT	4	8	X	
BERTHING LATCHES	6	6	X	
EMERGENCY VLV CLOSE	2	4	X	
EMERGENCY DISCONNECT	6	24	X	
VALVE OPEN/CLOSE				
. FLUID SYSTEM	28	68		X
. SATELLITE	-	8		X
PUMP START/CONTROL	6	6		X
VARIABLE REG & REL VLV	-	10		X
	65	147		

FIGURE 3.1.2.9-1

OSCRS Control Panel

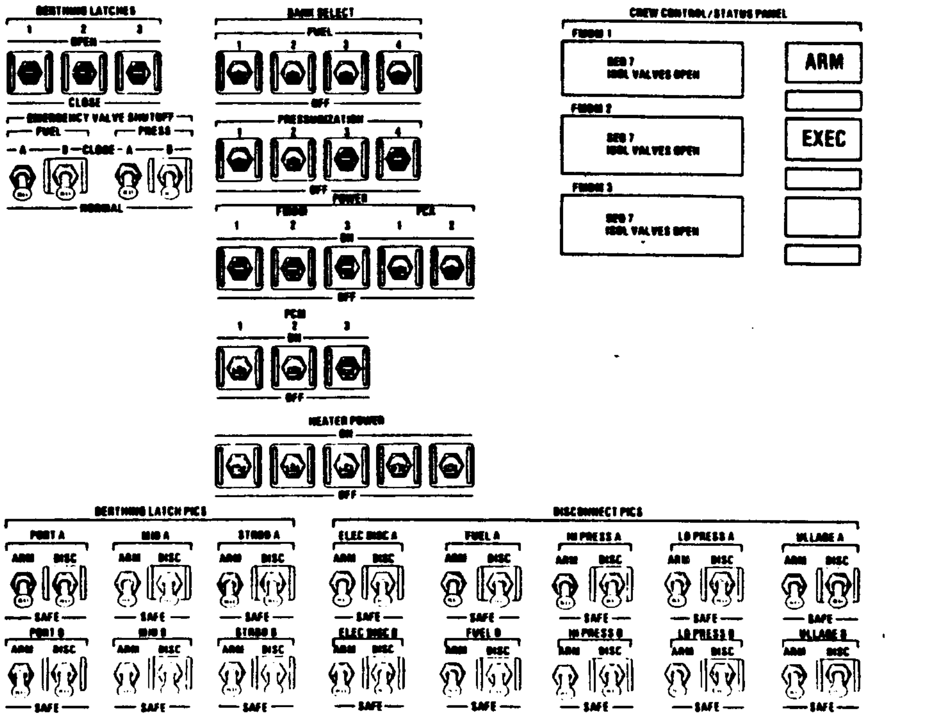
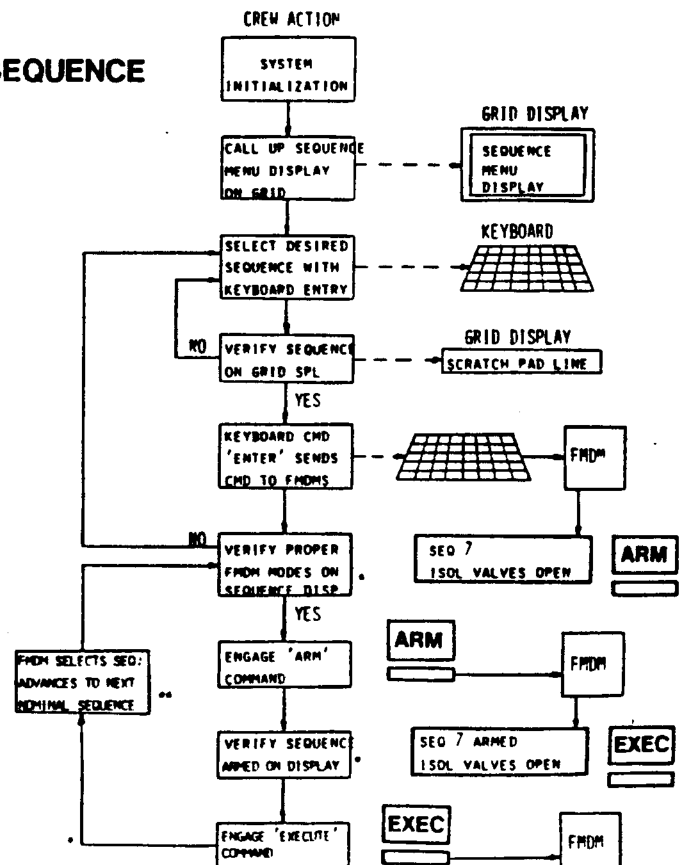


FIGURE 3.1.2.9-2

NOMINAL OPERATING SEQUENCE



* MESSAGE ALSO DISPLAYED ON GRID SCRATCH PAD LINE
** CREW MAY SELECT ANY SEQUENCE DISPLAYED ON SEQ MENU DISPLAY

Independent FMDM control paths, along with dedicated feedback Sequence Displays, prevents inadvertent actuation of sequences due to single point failures in the control system.

Each of the three FMDM's had a dedicated Sequence Display and Programmable Display Module (PDM) with a tactile feel switch on the Control/Status Panel. The Sequence Display is a 2 line by 20 character scratch pad display. The PDM consists of a 16 x 35 array of light emitting diodes (LED's) which can display any message. The PDM/Switch will be used to display and generate ARM and EXECUTE commands. Messages for the Sequence Display will be called up by the FMDM by coded commands. The control panel will be used in conjunction with two GRID Compass computers.

The sequence to be followed by the crew to select and execute a resupply sequence is shown on Figure 3.1.2.9-2. The figure shows the role of the GRID displays and keyboard in selecting the next sequence, and shows the crew action required to verify the proper sequence, arm it, and initiate the commands to the FMDM's to execute the sequence.

3.1.2.10 Optimization of Data Display to the Crew

The objective of this study was to define the optimum system for presenting data to the crew during an OSCRS resupply mission.

A graphic display was selected as the preferred method of providing crew data for the reasons given on Table 3.1.2.10-1.

Analysis of different display technologies, as presented on Table 3.1.2.10-2 resulted in selection of an electroluminescent screen for the OSCRS graphic display. An evaluation was conducted to determine if the size of available electroluminescent (EL) screens, 4 in. by 8 in., and the picture resolution of 64 pixels per inch, would be adequate for the OSCRS graphic display requirements. Figure 3.1.2.10-1 shows that the existing screens can display on OSCRS fluid system schematic in adequate detail.

The Grid Systems Compass Computer Model 1139, with a 4 x 8 inch electroluminescent display, meets all known requirements and is recommended as the graphics display for the OSCRS. The Grid Computer is an extremely powerful, highly integrated package whose use will greatly reduce hardware development risks/costs.

The GRID computer with EL display is an economical, low risk solution for an OSCRS aft crew compartment display.

- o The Display Memory, Display Driver Electronics, Computer, Keyboard, and Interfaces are a compact, fully integrated package.
- o The computer uses a mostly standard key typewriter keyboard.
- o The computer can be mounted with Velcro strips in almost any cockpit location.

The GRID computer is space-qualified and has flown on the Shuttle as the SPOC (Shuttle Portable On-Board Computer). The large screen GRID was first flown on Mission 51-B).

TABLE 3.1.2.10-1 ADVANTAGES OF GRAPHIC DISPLAYS

- O PICTORIAL REPRESENTATION SIMPLIFIES CONTROL AND MONITORING
- O MENUS AND CREW PROMPTS REDUCE OPERATOR TRAINING
- O GRAPHIC DISPLAYS CAN BE CHANGED TO EMPHASIZE MEANINGFUL DATA
- O GRAPHIC DISPLAYS EASILY MODIFIED FOR SYSTEM OR PROCEDURE CHANGE
- O SERIES ELEMENT DISPLAY REDUCES PROCEDURE STEP ERRORS
- O GRAPHICS NOT MISSION SPECIFIC
- O LESS CLUTTER, WIRING AND WEIGHT THAN DEDICATED DISPLAYS AND SWITCHES
- O EASILY EXPANDED

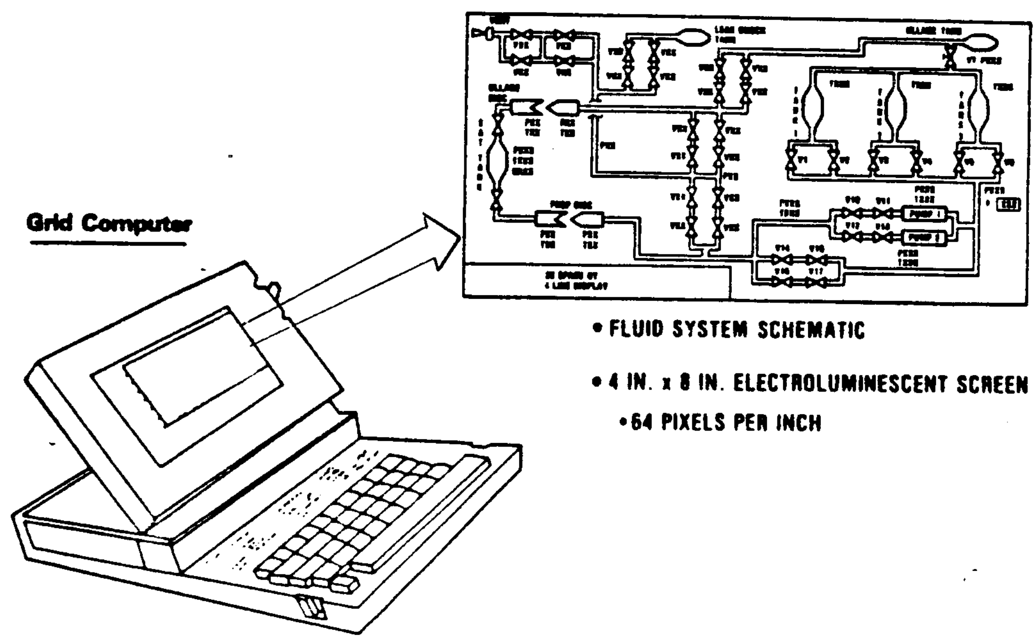
Table 3.1.2.10-2

RELATIVE ADVANTAGES AND DISADVANTAGES
OF DIFFERENT DISPLAY TECHNOLOGIES

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Cathode Ray Tube (CRT)	High resolution Good addressibility High contrast Flexibility Color capability Mature technology High luminous efficiency	High voltage Large depth Limited life under high ambient light Corner edge focus circuitry High maintenance cost Heavy
Vacuum Fluorescent Display (VFD)	Good reliability Mature technology Low production cost Low voltage	Poor in high ambient light Limited ability for large matrix display Vibration sensitive Background glow (in some cases)
Liquid Crystal Display (LCD)	Passive display Low switching voltage Very high resolution possible No contrast loss in high ambient Inherent memory possible	Slow switching speed (in most cases) External illumination required Temperature range Low yield Addressing, multiplexing, viewing angle, and contrast can be problems
Plasma Display Panel (PDP)	Inherent memory possible High resolution No flicker for most High contrast ratio Rugged, can be made very large Wide viewing angle for most High MTBF May be made transparent Mature technology	Poor in high ambient Generally orange Limited dimming range Background glow (some cases) Not space qualified
Light Emitting Diode (LED)	Extremely fast High resolution Rugged Reliable Low voltage	Short persistence Poor luminous efficiency Difficult to get uniform brightness High peak currents No blue Expensive in large arrays Yield problem
Electroluminescent (EL)	Rugged, lightweight, compact High contrast (black layer) Uniformity of brightness Large size potential, touch display available Potentially low cost Multicolor prototypes in work	Moderate luminous efficiency Moderate luminance Display requires refresh
Electrochromic Display (ECD)	Passive display High contrast Inherent memory	External illumination required Difficult to matrix address Need more stable electrodes and electrolyte Slow switching speed

FIGURE 3.1.2.10-1

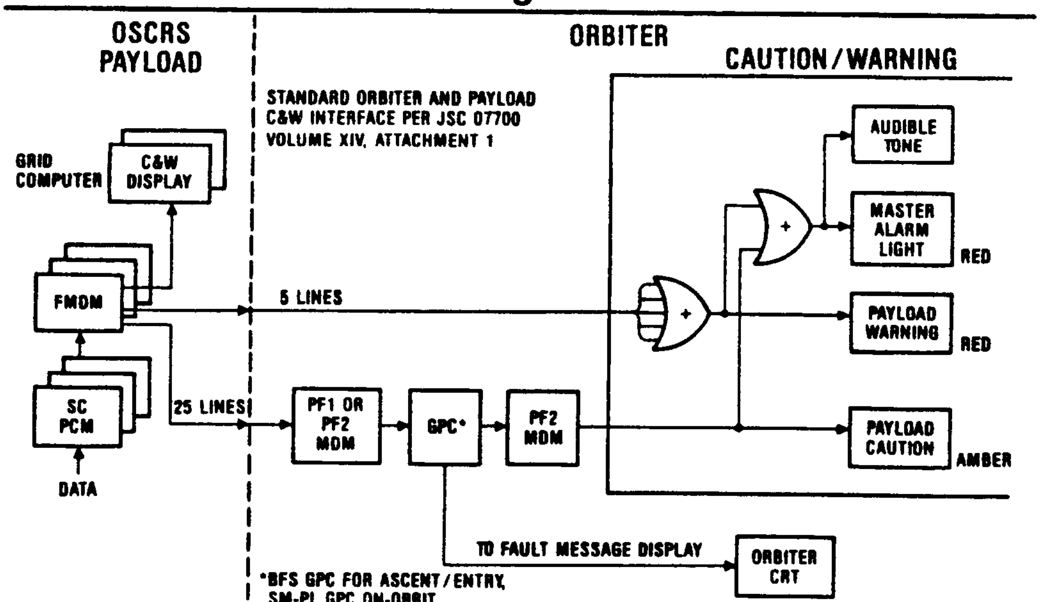
Grid Computer and Graphic Display Example



- FLUID SYSTEM SCHEMATIC
- 4 IN. x 8 IN. ELECTROLUMINESCENT SCREEN
  - 64 PIXELS PER INCH

FIGURE 3.1.2.10-2

OSCRS Caution and Warning



- ORBITER PROVIDES C&W FUNCTION DURING ALL MISSION PHASES (INCLUDING ASCENT AND ENTRY)
- DURING RESUPPLY OPERATIONS, OSCRS AVIONICS IS USED TO PROVIDE TWO FAILURE TOLERANT C/W CAPABILITY VIA THE GRID DISPLAYS

Software support tools and a software library are available from GRID Systems to support graphics development. Non-volatile bubble memory can be used to store display skeletons, offloading payload processor memory storage. The GRID provides expandability, and it can support an improved man/machine interface.

Included in the display studies was an analysis of OSCRS program Caution and Warning System requirements. Results of the study are shown on Figure 3.1.2.10-2 which indicates the capabilities of the standard Orbiter C&W system made available to the OSCRS system. The figure also shows how the OSCRS GRID display would be used to provide additional C&W data, with a two failure tolerant design, to supplement the limited Orbiter capabilities.

3.1.2.11 Redundancy Management and Health Monitoring

A study was conducted to analyze OSCRS failure tolerance requirements, evaluate various redundant avionics system concepts, and develop recommendations for OSCRS redundancy levels that would satisfy stated safety requirements.

OSCRS program safety requirements require that the avionics subsystems concept employ adequate redundancy to assure mission completion after one failure, and to assure safe operations after two failures. Table 3.1.2.11-1 summarizes these requirements. Under this study, two major avionics concepts that were considered viable candidates for the OSCRS application were analyzed. (See Table 3.1.2.11-2). These were:

1) Multiple active parallel string avionics, with active voting

2) Single active avionics string, with switchover to a backup string

In an active voting avionics system, parallel redundant strings are used to control critical functions using majority voting circuits that will reject an incorrect input from a failure in one of the strings. Uninterrupted operation of critical OSCRS resupply functions could be assured, following a system failure.

In an avionics system employing switchover circuits, one active avionics string would typically be controlling the resupply operation , with a second unpowered string available to be switched on should the first string fail. A manually controlled switchover would be expected to take several minutes.

Several obvious fluid system functions which will be under automatic control of the avionics system and which could create a hazardous condition as the result of an erroneous command that was not corrected immediately, are:

- o pump speed controls
- o variable pressure regulators
- o overboard vents

TABLE 3.1.2.11-1
FAILURE TOLERANCE REQUIREMENTS ESTABLISH NEED FOR REDUNDANT SYSTEMS

- OSCRS REDUNDANCY ANALYSIS BASED ON:
  - NBH 1700.7 "SAFETY POLICY & REQ'TS FOR PAYLOADS USING STS"
    - TWO FAILURE TOLERANT REQ'T AGAINST HAZARDS WITH POTENTIAL FOR PERSONAL INJURY OR LOSS OF ORBITER/STS EQUIPMENT
- STATEMENT OF WORK REQUIREMENTS

SRD PARA. NO.	
3.3.5.1-D	ONE FAILURE TOLERANT TO ACCOMPLISH MISSION
3.3.5.1-B	TWO FAILURE TOLERANT AGAINST INADVERTENT VALVE ACTUATION
3.3.5.1-C	TWO FAILURE TOLERANT TO CLOSE VALVES TO SAFE THE SYSTEM
3.3.5.1-E	TWO FAILURE TOLERANT TO PROVIDE PRESSURE, TEMPERATURE, FLOW, VALVE POSITION AND VALVE POWER DATA REQUIRED TO ASSURE SAFE OPERATIONS
3.3.5.1-F	TWO FAILURE TOLERANT, INDEPENDENT OF GPC'S, TO PROVIDE CAUTION AND WARNING DATA/ANNUNCIATION ON ALL CRITICAL DATA

TABLE 3.1.2.11-2
REDUNDANCY CONCEPT ALTERNATIVES

- MULTIPLE PARALLEL ACTIVE PATHS

  ADVANTAGES
  - CONTINUOUS OPERATION (ERRORS MASKED)
  - PREVENT INADVERTENT OPERATION (MAJORITY VOTE)
  - CONTINUOUS DATA VIA MULTIPLE PATHS
  - NOT NECESSARY TO ANTICIPATE ALL FAILURE MODES

  DISADVANTAGES
  - THREE OR MORE STRINGS REQ'D (WEIGHT/COST)
  - ALL PATHS POWERED ON
  - TIME SYNCHRONIZATION
  - VOTING CIRCUITS REQ'D
- ONE ACTIVE PATH, WITH SWITCHOVER TO BACKUP PATH

  ADVANTAGES
  - TWO STRINGS REQ'D
  - ONE PATH POWERED ON
  - NO VOTING CIRCUITS

  DISADVANTAGES
  - FAILED STRING MUST DETECT/REPORT ITS OWN FAILURE
  - SWITCHOVER TIME (LOSS OF CONTROL/DATA) HAZARDOUS
  - ALL FAILURE MODES SHOULD BE IDENTIFIED/VERIFIED
  - DIFFICULT TO ROLL BACK AND RESTART

It was concluded that the inherent hazards involved in controlling functions such as those listed should preclude the use of any system that does not provide immediate failure recovery which is available with a multi-string active voting system. Use of a multi-string system avoids involving the crew in time-critical decisions, as would be the case following certain failures in single-string systems. Therefore, a three-string avionics system, as defined on Table 3.1.2.11-3 has been baselined.

The OSCRS avionics subsystem is required to be two-failure tolerant to provide critical pressure, temperature, flow, valve position and power data, plus caution and warning data.

Analysis indicates that in a three-string avionics system the above requirement could be effectively implemented if a redundant instrumentation system was used, and if all data was provided to each string.

In a single string system, or in a system using a switchover concept, additional problems can occur. Since the same system that is controlling the resupply mission is also monitoring the OSCRS status and health, special provisions will be necessary to assure that no failure modes exist that would preclude detecting out-of-limit critical measurements.

Table 3.1.2.11-4 shows the results of the trade study comparing various redundancy levels versus redundancy requirements.

The results of the avionics redundancy analysis indicate that a three-string avionics system should be baselined for the OSCRS preliminary design. Key criteria for this recommendation are that two failure tolerant safety requirements are effectively satisfied both in control of the OSCRS and Satellite systems and in providing status and health monitoring data.

3.1.2.11.1 Failure Modes Effects Analysis

Additional analyses were performed to provide a functional failure mode effects analysis for all of the OSCRS subsystems; Avionics/Electrical, Fluids, Mechanical, Structures, and Thermal Control. The functions of each of these subsystems have been defined, and the worst-case potential direct effects of loss of each of these functions identified and assigned a criticality. Criticalities were grouped into five categories: 1) possible loss of life and/or vehicle with a single component failure, 1R) possible loss of life and/or vehicle with failure of all redundant components, 2) possible loss of mission objective with a single component failure, 2R) possible loss of mission objective with failure of all redundant components, 3) all other effects.

Each FMEA lists a potential failure mode of the given subsystem, possible causes of that failure mode, effects of the failure mode, criticality, interfacing subsystems, failure tolerance, and additional remarks. Basically, the failure modes can be grouped into the following categories:

a. Failure to berth satellite to tanker.

b. Failure to transfer fluids from tanker to berthed satellite.

c. Failure to separate satellite from tanker, normal mode with EVA.

TABLE 3.1.2.11-3
SELECTED REDUNDANCY CONCEPT

- o THREE STRING AVIONICS SYSTEM WITH MAJORITY VOTING SELECTED AS OPTIMUM SYSTEM
  - o CHOSEN OVER ONE ACTIVE STRING SYSTEM WITH SWITCHOVER CAPABILITY TO UNPOWERED BACKUP STRING
- o REDUNDANT COMMANDS ASSURE CONTINUOUS OPERATIONS
- o 2-OUT-OF-3 VOTING PREVENTS INADVERTENT OPERATIONS
- o REDUNDANT DATA PATHS ASSURE CONTINUOUS DATA
- o AVOIDS EXTENSIVE AND OFTEN INCONCLUSIVE SINGLE STRING ANALYSIS/VERIFICATION TASKS:
  - o ASSURE THAT FAILED STRING CAN DETECT AND REPORT ITS OWN FAILURE
  - o CONFIRM THAT SINGLE STRING SOFTWARE WILL SUPPORT TWO FAILURE TOLERANCE OPERATIONS
- o SUPPORTS GROWTH TO CURRENTLY UNDEFINED SPACECRAFT REQUIREMENTS
- o INCREASED COVERAGE AGAINST CRITICAL FAILURES OFFSETS ADDITIONAL WEIGHT AND POWER PENALTIES

TABLE 3.1.2.11-4
FAILURE TOLERANCE VERSUS REDUNDANCY

REQUIREMENT	2 STRING* (SWITCHOVER)	2 STRING (ACTIVE)	3 STRING	5 STRING
ONE FAILURE TOLERANT TO CONTINUE MISSION	YES, WITH SWITCHOVER DELAY	YES, USING BACKUP MANUAL SYST.	AUTOMATIC	AUTO. (EXCEEDS REQ'T)
TWO FAILURE TOLERANT AGAINST INADVERTENT VALVE OPERATION	REQUIRES CREW-INTENSIVE OPS, EXTENSIVE S/W ANALYSIS	YES, **USING "BANK SELECT" SWITCHES	YES, **USING "BANK SELECT" SWITCHES	YES
TWO FAILURE TOLERANT TO CLOSE VALVES FOR SAFING	YES, WITH MANUAL SAFING	YES, WITH MANUAL SAFING	YES, WITH MANUAL SAFING	AUTOMATIC OR MANUAL
TWO FAILURE TOLERANT TO PROVIDE CRITICAL DATA FOR MISSION COMPLETION, C&W AND SAFING	o REQUIRES HARDWIRED DATA TO AFD o CAN LOSE ALL BUT C&W DATA	REQUIRES HARDWIRED DATA PATCH TO A.F.D.	YES	YES

SELECTED CONCEPT

* 1 ACTIVE STRING, WITH 1 UNPOWERED BACKUP

** EXCEPT FOR TWO SIMULTANEOUS FMDM FAILURES

d. Failure to separate satellite from tanker, emergency mode without EVA.

e. Damage to Orbiter or other payload.

f. Damage to tanker.

g. Damage to satellite or degraded satellite performance after separation.

A detailed listing of all the subsystem functional FMEA's is contained in STS 86-0298 submitted as an attachment to DRD-6. The purpose of the FMEA's is to provide a system whereby all potential failure modes are tracked to ensure that the proper component redundancy and design margins are provided to meet the requirements of no single failure causing loss of mission, and no dual failure causing loss of life or vehicle.

Preliminary component level FMEA's have been generated for the fluids subsystem, in order to provide baseline information needed to support the trade studies. A listing of these FMEA's is also provided in STS 86-0298. In phase C/D of the contract, component FMEA's will be provided for all of the subsystems.

3.1.2.12 Automated Versus Crew-Controlled Propellant Transfer

The objective of this study was to investigate the control functions to be initiated during an OSCRS propellant transfer mission and to make recommendations as to whether the functions should be controlled automatically or if they should be initiated either solely by crew actions or by crew actions performed in conjunction with an automatic sequence.

The critical nature of the OSCRS resupply mission dictates that manual controls must be provided for many of the functions which could result in an unsafe condition if they either were actuated at the incorrect time, or failed to actuate at all, because of a failure in the automatic control system. Even though the use of redundant components and redundant circuits can provide a high degree of protection from failures in an automatically controlled system, it is still necessary to utilize the skills and intelligence of the crew to achieve the maximum level of safety.

The study included, first, the identification of the functions that must be controlled during a resupply mission, and second, an analysis of whether the functions should be controlled by a crew operated switch, or automatically, or by a combination of both.

The crew control panels referred to in this report were defined in the related OSCRS study "Optimization of OSCRS Control", Section 3.1.2.9.

A major factor influencing the results of the study was the architecture of the baselined avionics system. The avionics system employs three active strings, plus voting circuits, to satisfy the two-failure-tolerant safety requirement for control of the fluid system valves and components. Since the functions are controlled by simultaneous automatic sequences in the three FMDM's, it would not be practical to provide the crew with individual hardwired switch control of the critical fluid system components The crew is provided, however, control over the automatic sequences performed by the FMDM's. No resupply sequence can be initiated without two distinct commands, "ARM" and "EXECUTE", being sent to each FMDM on dedicated circuits from the crew-operated CONTROL/STATUS panel on the aft flight deck. The safety critical nature of the OSCRS resupply missions will always require a significant amount of participation by a skilled crew. The one exception would be a remote resupply mission, with the OSCRS operating with a carrier vehicle such as the Orbital Maneuvering Vehicle (OMV) outside the Orbiter payload bay. In this case the sequence ARM and EXECUTE commands would be sent from a ground station via an RF link.

Results of this study were shown on Table 3.1.2.9-1. The crew would have direct control over black box power and heater power functions via switches on the OSCRS Control Panel. Crew control of the bank select functions and the satellite berthing latch open and close commands would also be provided by switches on the OSCRS Control Panel (Figure 3.1.2.9-1). Also shown on Table 3.1.2.9-1 are the number of critical fluid system valve, pump, regulator and relief valve functions that are controlled by the redundant FMDM's and voter circuits discussed in the prior paragraph. The automatic sequences controlling these functions are initiated by "ARM" and "EXECUTE" switch commands from the crew CONTROL/STATUS panel.

The baseline multi-string avionics system provides automatic protection from critical failures where an incorrect command could result in a hazardous condition if immediate corrective action was not taken. Obvious examples are excessive pump speed commands, dangerous pressure settings for regulators and relief valves, or erroneous commands to open overboard vent valves. The crew would not be involved in such time-critical decisions, and would not be responsible to implement corrective action following the first system failure, under the baselined avionics concept.

It was determined in the study that the crew must have the capability to "SAFE" the OSCRS system, even in the event of a failure of the three redundant avionics strings. This capability, which is incorporated in the baseline Avionics system, is provided by hardwired circuits to operate the "CLOSE" coils to all critical valves on OSCRS. The emergency valve "CLOSE" command will be issued to a number, or bank, of valves at the same time. RF uplink commands for these functions would be possible during remote resupply missions.

The Emergency Disconnect function shown on Table 3.1.2.9-1 satisfies the requirement to provide the capability to initiate an emergency disconnect of the receiving satellite to permit separation in an emergency, without EVA support. The baseline concept utilizes pyrotechnic devices to separate all interconnecting systems. In compliance with NASA requirements for ordnance systems, the pyrotechnic initiators will be activated by Pyrotechnic Initiator Controllers (PIC's). Each of two redundant pyro systems require "ARM" and "FIRE" commands to the PIC's to initiate separation of each disconnect. Because of the critical nature of these functions they should be activated by hardwired circuits from crew switches on the OSCRS control panel (Figure 3.1.2.9-1). This function is not required during remote resupply missions.

Performance of the propellant transfer operation will employ two types of control, both direct crew control and automatic sequences initiated by crew controls. The system must have the inherent capability to support fully automatic operations during remote resupply missions to be defined in the future.

3.1.2.13 Pressurant Transfer System

The three pressure transfer options shown in Table 3.1.2.13-1 were evaluated.

- o Compressor
- o Hybrid Cascade Compressor
- o Cascade

Since there was no apparent advantage of the compressor only method of resupply, the discussion here under is limited to the comparison of the hybrid and the cascade method. The compressor only method is less appealing due to the cost, weight, and heat dissipation disadvantage with a 10/1 compressor ratio.

A cascade-compressor hybrid pressurant transfer system's method of operation is as follows: The first supply tank isolation and compressor by-pass valves are opened and pressurant is transferred to the receiver vehicle until pressure equalization occurs. Then the compressor by-pass valve is closed and the compressor is activated to remove as much pressurant as possible without exceeding the design compression ratio and maximum delta pressure. This procedure is repeated until each supply tank has transferred its pressurant to the receiver vehicle. The compressor removes pressurant after each cascade step, thereby reducing the size of each supply pressurant tank when compared to a cascade only resupply system with the same operating pressure.

To determine the optimum hybrid system two factors were examined: 1) the hybrid system weight for different compression ratio cases, and 2) the heat to be dissipated by the system for the different cases. The results of the analysis showed that the optimum compressor will have a compression ratio of less than 3 to 1.

The cascade only method involves multiple resupply tanks at a higher pressure being opened one at a time to the receiver tank(s) until pressure equalization occurs. The advantages of this method are its simple operating procedure, sequential valve openings, and its minimal equipment requirements - tanks and isolation valves only. Transfer occurs polytropically with the spacecraft pressurant tanks heating up and the tanker pressurant tanks cooling down. A polytropic constant of 1.1 was used in the analysis to limit the heating and cooling effects as would occur in an actual transfer. Sufficient pressurant was added to the spacecraft tanks to satisfy its BOL requirements after cool-down. The results of the analysis indicate that an optimum system will consist of 5 to 6 pressurant tanks in the resupply vehicle.

A comparison between the cascade pressurant transfer system and a cascade-compressor hybrid pressurant transfer system is seen in Table 3.1.2.13-1. There are two major differences between the two systems: 1) the cascade only system is operating at 8000 psia whereas the hybrid system is operating at 6000 psia, 2) the hybrid system is an active system compared to the passive cascade system. Both systems have the capability to deliver 20 lbs of GHe at BOL conditions of 4000 psia, 70°F.

TABLE 3.1.2.13-1 PRESSURANT TRANSFER OPTIONS

CHARACTERISTICS	COMPRESSOR	CASCADE-COMPRESSOR HYBRID	CASCADE
TYPE OF PRESSURANT TANK	KEVLAR COMPOSITE WRAPPED TI LINER	KEVLAR COMPOSITE WRAPPED TI LINER	CARBON COMPOSITE WRAPPED TI LINER
WEIGHT OF EACH TANK (LBS)	56 (2 USED)	50 (4 USED)	30 (5 USED)
OPERATING PRESSURE (PSIA)	6,000	6,000	8,000
PROOF PRESSURE (PSIA)	7,500	7,500	12,000
BURST PRESSURE (PSIA)	9,000	9,000	16,000
VOLUME OF EACH TANK (IN^3)	4,200	3,720	1,880
WEIGHT OF SYSTEM (LBS)	341* 388	297* 311	210 ---
DESIGN COMPRESSOR RATIO	10 TO 1	2 TO 1	---
ENERGY REQUIRED (W-HR)	1,170	350	NONE
TRANSFER TIME	SLOW	MODERATE	FAST
COST	MODERATE	MODERATE	LOW

* USING ORBITER POWER

CASCADE RESUPPLY METHOD IS RECOMMENDED.

The cascade only system will require qualification of a relatively new high-strength carbon fiber filament-wound composite fiber/metal pressurant tank. This will allow a weight savings of 20-30% over a comparable kevlar-49 fiber filament-wound composite fiber/metal pressurant tank. The weight of a 1880 in^3 tank is 30 lbs, with an operating pressure (OP) of 8000 psia and a burst pressure 2 times the OP. The hybrid system pressurant tank uses a kevlar fiber filament. It weighs 44 lbs for a tank volume of 3720 in^3 and a OP of 6000 psia (burst is 1.5 x OP). The advantage of using a kevlar wrapped tank is that the technology has been space qualified on several manned programs including the shuttle program.

The hybrid system is an active system due to compressor usage to transfer pressurant after each tank cascade. A space qualified compressor does not exist, but compressor technology is well established. As an active system it has the inherent potential for failure, preventing complete pressurant transfer. There is also the heat rejection problem from an expected compressor efficiency of 50%. The heat rejection problem increases by increasing the compression ratio of the compressor, this may necessitate the requirements of active thermal control system at high compression ratios.

Total system weight for the cascade only pressurant transfer system is 210 lbs which includes the five pressurant tanks, pressurant, and isolation valves. Total system weight for the hybrid pressurant transfer is 311 lbs (including battery weight) or 297 lbs without battery weight; and this weight estimate includes four pressurant tanks, pressurant, isolation valves, and two compressors.

The following are conclusions of the pressurant transfer system selection.

1) In designing a cascade-compressor hybrid pressurant transfer system a compression ratio of less than 3 to 1 will be optimum. Four or less pressurant tanks were determined to be optimum for the hybrid system.

2) A comparison between a cascade only and a hybrid pressurant transfer system favors the selection of the cascade only pressurant transfer system because of its lower system weight (210 lbs compared to 297 lbs), and reduced system complexity (the hybrid system is an active system requiring a power source and potential thermal control).

3) The higher the supply pressure the greater the volume and weight efficiency; therefore it is recommended that 8000 psia pressurant tanks be used.

4) It is recommended that at least 6 pressurant tanks be used in the supply vehicle.

3.1.3 Operational Trades

The operational trade studies and analyses optimize the OSCRS design and generic mission procedures. The results of these studies minimize operational time lines, system turnaround, operational handling complexity and cost, and to maximize the cost effectiveness, safety, and flexibility of OSCRS.

3.1.3.1 Launch Site Operations

Within the scope of the trade studies performed in evaluating the facilities classified for either nonhazardous or hazardous operations of KSC, the comparative services between the facilities did not clearly identify any one facility above the others. Therefore, strong consideration was given to identify the facilities which best meet the criteria of an optimum processing flow with the least impact on Orbiter turnaround operations. An optimum processing flow can be defined as one in which the handling and moving of the OSCRS tanker and its unique GSE is kept at a minimum. As determined by the trade studies, propellant and pressurant servicing of the OSCRS tanker should take place in a Hazardous Processing Facility (HPF) prior to being transferred to the launch pad in the payload canister. Any servicing undertaken at the launch pad will be an impact on the normal Orbiter launch schedule.

The typical turnaround processing flow of an OSCRS tanker (Figure 3.1.3.1-1) will start at the Orbiter Processing Facility (OPF) where it will be safed; removed from the Orbiter, and installed in its shipping/handling/storage container for transfer to a HPF. Assuming the optimum turnaround operation wherein the tanker will be processed in one facility through its propellant and pressurant servicing, the following typical operations will be performed: postflight inspection; flight anomaly investigation and correction; system maintenance, refurbishment and reconfiguration; subsystem test and system checkout; preparation for storage (if required), and servicing propellants and pressurants for next flight. Upon leaving the HPF, the fully loaded OSCRS tanker will be transferred to the Vertical Processing Facility (VPF) where, if required, CITE testing will be performed prior to the tanker installation into the payload canister for transfer to the launch pad. At the pad, the canister will be raised into the Payload Changeout Room (PCR) on the Rotating Service Structure (RSS) and transferred to the Payload Ground Handling Mechanism. A final pre-installation system health check is made on the OSCRS and then it is installed in the Orbiter payload bay. The electrical interface connection is made and verified for launch.

The turnaround processing flow of the OSCRS tanker at VAFB (Figure 3.1.3.1-2) is more optimized than at KSC in that after the tanker is removed from the Orbiter in the Orbiter Maintenance Checkout Facility (OMCF) and deserviced there (if required) it is installed in its shipping, handling and storage container and transferred to the Payload Preparation Room (PPR) at the launch site where all the processing operations are performed, including CITE testing (if required), and propellant and pressurant servicing for flight. Upon completion of servicing, the OSCRS tanker is transferred within the PPR using a strongback and installed in the PGHM which is then transferred into the mobile (tracked) PCR. After a short transfer to the Launch Mount (LM), the PCR is mated with the Orbiter and the payload bay doors are opened. A final pre-installation health check is made on the OSCRS and then it is installed in the Orbiter payload bay. The electrical interface connection is made and verified for flight.

FIGURE 3.1.3.1-1

OSCRS Processing Timeline (KSC)

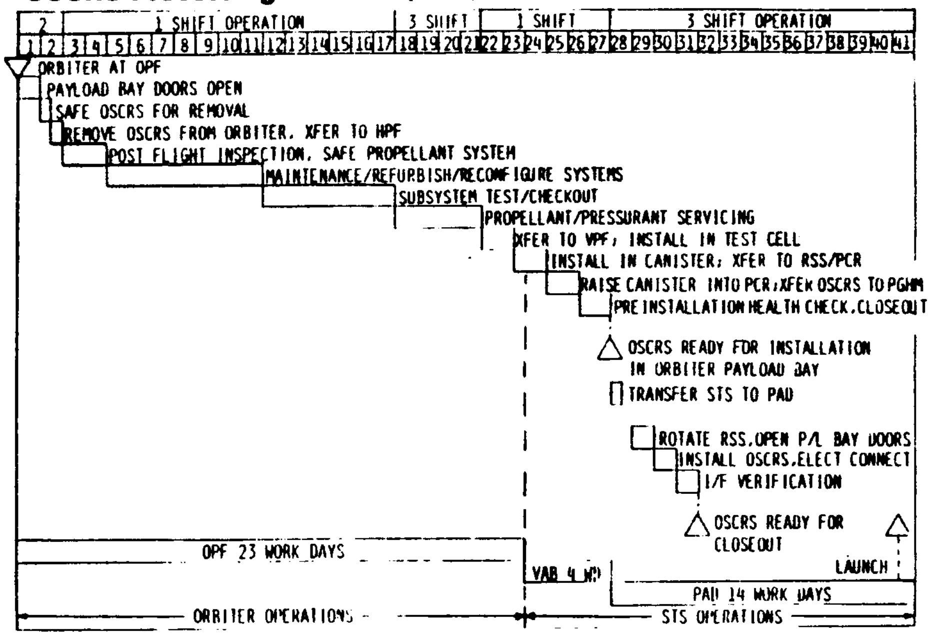
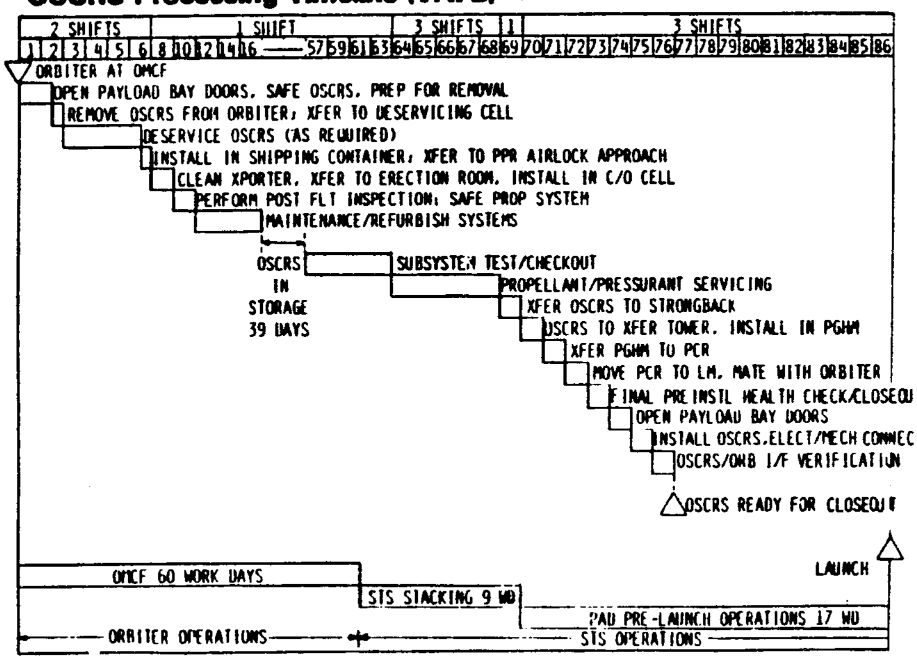


FIGURE 3.1.3.1-2

OSCRS Processing Timeline (VAFB)



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3.1.3.2 Landing Site Operations

The postlanding operations for all normal landings, which include Return to Landing Site (RTLS) and Abort-Once-Around (AOA) landings, will not require any specialized equipment or techniques to remove the OSCRS from the Orbiter payload bay in the OPF other than the OSCRS-unique GSE and standard payload removal and handling procedures. The safety aspect of removing and handling a fully loaded OSCRS tanker, versus one with only residual propellants aboard, will not vary too much. All of the handling GSE will be designed to support a weight equivalent to that of a fully loaded bipropellant tanker (fluid capacity of up to 8545 lb). If a problem were to develop with the OSCRS tanker while it is still in the OPF, such as to require emergency detanking, there are adequate facilities in the OPF to support this operation.

After the OSCRS tanker has been removed from the Orbiter and installed in its shipping/handling/storage container, it will be transported to a Hazardous Processing Facility (HPF) on a flatbed trailer. No other special equipment is required during this relatively short trip.

Operations at the HPF will vary depending on the status of the OSCRS at the time of its removal from the Orbiter. If the OSCRS mission had been fully accomplished, thereby leaving only residual propellant aboard, then the standard postflight operations will take place. These operations will include but not be limited to the following: (1) postflight inspection; (2) flight anomaly investigation and correction (if any); (3) system reconfiguration or refurbishment; (4) system test and checkout, and (5) preparation for storage or servicing for next flight. If the mission was aborted, but not caused by the OSCRS, the fully loaded OSCRS will have several options available as to what processing steps will be taken. These options are: (1) leave the OSCRS tanker loaded and monitor system health using OSCRS-unique GSE until its next mission; (2) deservice the OSCRS tanker propellant and pressurant systems, and (3) depressurize the high pressure tanks while maintaining and monitoring the propellant load. Selection of the appropriate option will be done on a real-time basis in support of the KSC launch schedule. Based on the option selected, some portion or all of the operations listed above will be initiated.

Landing at a contingency landing site, such as DFRC, will require additional tasks to be performed on the OSCRS. The tanker cannot remain in the Orbiter payload bay during the ferry flight to KSC due to potential thermal problems associated with the freezing temperature (35°F) of hydrazine or the diaphragm in the fuel tanks. Orbiter payload bay doors strongbacks (GSE) and associated hardware will be shipped to DFRC along with the OSCRS-unique GSE required to support the postlanding operations. After the payload bay doors are opened the OSCRS tanker will be removed; the propellant system will be deserviced and the OSCRS tanker will be prepared for shipment to KSC aboard a C5A aircraft or another type aircraft. Upon arrival at KSC or Cape Canaveral Air Force Station (CCAFS), the OSCRS tanker will be transported to an HPF, and the postlanding operations associated with a normal landing will be implemented.

3.1.3.3 GSE and Facility Operations

The approach taken by the trade study in determining the GSE required to support the OSCRS tanker program, was to evaluate the requirements within each processing element at the launch site. Based on the handling, checkout and servicing philosophies developed to support the OSCRS tanker design concept, each task was analyzed to ascertain the most viable GSE approach. A conceptual design requirement was prepared for each item of GSE identified. These requirements were in turn used as the basis for establishing the design, manufacturing, development, test, delivery schedule and estimated costs of the required GSE. As part of the trade study, the STS program's GSE designs were reviewed to ascertain which designs, if any, were feasible for use on the OSCRS program. Several STS GSE designs were found to be acceptable either as designed or with some design modifications. Certain OSCRS tanker unique GSE items, such as the Tanker Lifting/Handling Sling Set; the Tanker Support Stand, and the Propellant Servicing/Deservicing Unit (Figure 3.1.3.3-1 and Figure 3.1.3.3-2), will be designed, fabricated, tested, and delivered in time to support the tanker Qualification Test program. All GSE items, other than the Tanker Shipping/Handling/Storage Container and the Tanker Lifting/Handling Sling Set, will be delivered to KSC prior to delivery of the flight tanker.

KSC and Cape Canaveral Air Force Station have a variety of payload processing facilities in both the hazardous and nonhazardous categories. Not all of these facilities are acceptable for use by the OSCRS program. Since the OSCRS tanker is a vertical payload, those facilities handling horizontal payloads were eliminated from the trade study's selection process. In selecting the facilities which best support an optimized turnaround processing flow, strong consideration was given to a facility's availability and storage capability. The OSCRS tanker is, by its function, considered to be a hazardous payload. Therefore, it is very important that excessive moving/handling of the tanker be avoided. The use of one facility, dedicated to the OSCRS program, in which all processing operations from inspection through servicing can be performed, will greatly reduce the moving/handling of the tanker. A dedicated facility will provide a home base for all OSCRS unique GSE and a storage place for the tanker between missions. Building M7-1410, Cryogenics #2, ideally located in the vicinity of the Cargo Hazardous Servicing Facility (CHSF) and the Vertical Processing Facility (VPF), is a prime candidate to be the dedicated facility for the OSCRS program. Selection of this facility would eliminate conflict of interest with other programs, such that might be encountered in the CHSF or HMF.

3.1.3.4 On-Orbit Operations

A trade study was performed to develop an on-orbit operational timeline representative of a typical Extravehicular Activity (EVA) in support of a monopropellant tanker transferring consumables to a berthed spacecraft in the Orbiter payload bay.

The results of this study (see Figure 3.1.3.4-1) indicate that sufficient time is available to perform a single transfer of hydrazine (N_2H_4) supported by normal EVA activity. Inclusion of an OSCRS on-orbit relocation significantly extends this timeline.

FIGURE 3.1.3.3-1 TYPICAL HANDLING GSE CONCEPT

TOP COVER INSTALLATION - CONTAINER ASSY & LIFTING/HANDLING SLING SET

TOP COVER - CONTAINER ASSY

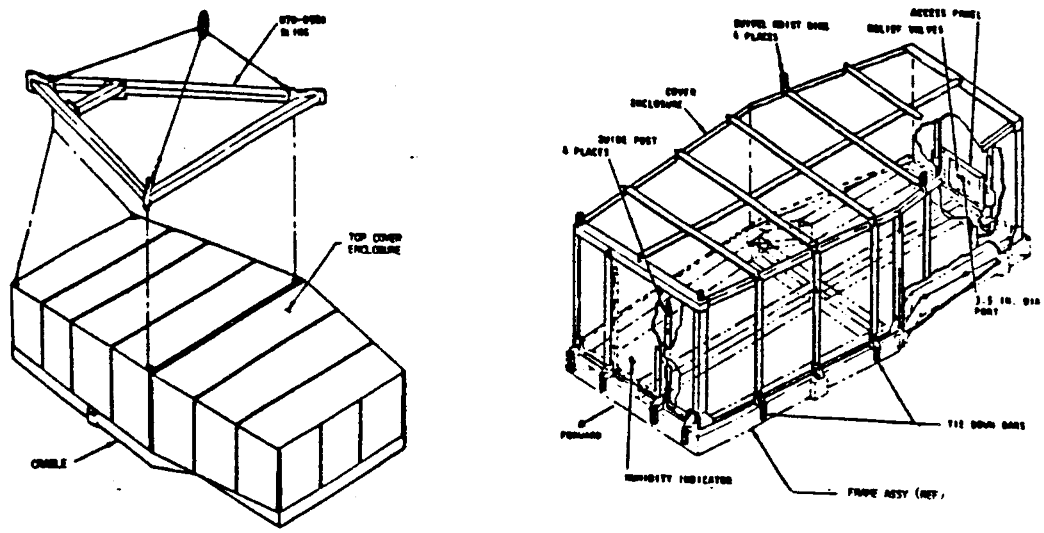


FIGURE 3.1.3.3-2 TYPICAL FLUID/MECHANICAL GSE CONCEPTS

FUEL SERVICING/DESERVICING UNIT

TANKER SUPPORT STAND

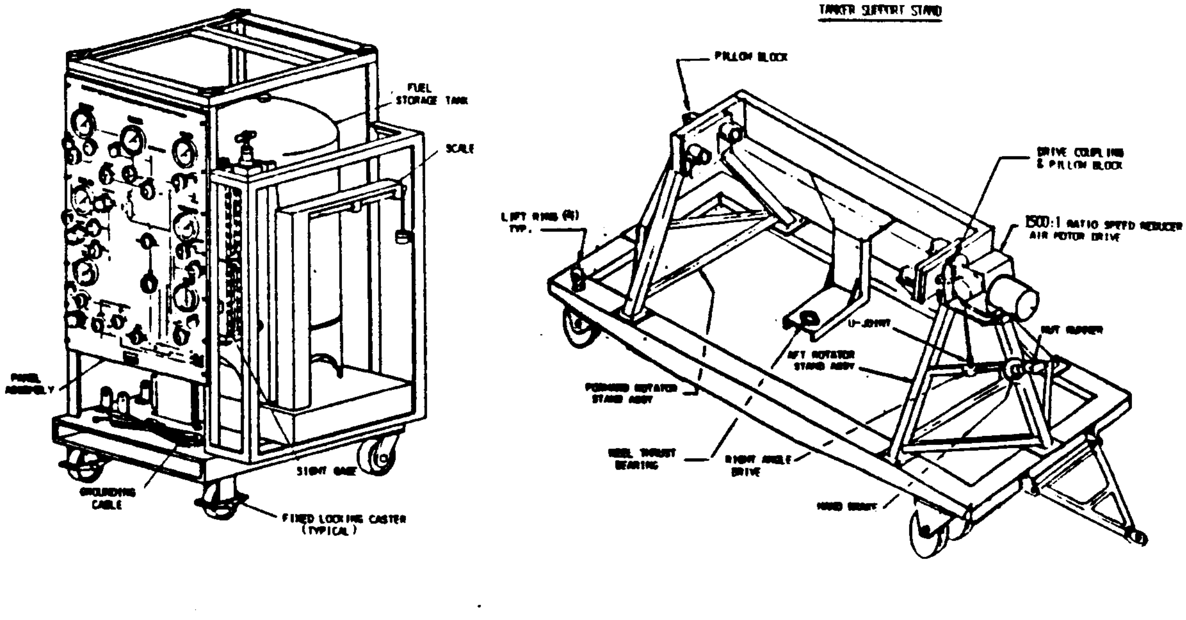


FIGURE 3.1.3.4-1 TRANSFER OPERATION TIMELINE

- EVA OPERATIONS

TRANSFER OPERATION

	EVENT TIME HRS: MIN	CUM TIME HRS: MIN
o LEAVE AIRLOCK	00:01	00:01
o OBSERVE AND ASSIST BERTHING	00:23	00:24
o OBTAIN MFR, TOOLS, AND TRANSLATE TO GRO	00:13	00:37
o CONNECT ELECTRICAL UMBILICAL	00:04	00:41
o CONNECT AND VERIFY FLUID COUPLING	00:44	01:25
o EVA STANDBY DURING FLUID TRANSFER	01:45	03:10
o AFD AND EVA CREW CLOSE/VERIFY COUPLING SEAL, EVA CREW DISCONNECTS AND STOWS COUPLING AND CONNECTOR	00:58	04:08
o AFD CREW VERIFIES S/C SYSTEMS AND EVA SECURES S/C PANELS	00:15	04:23
o AFD CREW UNLATCHES S/C WITH EVA OBSERVE AND ASSIST	00:08	04:31
o AFD CREW RELEASES S/C AND EVA CREW STOWS EQUIPMENT AND RETURNS TO AIRLOCK	00:27	04:58

With the concern of the time factor of relocating the OSCRS in the payload bay, it is recommended that the relocation of the OSCRS be kept to a minimum, if relocation is necessary at all.

The procedures and specifications of a bipropellant resupply tanker differ in major respects as to basic transfer operations from the developed monopropellant design. This lack of commonality was evaluated in a separate IR&D study (Project 86210). The summary and conclusions/recommendations from that study are presented here for information.

The IR&D study (86210) presents EVA activities, time-lines and related information describing the on-orbit pre/post consumables transfer procedures, equipment and operational scenarios for a bipropellant preliminary tanker design. All transfer couplings (umbilicals) were; manually connected, configured for transfer operations and disconnected/stored. The EVA time-lines produced by this approach exceeded the maximum allowable single EVA by 3 hours and 50 minutes.

By re-defining the umbilicals to exclude EVA involvement (except for contingency support) and by developing automated/remote transfer couplings, including electrical connectors, the time-lines are significantly reduced to acceptable levels that can include EVA support well within the single EVA span of 6 hours.

Clearly the operation items requiring re-evaluation are the manual couplings for fluids/gaseous transfer of a bipropellant system. The recommended approach on on-orbit birpopellant pressurant, and ullage transfer requires the development of automatic, remotely operated (AFD) couplings and connectors.

3.1.3.5 Airborne Support Equipment (ASE)

The necessary ASE required to support the GRO resupply is summarized in Table 3.1.3.5-1. One major piece of existing ASE required to facilitate timely umbilical connections was identified. The Manipulator Foot Restraint (MFR) is a small work platform attached to the RMS by a standard grapple fixture and is capable of supporting a crew member and equipment during accomplishment of extravehicular tasks.

The OSCRS design will permit use of the Remote Manipulator System (RMS) foot restraint at required crew work stations for both OSCRS and OSCRS/Satellite interfaces. Special tools will be tethered to and stored on OSCRS adjacent to their use locations. Handholds/foot restraints integral to OSCRS structure also will be provided. Modification of the MFR appears necessary to permit adequate visibility and freedom of movement during the man/vehicle interface activities (Figure 3.1.3.5-1).

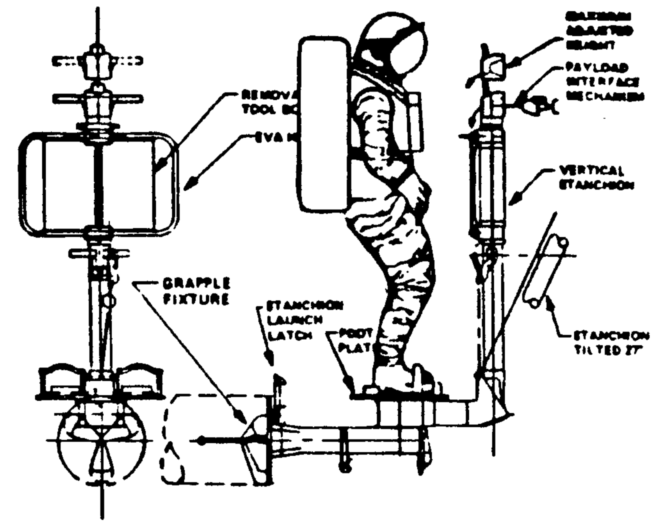
All Orbiter extravehicular activity (EVA) provisions including carry-on equipment required will have to be identified for each separate Orbiter mission. The consumables available on any single flight provide for three two-man EVA's. Two EVA's are for the use of payload related operations at no weight/volume cost to the payload. The third is reserved for Orbiter contingency.

TABLE 3.1.3.5-1
AIRBORNE SUPPORT EQUIPMENT

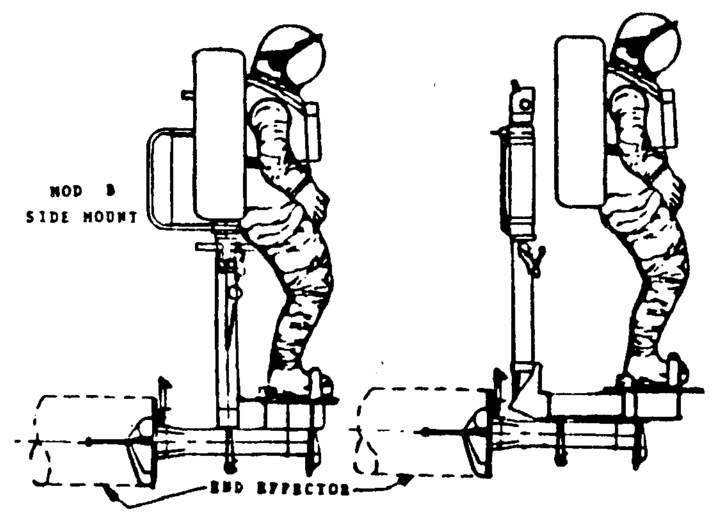
TOOL NOMENCLATURE	TOOL CATEGORY (1) A	TOOL CATEGORY (2) B	TOOL FUNCTION	MOD. REQ'D FOR OSCRS
RMS (Remote Manipulator system)		X	A mechanical arm which augments the systems in performing the deployment and/or retrieval of a payload	No
SEE (St'd. end effector for the RMS)		X	The endmost device on the RMS ARM-its prime function is to capture, hold, release payloads.	No
EMU-TV (extra-vehicular mobility unit television system		X	Helmet mounted television camera used for monitoring EVA crew activities	No
MFR (manipulator foot restraint)		X	A small work platform attached to the RMS by a st'd grapple fixture. It is capable of supporting a crew member and equipment during an EVA.	Yes (Ref. Figure 3.1.3.6-1 3.1.3.6-2
BPT (battery power tool)		X	Cordless, battery-powered, variable speed unit with a socket adapter fitting for attaching screwdrivers or wrenches.	Final tool for use on NAS9-17333 coupling not yet identified by NASA-JSC
HAND WRENCH		X	Manual socket wrench back-up tool for BPT	New-produced by Fairchild Controls Co.

① Category A equipment are those items considered standard for all extravehicular activities and is designed to enable the crew member to carry out tasks during EVA's. This equipment is normally manifested on each Shuttle flight. Examples: EVA mobility units (EMU), EVA cuff checklist, cargo bay storage ass'y (CBSA), portable foot restraint (PFR), etc. (A complete listing is given in JSC 19211, "Satellite Services & Equipment Catalog".)

② Category B equipment includes those systems and tools that have been developed for use with the orbiter but must be requested for use on any particular mission.



MFR/RMS COMBINATION TRANSPORTS CREW MEMBERS AND EQUIPMENT



MODIFICATIONS ARE REQUIRED TO PERMIT CREW MEMBERS MAXIMUM FRONTAL ACCESSIBILITY

FIGURE 3.1.3.5-1

The close proximity of the GRO electrical/avionics umbilical to the fluid coupling interface allows use of the RMS/MFR as configured for the fluid coupling engagement operation . No significant additions of ASE handholds nor foot restraints are foreseen due solely to the operational requirements of the electrical connectors. Additional handholds and foot restraints will be required as integral OSCRS structure. Appropriate location of these items must be addressed during the OSCRS structure design effort.

3.2. Monopropellant OSCRS Preliminary System Design/Development

The preliminary monopropellant OSCRS system design was created under statement-of-work task 2.2 and further developed under task 4.1. The discussions herein covers the results of both tasks.

The development of the detailed design of a hydrazine monopropellant resupply system builds on the preliminary system design resulting from the trade studies of paragraph 3.1. The depth and fidelity of the system design leads to the piece-part design and fabrication and provides a basis for establishing the development qualification and production program scope and cost estimate.

The tanker is the flight system mounted in the space shuttle payload bay which provides the propellant storage and servicing equipment needed to resupply the spacecraft. The baseline monopropellant tanker is designed specifically to resupply the Gamma Ray Observatory with up to 2450 lbm of hydrazine (N_2H_4). The hydrazine, which is stored in positive explusion propellant tanks, is pumped to the receiving satellite using lightweight gear type pumps. Quantities delivered are accurately measured using redundant turbine flow meters. The resupply operation is controlled by the crew in the Shuttle Orbiter AFD using avionics controls which employ three active strings to insure mission success with any single failure and safe operation with any two failures (FO/FS).

A major characteristic of the baseline monopropellant tanker is its design to accommodate growth with minimum scar weight impact due to its modular concept. The inboard profile of the tanker is depicted in Figure 3.2-1. A larger copy of the inboard profile (minus the insulation blanket) is provided for handy reference inside the back cover of this report.

The tanker is thermally insulated using 10 layer MLI with an outer beta fabric and the inner compartments are heated using lightweight panel heaters.

The OSCRS structure is constructed to form a 12-sided regular polyhedron periphery around a central hexagon cavity. The structure thickness (53.7 in.) is determined by the enclosed propellant tanks.

The geometry results in 6 square compartments designed to contain the propellant tanks. Pressurant tanks can be installed in any one of the 3 lower traingular bays between the square propellant bays.

Four of the propellant tanks are installed by removal of the exterior shear panels. The longeron trunnion box structure is permanent to basic structure and requires installation of the two middle tanks through removal of the interior shear panels. Pressurant tanks are installed and removed by removal of the outer perimeter shear panels of the triangular bays.

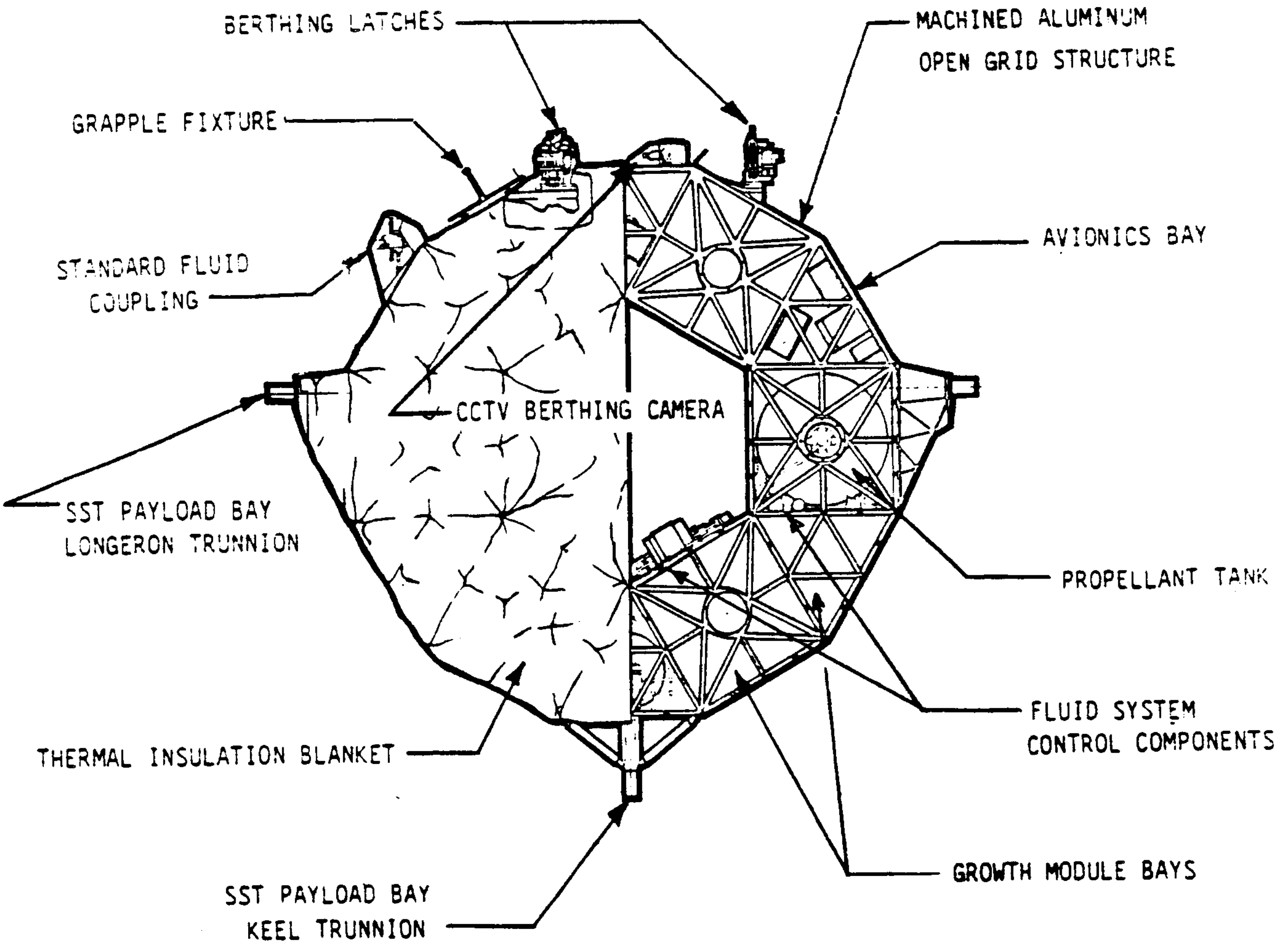


FIGURE 3.2-1 **MONOPROPELLANT OSCRS TANKER**

The fluid subsystem modular components will be installed in the upper and lower triangular volumes integral to the central hexagon.

The electrical/avionics subsystem will be mounted on the inside facing radiator panel that is also the shear panel for one of the triangular bays on the upper starboard side of the tanker.

Longeron trunnion fittings (i.e., integrally machined aluminum torque boxes) on this structure extend to each side and contain 2 trunnions each. The single keel trunnion fitting is designed in a similar fashion. The trunnion spacing was defined by the minimum centerline spacing compatible with the handling by the Payload Ground Handling Mechanism (PGHM).

The standard fluid servicing coupling, and associated ASE tools, are located in a triangular bay on the port side of the tanker. On the shear panel directly above the coupling storage bay, a flight releasable grapple fixture (FRGF) is attached to permit in bay relocation of the tanker.

The docking latches, and a closed circuit TV (CCTV) camera to assist the AFD crew in berthing, are located on top of the tanker structure.

3.2.1 Structure Definition

Low cost and light weight were characteristics that were highly influential in selecting the structural configuration. Study of past space programs containing major structural elements indicates that the assembly with the fewest parts per unit of weight costs less than competing structures.

It has been assessed that the most economical method for building an aerospace structure of this type is to machine large integral structural parts which combine all the necessary features for assembly. This reduces the high cost of assembly fixtures. The basic structure serves that role itself. The recommended structural configuration is integrally machined open truss triangular structure with individual members as large as possible. The weight is kept to a minimum by keeping the number of parts down. This occurs because wherever separate members transfer load to each other there is an overlap and wherever there is an overlap, there is a weight penalty.

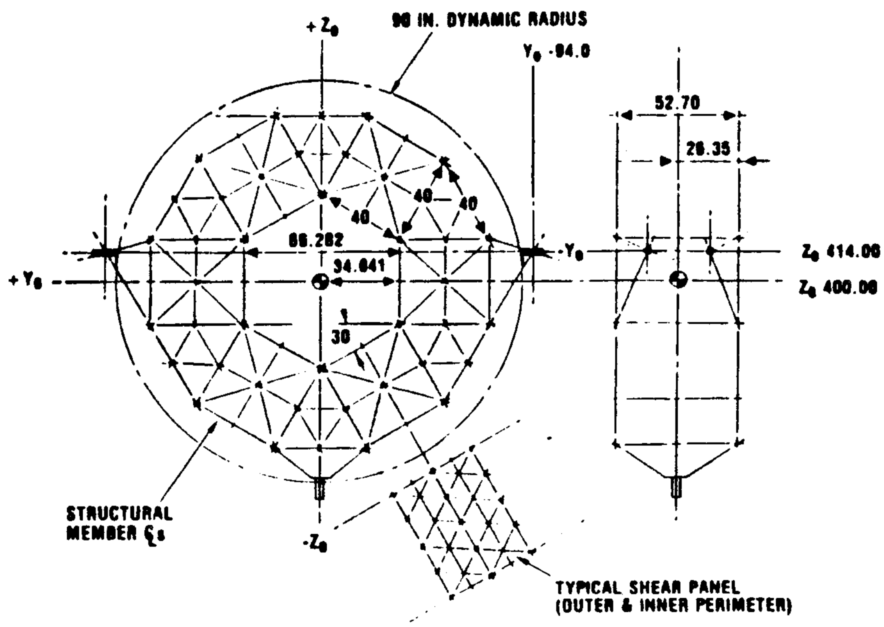
The OSCRS basic structural geometry, shown in Figure 3.2.1-1, evolves from a 12-sided regular polyhedron periphery around a central hexagon cavity. The structure thickness is determined by the enclosed propellant tanks, in this case up to six Gamma Ray Observatory (GRO) fuel tanks.

The geometry results in 6 square compartments containing from 1 to 6 tanks. All longitudinal surface elements, i.e., shear panels, for these 6 compartments are geometrically identical in length and width, simplifying fabrication and assembly. Typical construction details are shown in Figure 3.2.1-2.

Longeron trunnion fittings, i.e., integrally machined aluminum torque boxes, (Figure 3.2.1-3) on this structure extend to each side and contain 2 longeron trunnions each. The trunnion spacing was defined by the minimum centerline spacing compatible with the handling by the Payload Ground Handling Mechanism (PGHM). The single keel trunnion fitting is designed in a similar fashion.

FIGURE 3.2.1-1

Basic Structural Dimensions



Basic Structure Features Simple Shear Joints

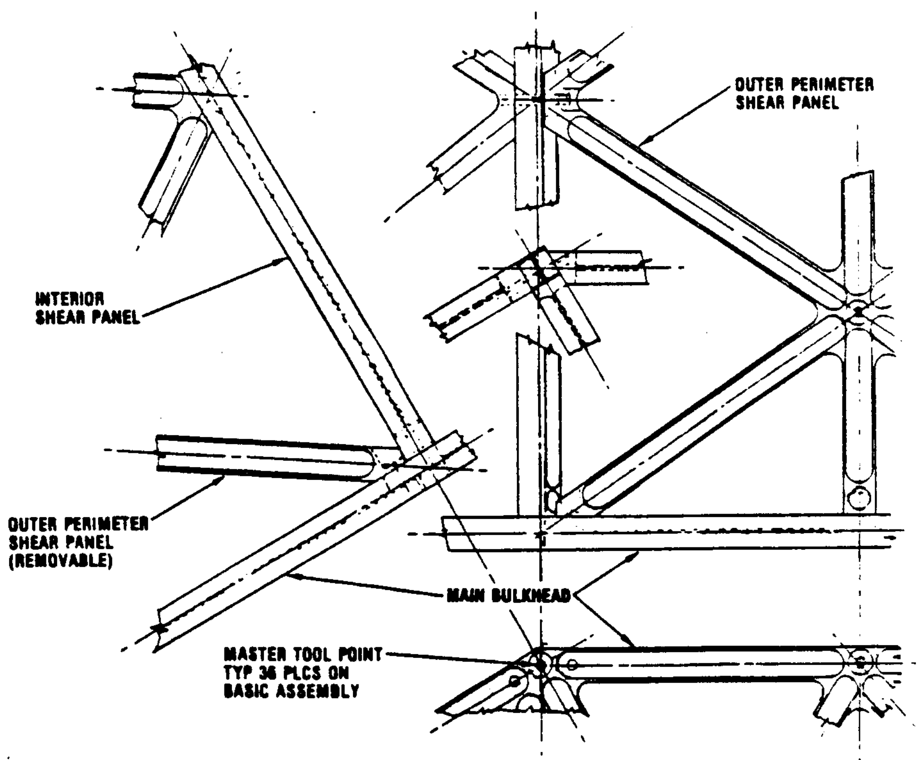


FIGURE 3.2.1-2

Longeron-Trunnion/Fitting Structure
(Scuff Plates Not Shown)

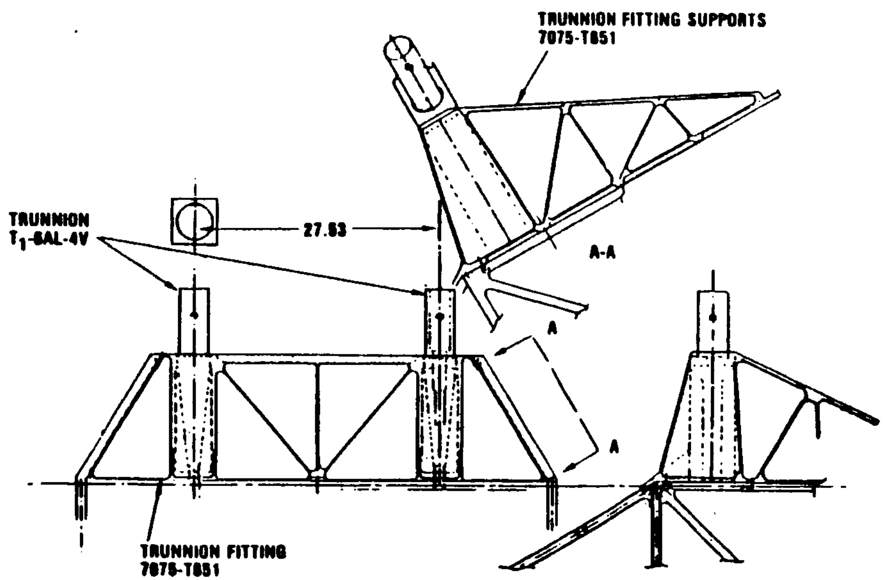


FIGURE 3.2.1-3

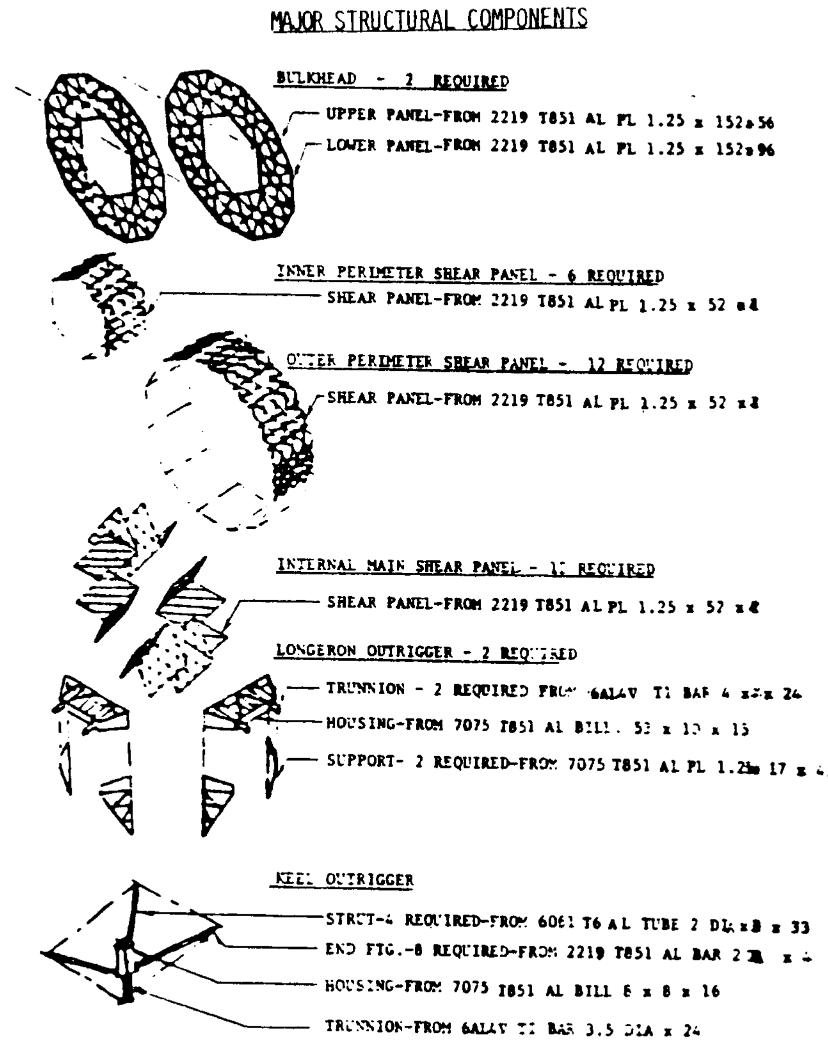


FIGURE 3.2.1-4

For maximum stiffness, minimum weight and cost, all major structural components are machine 2124-T851 (if welding is desired) or 7075-T7352 aluminum alloy. Parts made from these materials (Figure 3.2.1-4) will be finished to provide protection from corrosion in accordance with the requirements of MFSC Spec 250, class II, as a minimum. As required for specific load intensities such as propellant tank and trunnion reactions, machined strut elements are tailored for the defined load paths.

Forward and aft bulkhead frames are milled in two pieces each from the largest available mill-run plate stock.

3.2.2 Fluid Subsystem Design

The baseline fluid subsystem design, for the monopropellant OSCRS, is presented in Figure 3.2.2-1.

Layout of the fluid subsystem schematic divides subsystem components into several convenient units based on their functional operations:

1. Propellant Storage Unit.
2. Propellant Tankage Ullage Control Unit.
3. Propellant Transfer Control Unit.
4. Coupling Leak-Check/Vent Control Unit.
5. Tanker/Spacecraft Propellant Interface Unit.

3.2.2.1 Propellant Storage Unit

The propellant storage unit (Figure 3.2.2-2) is comprised of the OSCRS propellant tankage and the tank interconnect manifold hardware. Rockwell's baseline conceptual design of the monopropellant resupply tanker utilizes two GRO propellant tanks for propellant storage. The resupply capacity of the two GRO tank configuration is 2472 lbm of hydrazine. Additional GRO tanks can be attached to the baseline design; up to four additional tanks, bringing the resupply capacity to 7416 lbm of hydrazine.

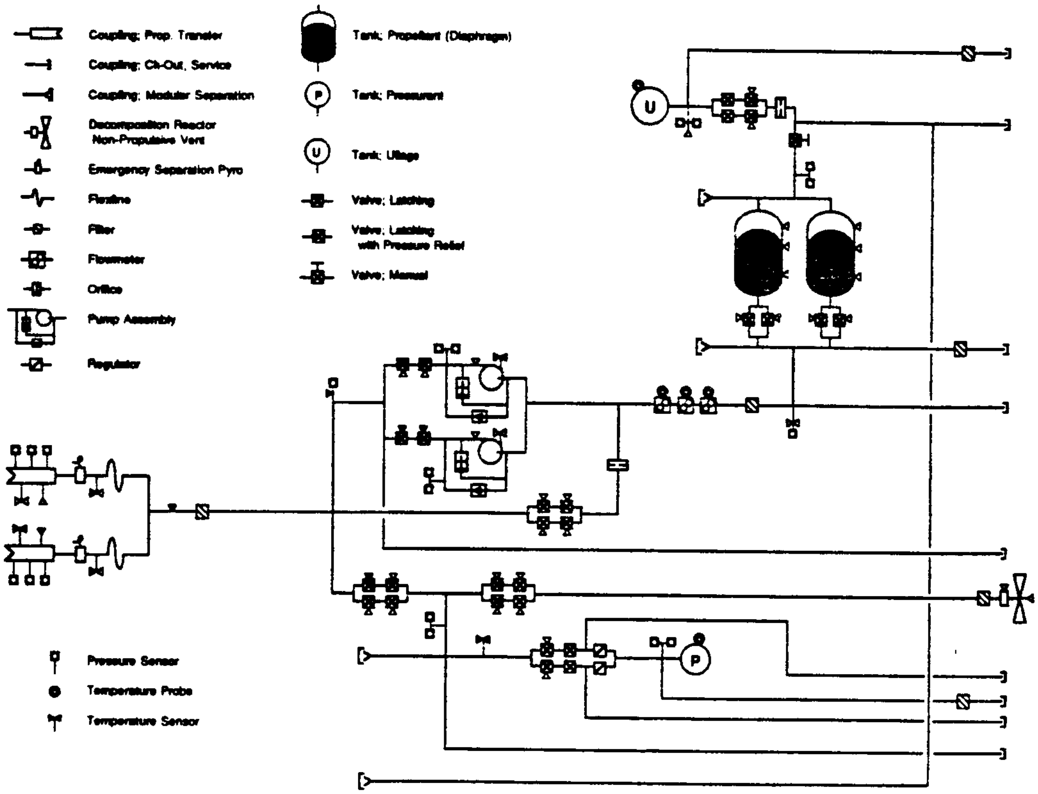
The GRO propellant tank is conoellipsoidal in shape; approximately 36 inches internal diameter and 47 inches internal length. Gas-free expulsion of propellant is achieved using an elastomeric diaphragm as the tank propellant acquisition device. The GRO tank is designed for a maximum operating pressure of 400 psid, with a minimum burst capability of 800 psid. GRO propellant tanks, which have been qualified for the GRO satellite, weigh approximately 99 lbs.

The propellant tanks are interconnected in parallel, with parallel redundant valves at each of the tank outlets. Tank isolation valves are magnetically latching and possess a reverse flow pressure relief capability.

Mechanical couplings are utilized to attach additional propellant tanks to the tank manifold.

FIGURE 3.2.2-1

BASELINE MONOPROPELLANT FLUID SUBSYSTEM SCHEMATIC



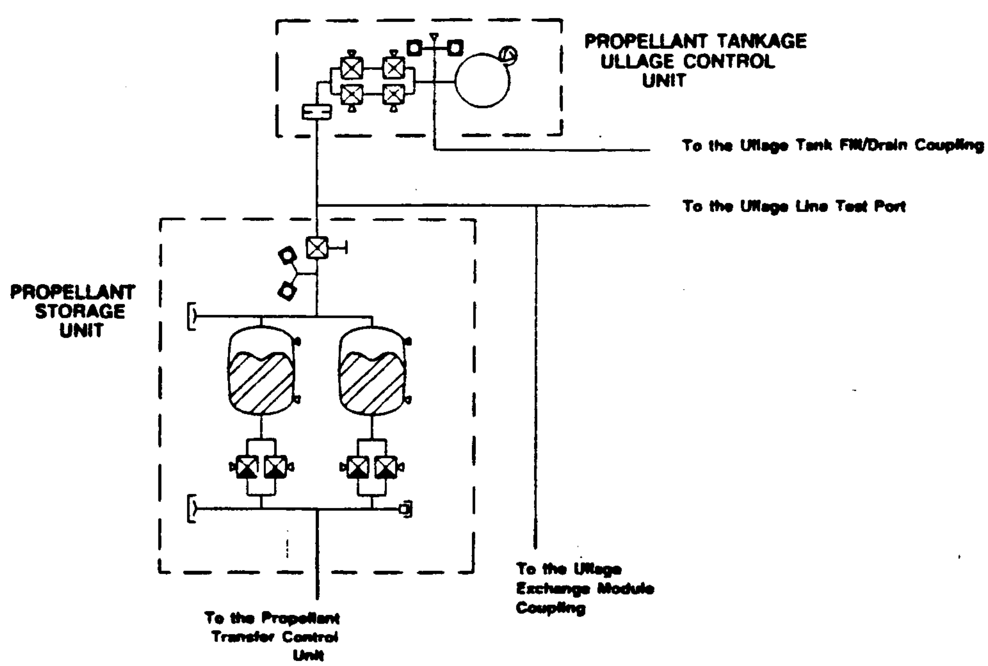


FIGURE 3.2.2-2 Schematic of Propellant Storage and Ullage Control Unit

3.2.2.2 Propellant Tankage Ullage Control Unit

Prior to the on-orbit activation of the OSCRS' fluid transfer system, the transfer propellant is exposed to as little ullage gas as possible; this insures a minimal percentage of gas saturating the propellant. As propellant is transferred out of the propellant tanks, additional pressurant is required to maintain the propellant tank ullage pressure. The ullage control unit (Figure 3.2.2-2) supplies the OSCRS' propellant tanks with an auxiliary source of pressurant.

This unit consists of an ullage tank, a flow restricting orifice, and a series/parallel redundant cluster of isolation valves.

The ullage tank is spherical and of a composite construction consisting of a titanium liner with a Kevlar structural overwrap. The approximate diameter of the tank is 19 inches, with an MEOP of 2000 psia. The ullage tank is filled to meet the specific needs of each resupply mission. The initial pressure of the ullage tank is such that when the ullage tank isolation valves are opened, the operating pressure of the propellant storage unit does not exceed the MEOP of the propellant tanks.

Pressurant flow into the propellant tank is restricted by a fixed tortuous orifice. The orifice is located downstream of the ullage tank isolation valves.

3.2.2.3 Propellant Transfer Control Unit

The propellant transfer control unit (Figure 3.2.2-3), transports resupply propellant from the OSCRS propellant tankage into the propulsion system tankage of a receiver vehicle.

The unit consists of the three quantity gauging flowmeters, two parallel redundant propellant transfer pump assemblies; a flow restricted, pump by-pass orifice/valve assembly; and the flexline manifold.

Gauging of resupply propellant is performed by triple redundant flowmeters. Trade studies have identified drag body and/or turbine type flowmeters as a viable approach to determining and controlling the mass of propellant transferred during on-orbit resupply operations. Verification of propellant mass transferred, to an accuracy of (+/-) 1% is considered attainable with available state-of-the-art hardware. Three flowmeters are placed in series to provide accuracy/failure redundancy.

Each pump assembly is made up of three separate elements; 1) the transfer pump, 2) a satellite overpressurization relief circuit, and 3) a pump by-pass circuit.

Preliminary operational characteristics of a monopropellant transfer pump have been identified by various trade studies. These studies have identified a monopropellant pump design flowrate of 2.5 and 5 gpm, with a head pressure of approximately 400 psia. By use of dual pumps, flow rates of 7.5 and 10 gpm can be achieved.

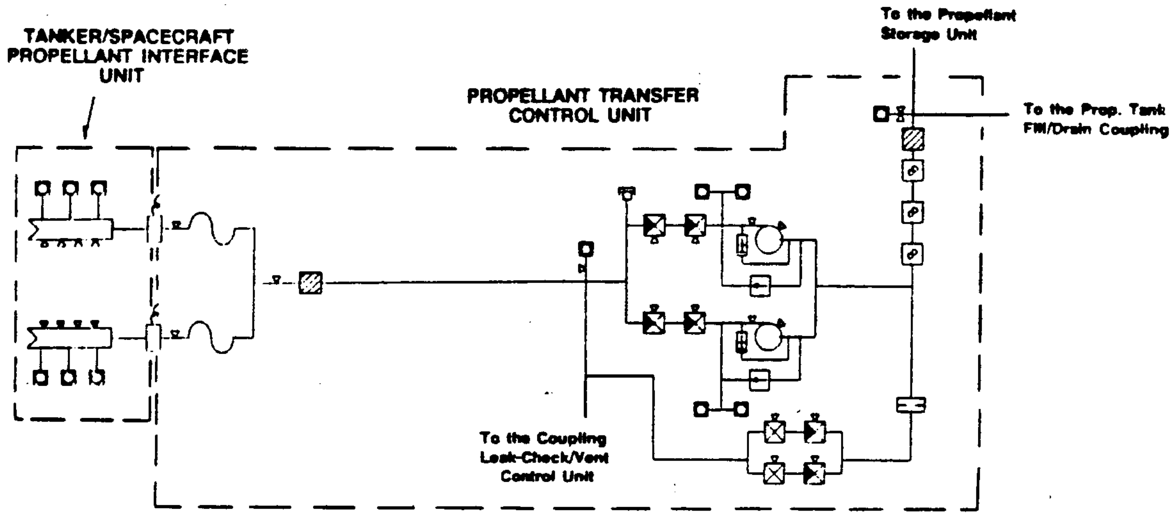


FIGURE 3.2.2-3 Schematic of Propellant Transfer Control Unit

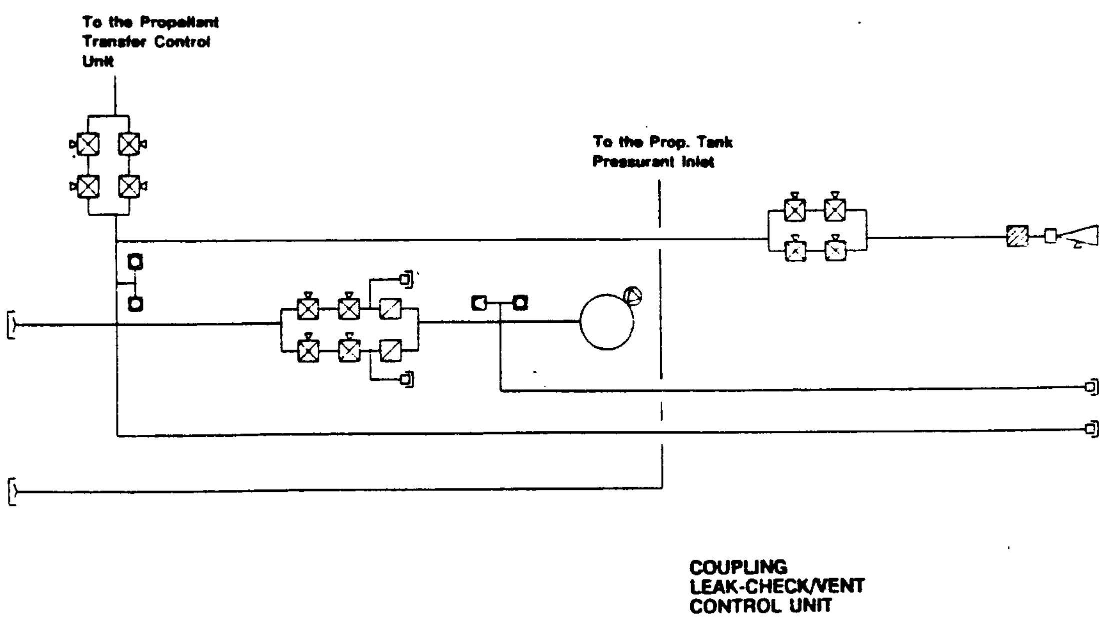


FIGURE 3.2.2-4 Schematic of Coupling Leak/Vent Control Unit

Each pump assembly has a by-pass circuit, allowing the transfer of propellant, by taking advantage of the positive pressure differential between the OSCRS propellant tankage and the receiver satellite's tankage. Propellant backflow is controlled by a check valve.

To protect the receiver satellite's propulsion system from overpressurization, a relief valve has been incorporated into each of the pump assemblies. In the event that the pump outlet pressure is greater than the desired transfer pressure, the relief valve would relieve back to the pump inlet.

Isolation of the pump assemblies is achieved by series redundant magnetically latching valves, possessing a reverse flow pressure relief capability.

The pump by-pass orifice/valve assembly is designed to slowly fill the evacuated coupling manifold, prior to opening the pump assembly isolation valves.

Use of the by-pass circuits built into each of the pump assemblies, to fill the evacuated coupling manifold, is not recommended. As the pump isolation valves are opened, the pressure differential between the evacuated coupling manifold and the upstream pressure of the valves would cause the propellant entering the manifold to initially vaporize. As the propellant vapors in the manifold are recompressed back to a liquid, the propellant flowrate through pump assembly's by-pass circuit would not allow enough time for the heat generated by the recompression to dissipate. The increasing temperature in the manifold would cause the adiabatic detonation of the transfer propellant. Inserting an orifice upstream of the pumps would greatly hinder the performance of the pumps and increase the length of the resupply operation.

The flexline manifold connects the propellant transfer control unit to the tanker/satellite propellant interface unit. Approximate length of each of the two flexlines is 6 feet. Each flexline is connected to the propellant interface unit by the tanker half of the emergency separation valves.

3.2.2.4 Coupling Leak-Check/Vent Control Unit

The coupling leak-check unit (Figure 3.2.2-4) is designed to provide an EVA operated gas supply (separate from the propellant transfer unit's pressurant source), for fluid connection leak checks of the OSCRS/receiver vehicle interface.

The leak check unit consists of a small helium bottle, pressure regulators, and several series/parallel redundant clusters of isolation valves.

The helium bottle is spherical in shape and made of titanium. The approximate diameter of the tank is 8 inches, with an MEOP of 1000 psia.

There are two parallel redundant, fixed set point pressure regulators between the helium tank and the regulator isolation valves. The pressure regulators reduce the helium source pressure to the desired working pressure. Preliminary analyses of the operation of the leak-check unit, has defined a nominal regulating pressure of 100 psia.

Propellant contaminated gases and small quantities of raw propellant can be vented overboard, through the non-propulsion catalytic reactor. The design requirements for the catalytic reactor have not yet been determined. The combustion products from the reactor are expelled in selected directions, in a non-propulsive manner to maximize safety.

Fluid flow into the reactor inlet is controlled by a cluster of series/parallel redundant isolation valves.

3.2.2.5 Tanker/Spacecraft Propellant Interface Unit

The propellant interface unit (Figure 3.2.2-3) utilizes the NASA/Fairchild fluid transfer coupling (NAS9-17333) as the standardized tanker-to-spacecraft propellant transfer interface. Two propellant transfer couplings are required to meet the fluid subsystem's requirement for a fail operational functional capability. Each of the couplings are connected to a jettisonable half of the emergency separation valve. The other half of each emergency separation valve is connected to the flexline manifold.

3.2.2.6 Component Installation

The fluid subsystem components are installed in modules to aid in rapid changeout for maintenance or mission specific requirements. Each module is removable by disconnecting mechanical fittings (lines and panel mounting bolts) and lifting it out with appropriate GSE and or manufacturing tools. The component modules for the baseline tanker are depicted in Figure 3.2.2.6-1.

3.2.3 Avionics System Schematic

An avionics system has been defined for the OSCRS that will provide the capability to safely control the OSCRS fluid systems and the receiving satellite during resupply operations. The avionics system will also provide OSCRS/satellite status and performance data needed by the crew and ground personnel to support on-orbit operations, including system safing if required. Figure 3.2.3-1 is a block diagram of the three-string OSCRS avionics system which is comprised of equipment located on the Orbiter aft flight deck (AFD) and equipment located on the OSCRS tanker module located in the payload bay.

As shown on Figure 3.2.3-1, the OSCRS avionics will interface with: the Orbiter electrical power system to acquire the required power; with the Orbiter instrumentation system to route data to the ground via the telemetry system; and with the Caution and Warning system to alert the crew of serious out-of-limit conditions. An interface with Orbiter GPC's is provided in anticipation of future resupply mission requirements, but the currently defined avionics system operates independently of the GPC's.

Figure 3.2.3-2 gives a more detailed view of the avionics system, showing the basic control concept. The AFD avionics consists of a dedicated OSCRS Control Panel and two portable GRID computers. The GRID computers provide graphic displays of OSCRS system status as well as tabular data formats and text formats for crew information. The GRID keyboard is used for non-critical command inputs to the OSCRS system. The crew will use the dedicated OSCRS Control panel to select FMDM sequences to be run, to select banks of valves to be operated and to initiate manual valve safing, if required.

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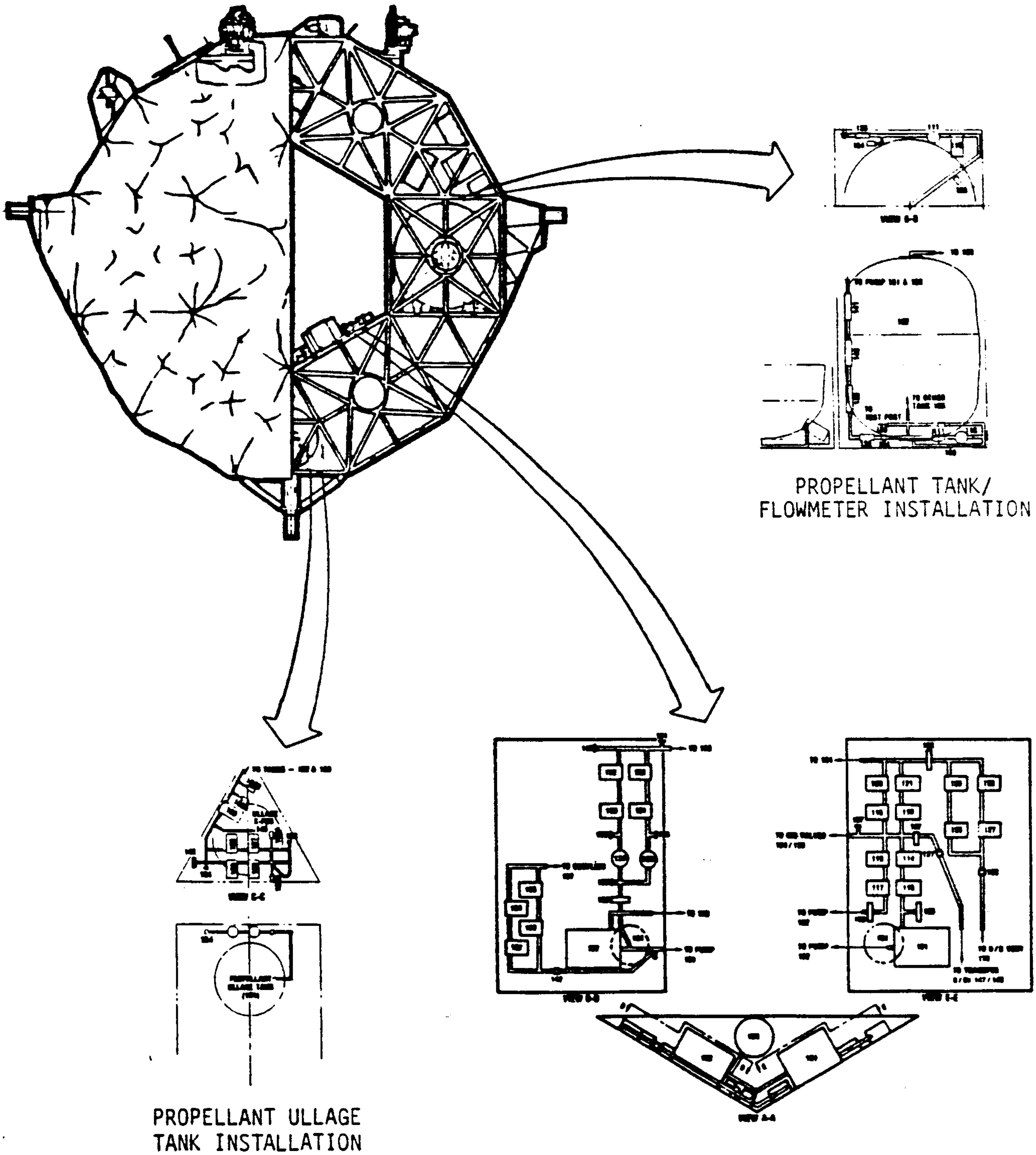


FIGURE 3.2.2.6-1 COMPONENT INSTALLATION

FIGURE 3.2.3-1
OSCRS Avionics System Block Diagram

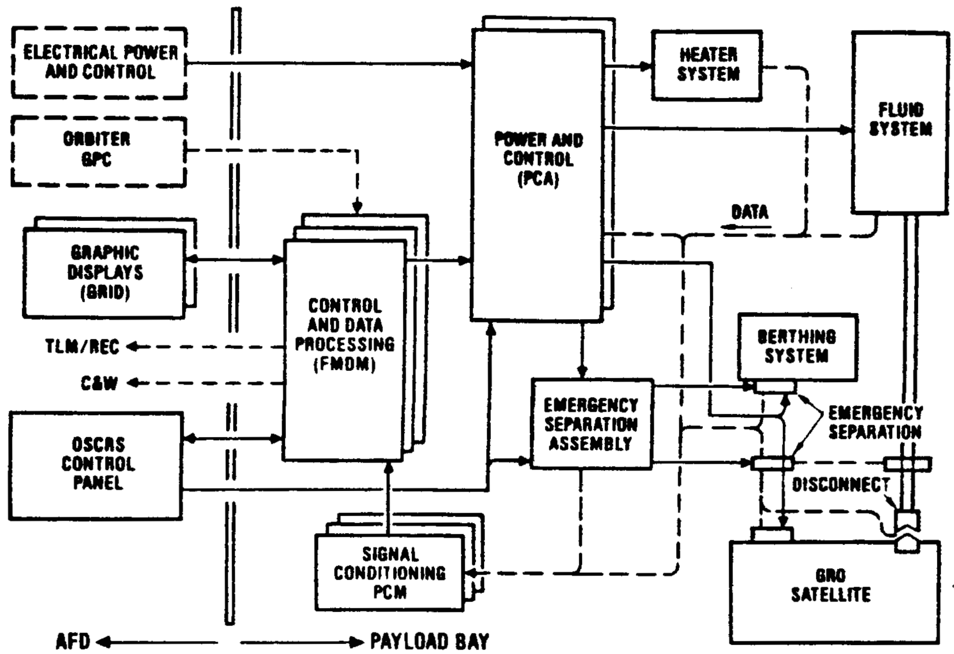
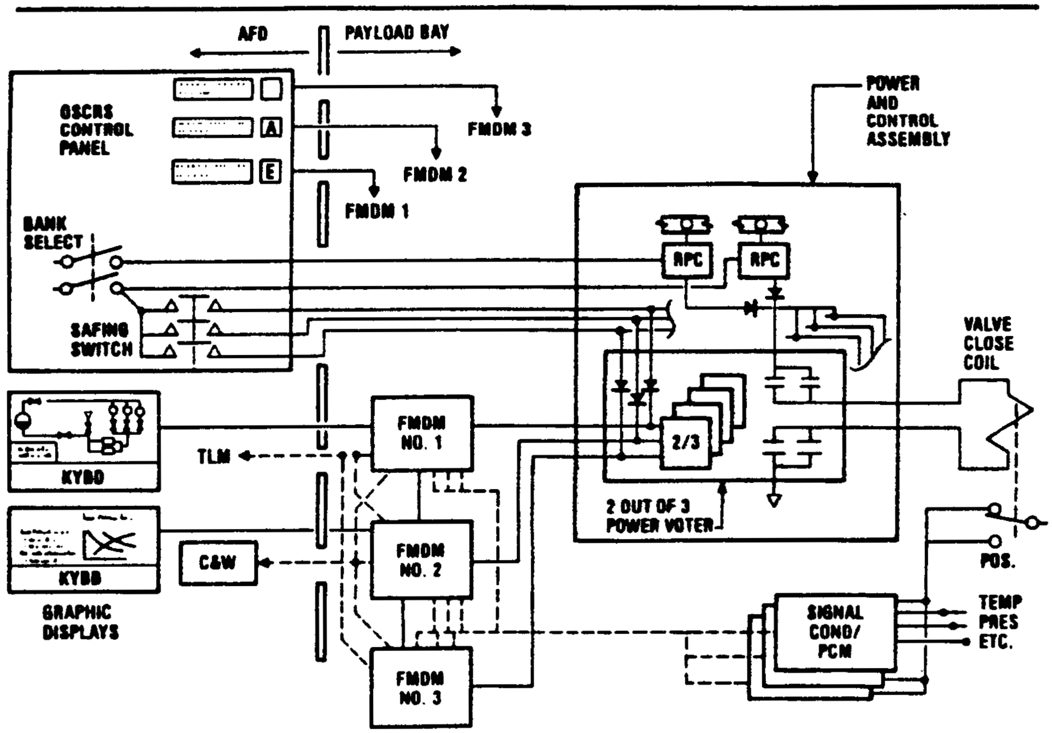


FIGURE 3.2.3-2
Avionics Control Concept



The three-string avionics system will utilize three flex multiplexer-demultiplexer (FMDM) units, which are a derivative of the proven Orbiter MDM units, for system control and data processing. The FMDM, which incorporates a microprocessor and memory capabilities into the existing MDM design, minimizes cost and schedule problems typically associated with developing an integrated avionics system. Figure 3.2.3-3 is a block diagram of the FMDM.

The three-string concept permits the OSCRS resupply mission to continue after any one system failure and supports safing the system after two failures. Adequate data is provided to the crew for safe control of the system, even after two failures.

A new concept included in the avionics system as shown in Figure 3.2.3-2, is the use of a 2-out-of-3 power voter module. Input commands are provided to the voter module from the 3 FMDM's, and when any 2 of the 3 inputs are activated, 28 VDC power is applied to the valve or other component being controlled. The voter modules represent a significant simplification in the logic and interconnecting wiring required in typical redundant systems.

The emergency separation function, shown on Figure 3.2.3-1, provides the capability to separate the receiving satellite from the OSCRS tanker without the use of the EVA. Pyrotechnic devices are used to separate fluid supply lines, electrical lines and berthing latches to permit the satellite and OSCRS to separate. The pyrotechnic devices are fired by Pyrotechnic Initiator Controllers (PIC's) located in the Emergency Separation Controller. The PIC's are activated in response to ARM and FIRE commands from crew-operated switches on the AFD OSCRS Control Panel.

The instrumentation system uses three integrated Signal Conditioner/Pulse Code modulation packages to acquire and process OSCRS system data. In the SC/PCM unit, common signal conditioning circuits are used rather than the typical dedicated circuits, and the data is formatted into a PCM stream and routed to the FMDM's. Three independent data paths are provided, as shown in Figure 3.2.3-4, to assure that adequate data will be available to support safe operations even after two system failures.

The capabilities of the Orbiter Caution and Warning System are available to payloads through a standard interface, as shown on Figure 3.2.3-5, which shows the OSCRS C&W concept. The Orbiter C&W provides OSCRS status information to the crew during ascent and entry, when the GRID displays would not be available. During resupply operations, OSCRS Avionics provides two failure tolerant C&W data in addition to the Orbiter C&W data.

The avionics component installation into the tanker is shown in Figure 3.2.3-6.

3.2.4 Thermal System Definition

The preliminary thermal control system design will support OSCRS operations under all conditions for any mission duration. Additional analysis is required to optimize the design and to verify the thermal subsystem capabilities. Specific details of the design are discussed in the following subparagraphs.

FIGURE 3.2.3-3 OSCRS FMDM

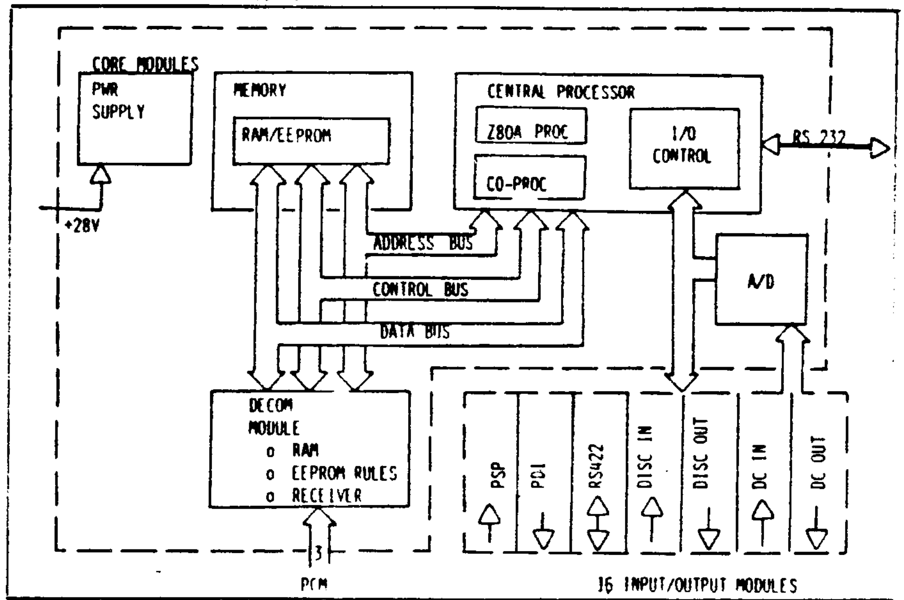


FIGURE 3.2.3-4

Redundant Measurement Concept

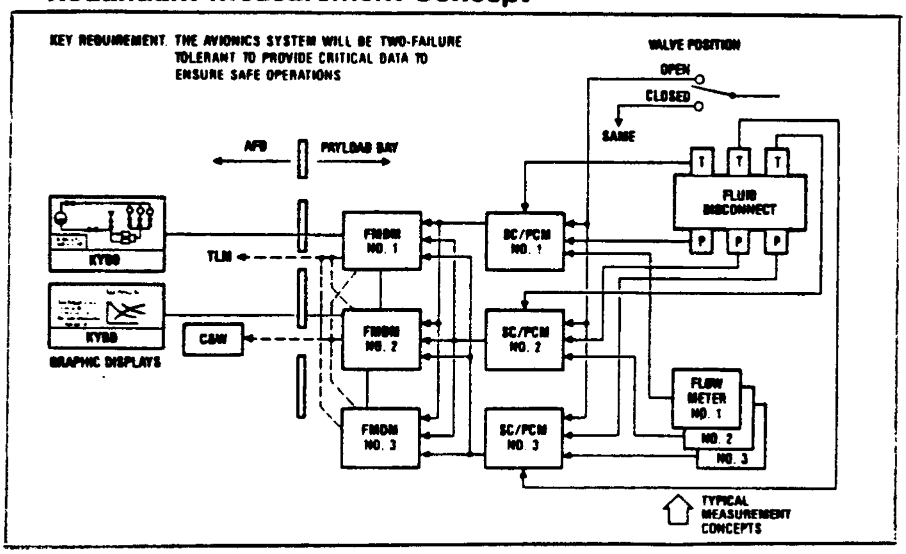
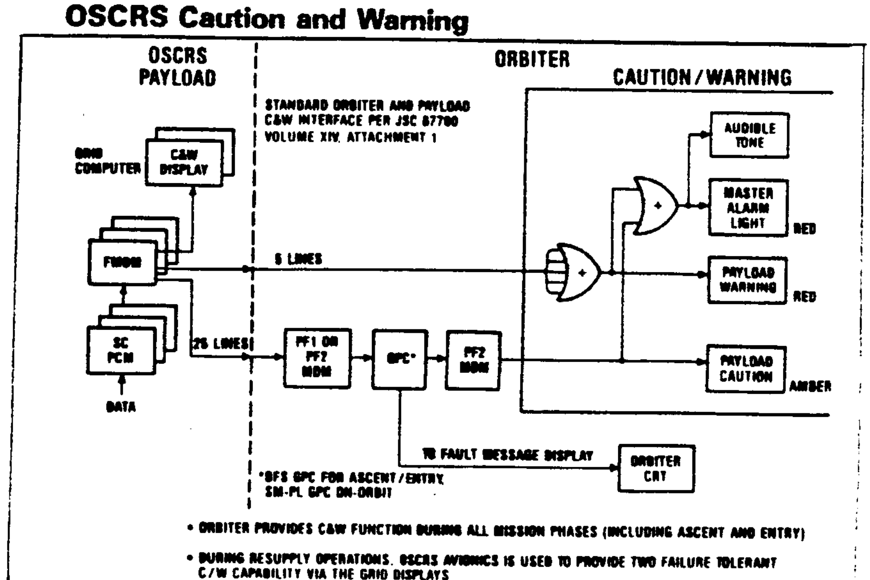


FIGURE 3.2.3-5

OSCRS Caution and Warning



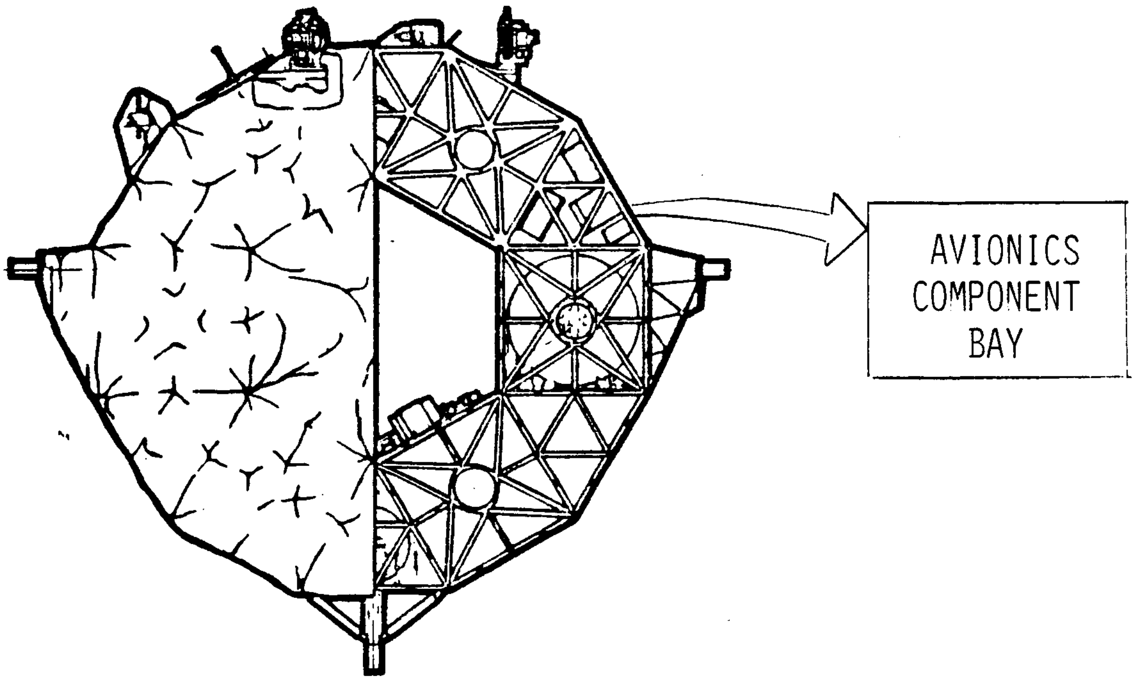


FIGURE 3.2.3-6 AVIONICS COMPONENT INSTALLATION

3.2.4.1 Envelope

The outer surface of the OSCRS tanker is insulated with multilayer insulation, covered with beta fabric, to protect the MLI and to obtain the desired optical properties (Figure 3.2.4.2-1). Construction of the MLI blankets follows typical Orbiter practices.

3.2.4.2 Interior TCS

Heating is provided by panel type electrical heaters. Provision for the heaters are (1) a panel on each of the central (inner perimeter) shear web structures with 215 square inches of surface area, each, and (2) a panel on each of the twelve internal shear web structures with 215 square inches of surface area, each. The actual heaters occupy about 195 square inches each. The additional area is used to ensure sufficiently low heater temperatures. The heaters are not centered on the shear panels; they are offset forward and aft alternately, as shown in Figure 3.2.4.2-1. The heaters operate at less than 125°F. They are located near the tank ends to maximize the gap between tank surfaces and heaters. In addition, this places the heaters near the large, conductive bulkhead members. The supporting panels are aluminum, .032 inch thickness or less, coated with high emissivity material on areas not covered by the heaters.

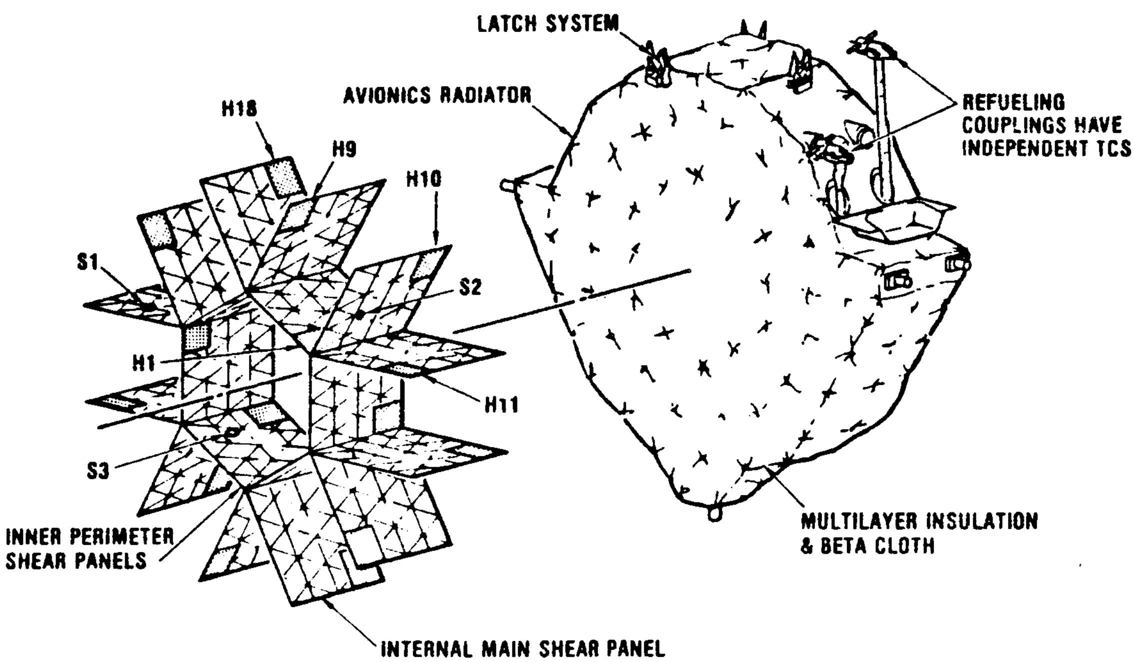
The heaters are either the patch type utilized on the Orbiter OMS pod or the panel type used in the Orbiter FRCS. The printed circuit design used in the OMS pod is believed to be lower cost. Lightning protection incorporated in the pod heaters is not required. Power density of the heaters is much lower than for the pod heaters. The heaters will be of the dual circuit type. That is, each heater will have two independent electrical heater circuits, either of which can provide the required heater output, designated circuits A and B. The avionics system provides the capability to manually select either circuit A or B of a group (or all) of the tanker heaters in the event of a heater failure.

In the event that both an A and B circuit thermostat fail off in a single heater zone, the minimum remaining power capability of the heater system is 308 watts at 100 percent duty cycle. This is sufficient for a continuous cold case, but heat distribution is not uniform. Under this failure state, long term cold conditions could not be supported. Total compartment heater power on orbit is 616 watts peak power. With this power level, a cold attitude is supported for at least 50 hours with a 50 percent heater duty cycle, under radiator heat loss conditions.

Heaters are controlled by mechanical thermostat switches in three separate groups: upper right, upper left, and lower compartment as viewed looking forward (Figure 3.2.1-1). Upper right hand heaters consist of the three heaters located nearest to the avionics radiator. These heaters are located on two internal and one inner perimeter shear panels and are directly controlled by a single thermostat, in series with an overtemperature thermostat.

FIGURE 3.2.4.2-1

Thermal Control System Concepts



Upper left hand heaters are powered by a thermostat in conjunction with RPC's in the Power Control Assembly. The lower compartment heaters are controlled by a thermostat located on the fluid system hardware panel. This thermostat also operates in conjunction with the RPC's. If phase C/D analysis shows that additional control is required in the lower area, a second thermostat may be wired in parallel with the first at another location. Each of these thermostats is also in series with an overtemperature thermostat. The B circuit is identical to the A circuit which is described above.

The use of the RPC's to power some of the heaters is dictated by the limited power carrying capability of the thermostats. In concept it is somewhat similar to the use of LCA drivers in the Orbiter OMS Pod control system, and avoids use of the instrumentation system and Flex MDM's. In addition, the number of heater zones is reduced. This decreases the likelihood of uneven cycling of the various heater zones.

To avoid increasing the avionics requirement, the thermostats are located in series between the crew switches and the Power Control Assemblies. Orbiter passive thermal control attitudes are a final backup for heater failure problems.

A maximum total conductance to Orbiter structure of 1.26 Btu/Hr-°F is required. To achieve this conductance, external insulation is required for the trunnion fittings and trunnion fitting supports. Analysis will be required to determine whether low emissivity material will be required within the fitting and support to reduce thermal interchange, whether internal insulation will be required, and whether some further form of isolation is required to achieve this conductance. If this level of isolation cannot be achieved, structure heaters may be necessary.

Figure 3.2.4.2-2 shows a schematic representation of the thermal control subsystem.

To support ferry operations from Dryden Flight Research Center to Vandenburg Air Force Base via Shuttle payload bay, all internal fluid lines 1/2 inch outer diameter and less and small fluid subsystem components will be insulated with MLI. Prior to 747-SCA takeoff, the Shuttle bay will be thermal control purged to a 70°F minimum temperature.

3.2.4.3 Fluid Transfer System TCS

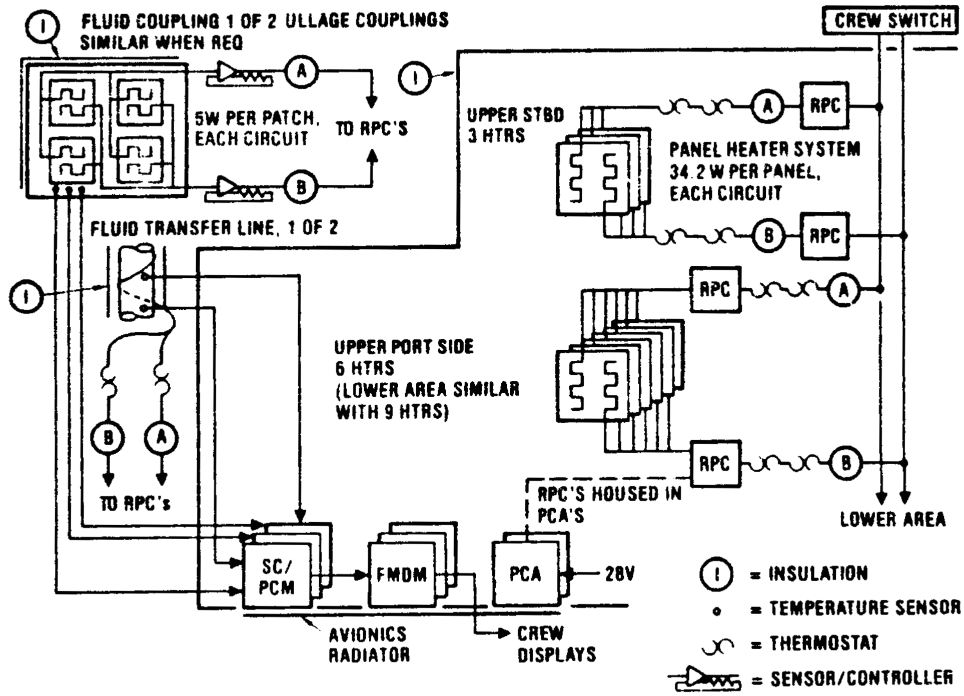
The Fluid Transfer System TCS is divided into two zones, the fluid transfer line and the fluid transfer coupling.

The fluid transfer line on Figure 3.2.4.2-1 will be insulated using MLI with a beta fabric cover installed using Velcro during line deployment. The line will be heated by a two-element heater tape or wire in order to satisfy redundancy requirements. Heater control is provided by mechanical thermoswitches. The heater is protected from handling damage by tape and heat-shrinkable material.

The fluid transfer coupling is provided with patch heaters having redundant circuitry. Control is provided by resistance temperature elements, located on the coupling, in conjunction with remotely located temperature controllers. Redundancy is provided by dual circuitry combined with temperature monitoring sensors.

FIGURE 3.2.4.2-2

Thermal Subsystem Schematic



Heaters on systems are activated prior to deployment, and deactivated following stowing, since they are stowed in a thermally controlled portion of the OSCRS. Thermostat ranges are set above the OSCRS internal heater temperature range. In this way, the A and B circuits of each heater may be sequentially activated briefly, prior to deployment, as a function test. Thermal control attitudes can also be used as a final backup with the heaters turned off.

Following deployment and attachment to the spacecraft, the multilayer insulation cover is placed over the coupling-line assembly. The insulation is removed prior to stowing of the assembly. The backup coupling is covered by an insulated cap while stowed.

3.2.4.4 Avionics TCS.

The avionics system is estimated to dissipate 380 watts. To remove this heat, a passive main avionics radiator is used (Figure 3.2.4.2-1). The heat dissipating components (Flex MDM's, Signal Conditioner/PCM units and two Power Control Assemblies) are attached to the inner surface of the radiator. The remaining avionics components, including the additional Power Control Assemblies used on the growth OSCRS, operate intermittantly and dissipate very little power. They are mounted on internal main shear panels. Heater locations are adjusted where necessary to prevent overheating of these components.

The radiator panel outer surface is covered by silver-teflon material, as used on the Orbiter radiator, in order to tolerate solar exposure. Radiator louvers or thermal shades are not used. The radiator panel, which acts as the avionics baseplate, is designed with a maximum of 14.7 ft^2 of surface area, and approximately 14.0 ft^2 of effective inner surface area, assuming that some conduction is available in the box material. Prior to flight, the radiator area is partially insulated, based on the worst hot conditions expected during the mission. These conditions are driven by whatever payloads are co-manifested with OSCRS, as well as the requirements of the resupply candidate and the Orbiter. A nominal 12.0 ft^2 may be obtained on the outer surface without blocking areas opposite the avionics box bases. This area supports combined earth and sun exposure or earth plus albedo, and results in radiator temperatures slightly above the OSCRS interior temperature under cold conditions while providing the capability to tolerate moderately high environmental heating loads. For a severe top sun environment combined with earth heating at $\beta = 90$ degrees, the surface area is increased to 13.8 ft^2 by reducing the MLI covering. Maximum area is about 14.3 ft^2.

3.2.4.5 Instrumentation

The GRO mission requires 102 temperature sensors, with 155 sensors for the growth version. Of these, 65 and 103 respectively are required for thermal control purposes, the others being used for safety, gauging, etc.

Sensor distribution is given by Table 3.2.4.5-1.

FIGURE 3.2.4.5-1 TEMPERATURE INSTRUMENTATION (ALL SUBSYSTEMS)

	2 TANK GRO		6 TANK MAXIMUM	
	TCS	OTHER	TCS	OTHER
FLUID SUBSYSTEM				
TANKS, VALVES, PUMPS, LINES, FLOWMETERS	7	33	15	49
TRANSFER LINES, COUPLING CHECKOUT COMPONENTS, CAT/VENT	14	3	14	3
ULLAGE TRANSFER & PRESSURANT	0	0	34	0
MISCELLANEOUS	4	1	2	0
HEATER DEDICATED	12	0	12	0
AVIONICS & RADIATOR	20	0	24	0
STRUCTURE				
BERTHING SUBSYSTEM	2	0	2	0
FIRST FLIGHT TEST	6	0	0	0
	65 +	37 = 102*	103 +	52 = 155**

POTENTIAL FOR REDUCTION FOLLOWING TEST AND ANALYSIS PROGRAM: *26, **31

3.2.4.6 Power Estimate

Peak load for the main compartment is estimated at 616 watts. Coupling power is conservatively estimated at 21 watts maximum each or 42 watts for the two couplings. Maximum power for the transfer lines is about 20 watts each, 40 watts total. An equal amount is assumed for the ullage transfer system, when utilized. Power for avionics equipment heaters is limited to the compartment heaters in the avionics area. Some equipment designs, such as fluid panels, have not been developed. The transfer line coupling heaters are probably overdesigned. A 5% heater growth factor is not unreasonable. This results in a total growth version installed thermal power capability of 819 watts, with 733 watts for the GRO baseline. Since unused couplings are not heated, peak power levels are 733 (growth) watts and 690 watts (GRO).

3.2.4.7 Thermal Subsystem Mass Properties

Thermal control subsystem component weights have been evaluated based on reasonable or conservative methods. MLI, which is the main weight component, is relatively lightweight material. A factor of 1/4-lb/ft^2 is used to include the necessary attachment hardware weight. Radiator panel weight depends on the panel thickness. A 1/8 inch thickness is assumed. Heater weight is based on earlier OMV mass properties analysis. Heater panel weight is based on 0.032 inch aluminum. Wire weights are not considered here, as they are part of the electrical system. A weight summary is shown in Table 3.2.4.7-1.

3.2.5 Instrumentation and Signal Conditioning

A preliminary design has been defined for an instrumentation system that will be capable of determining the system integrity and performance of the OSCRS resupply system. Instrumentation on safety critical components will be two failure tolerant to provide condition monitoring and insure safe operations during the resupply mission operations. Requirements for measurement and control functions were determined by studies, trades and design of the mechanical, fluid, thermal and avionics subsystems as well as the satellite interfaces.

The instrumentation system addressed by this study was an integral part of an Avionics System for the OSCRS System, that included the use of redundant Flex Multiplexer-Demultiplexers (FMDM)'s as the devices that would receive and process the Instrumentation System output data.

The study included an evaluation of the use of a Dedicated Signal Conditioner (DSC) concept, as is used on the Orbiter, with all data routed to the FMDM's via direct wiring. An alternate concept, which was accepted for the OSCRS design, employed a Signal Conditioner/PCM box that employs common signal conditioning and routed data to the FMDM's in a multiplexed PCM data stream. Cost, power and weight savings were realized.

The baselined instrumentation concept is shown on Figure 3.2.3-4.

The number and the types of measurements, as determined by analysis of the fluid system, thermal control system, separation system, avionics and receiving satellite are shown on Table 3.2.5-1.

Table 3.2.4.7-1 Weight Summary

Weight, lb	Component
Insulation Blankets	102
Radiator Panel	26
Heaters	10
Heater Panels	12
Total	150

TABLE 3.2.5-1 INSTRUMENTATION REQUIREMENTS

OSCRS MONOPROPELLANT SYSTEM PRELIMINARY MEASUREMENTS REQUIREMENTS ARE:

		GRO	GROWTH
OSCRS	PRESSURE	20	53
	TEMPERATURE	102	153
	DISCRETES	71	202
	PUMP SPEED	2	2
	FLUID GAGING	3	3
	PCA CMDS	41	87
SATELLITE	PRESSURE	7	14
	TEMPERATURE	6	12
	DISCRETE	-	24
	FLUID GAGING	-	4

3.2.6 Weight and Power Requirements

As the tanker design evolved various techniques were employed to predict, analyze and establish mass properties. The final tanker weights were established through analysis of detailed structure layouts; component weight estimates derived either from vendor estimates based on letter specifications, or use of existing Shuttle or other aerospace components; strength and weight analysis of lines and pressure vessel components; and comparisons to similar elements on the Shuttle or other aerospace vehicles.

Where room for doubt or interpretation existed in subsystem operation or component weight estimates, a conservative approach was used. Therefore, the weights presented herein are conservative, that is, they generally represent maximum values. During the OSCRS tanker design and development phase these weights can be reduced through optimization of system requirements and trades of manufacturing cost versus weight.

3.2.6.1 Monopropellant Tanker Mass Properties

The dry and wet lift-off weights and centers of gravity of the monopropellant tankers and their major subsystems are presented in Tables 3.2.6.1-1 (Baseline GRO Tanker) and 3.2.6.1-2 (Growth tanker). In addition to the tanker weights, there is an additional 35 lbs of dedicated OSCRS avionics equipment located on the AFD, 5 lbs for the control display panel and 10 lbs each for three GRID computers.

Table 3.2.6.1-3 presents a typical detailed subsystem/component weight summary of the baseline GRO tanker. Similarly detailed weight summaries have been completed for all three configuration received herein.

3.2.6.2 Birpropellant Tanker Mass Properties

The dry and wet liftoff weights and centers of gravity of the fully loaded bipropellant tanker are shown in Table 3.2.6.2-1.

3.2.6.3 Power Requirements

In order to generate power requirements for the vehicle, a number of assumptions had to be made.

(1) Only two GRID computers will be operating at the same time, and they will use orbiter power.

(2) The OSCRS vehicle will be subjected to cold soak for short durations only. Therefore, all heaters could be energized simultaneously, but on the average only one-third of the heaters will be on at one time.

(3) A maximum of 2 fluid system isolation valves will be operated simultaneously. All valves are "dual-latching" and do not require power after actuation (valve position indicator power drain is considered negligible).

(4) Fluids subsystem and portions of avionics subsystem will be powered down during launch and re-entry.

TABLE 3.2.6.1-1 BASELINE (GRO) TANKER MASS & C.G.

	WEIGHT	C.G. LOCATION		
2 TANK MONO		X	Y	Z
STRUCTURE	711	26.4	-2.2	400
AVIONICS	445	24.7	57.8	431.8
THERMAL	150	26.35	16.5	410
MECHANICAL	241	27.8	-4.7	474
FLUIDS SUB-SYSTEM	454	23.7	-8.3	414
DRY WT & C.G.	2001	25.6	12.4	420
WET WT & C.G.	4482	26.0	5.5	409

TABLE 3.2.6.1-2 GROWTH MONOPROPELLANT TANKER MASS & C.G.

	WEIGHT	C.G. LOCATION		
6-TANK MONO		X	Y	Z
STRUCTURES	893	26.4	-2.0	401
AVIONICS	545	25.1	58	430
THERMAL	150	26.35	16.5	410
MECHANICAL	241	27.8	-4.7	474
FLUIDS SUBSYSTEM	1340	24.0	-6	408
DRY WT. & C.G.	3169	25.2	12.4	415
WET WT. & C.G.	10612	26.0	3.7	404

TABLE 3.2.6.1-3 BASELINE (GRO) MONOPROPELLANT MASS
PROPERTIES & C.G. LOCATIONS

	WEIGHT	C.G. LOCATION			MOMENT		
		X	Y	Z	X	Y	Z
STRUCTURE	(711)	(26.4)	(-2.2)	(400)			
CRADLE - CORE	440	26.35	0	400			
- LONG SUPT	84	26.35	0	410			
- KEEL SUPT	20	26.35	0	310			
SECONDARY -	(167)	26.35					
ATTACHMENTS	25	26.35	0	400	18798	1560	284466
SUPT - AVIONICS	8	26.35	-60	435			
- FLUIDS	48	26.35	0	372			
- FLUIDS MISC	30	26.35	0	372			
- CCTV	5	39	-8	475			
- FSS LATCH	25	26.35	0	470			
- GRAPPLE	5	26.35	-40	465			
- COUPLING	12	26.35	-70	440			
- TANK	9	26.35	0	400			
AVIONICS	(445)	(24.7)	(57.8)	(431.8)			
FLEX MDM	120	26.35	58	443			
CONTROL - POWER	100	26.35	67	425			
- SIGNAL	75	26.35	67	425	11008	25785	192135
EMERGENCY SEP.	50	12	30	420			
WIRING/CONNECTORS	100	26.35	56	436			
THERMAL	(150)	26.35	(16.5)	(410)			
BLANKETS	102	26.35	0	400			
PANEL - RADIATOR	26	26.35	65	438	3952	2470	61444
- HEATER	12	26.35	+65	438			
HEATERS	10	26.35	0	400			
MECHANICAL	(241)	(27.8)	(-4.7)	(474)			
BERTHING MECH.	180	26.35	0	477			
CCTV	28	38.7	-8	478	6696	-1144	114148
GRAPPLE	23	26.35	-40	468			
SCUFF PLATES	10	26.35	0	414			
FLUIDS SYSTEM	(454)	(23.7)	(-8.3)	(414)			
TANKS - PROPELLANT	198	26.35	0	400			
- PRESSURE	25	15	0	336			
- LEAK CHECK	5	26.35	0	375			
LINES	16	26.35	0	400			
CONTROL - CHECK/VENT	41	26.35	0	470			
- TRANSFER	50	15	-63	460	10786	-3790	187955
- ULLAGE	16	6.0	0	375			
- TANKAGE	36	26.35	0	375			
EMERG. SEP.	10	26.35	-64	445			
DECOMP. REACT.	6	26.35	0	400			
COUPLINGS	51	26.35	0	460			
FLUIDS	(2481)	(26.32)	(0)	(399.8)			
PROPELLANT	2475	26.35	0	400	65306	0	992016
PRESSURANT	6	15	0	336			

TABLE 3.2.6.2-1 FULLY LOADED BIPROPELLANT TANKER MASS & C.G.

	WEIGHT	C.G. LOCATION X	Y	Z
6-TANK BI-PROP				
STRUCTURES	816	26.35	-0.8	402.8
AVIONICS	645	25.2	60.7	429.7
THERMAL	150	26.35	16.5	410
MECHANICAL	33	26.35	-29	452
FLUID SUBSYSTEM	1687	26.35	0.4	404
DRY WT. & C.G.	3331	26.12	12.2	409.4
WET WT. & C.G.	11876	26.3	3.4	403

TABLE 3.2.6.3-1

OSCRS POWER REQUIREMENTS (WATTS)

MISSION PHASE	AVIONICS CONSTANT	AVIONICS MAX.	FLUIDS CONSTANT	FLUIDS MAX.	THERMAL CONTROL CONSTANT	THERMAL CONTROL MAX.	TOTAL CONSTANT	TOTAL MAX.
LAUNCH/RE-ENTRY	250	310	0	0	230	790	530	1100
PROPELLANT TRANSFER	610	670	765	1635	280	790	1655	3095

Using the above assumptions, a preliminary analysis of the OSCRS power requirements was generated, and is shown in Table 3.2.6.3-1. Constant power drain for all subsystems was estimated to be approximately 1655 watts during propellant transfer. Max power usage (both propellant pumps operating, all heaters on, all avionics up) was found to be approximately 3095 watts.

3.2.7 Subsystem Performance Predictions

The objective of this analysis was to evaluate the performance of the OSCRS Fluid subsystem. To do this, a micro-g thermal math model, and a zero-g pressure math model were used to make temperature predictions for the receiver and supply tank ullages, perform steady state pressure drop analyses for the fluid system components, make line sizing recommendations, and perform a pump requirements analysis.

3.2.7.1 Flowrate

Pump flowrate was found to be limited primarily by heat buildup in the receiver tank as the ullage volume is compressed. Using the thermal math model, it was determined that the maximum allowable continuous flow rate is 2.5 gpm (see Figure 3.2.7.1-1).

As can be seen from the figure, the maximum ullage temperature (i.e., "hot spot") is at 150°F at the completion of the transfer. This point was chosen as the upper limit because it provides a safety margin comfortably below the autoignition temperature of the N_2H_4 vapor.

Use of dual flowrates (10.0 gpm and 2.5 gpm) is also possible, as long as the flowrate is throttled back when the ullage temperature reaches 150°F. Such a transfer is shown in Figure 3.2.7.1-1. Using dual flowrates, the transfer can be completed in just under 1-1/2 hours, as compared to 2.0 hours for a straight 2.5 gpm transfer.

The optimum pump design was therefore found to be one that incorporates dual flowrate capability (2.5 gpm and 5.0 gpm). A 10.0 gpm flow can be achieved with simultaneous pump operation at the high flowrate setting. A 2:1 gpm ratio was chosen over the 10.0/2.5 gpm ratio (4:1) because the lower ratio allows for a more efficient design.

3.2.7.2 Line Sizing

With the minimum flowrate set at 2.5 gpm and the maximum flowrate at 10.0 gpm, the optimum line diameter was then determined. Table 3.2.7.2-1 presents a summary of the pressure losses and delta weights for the various line sizes under consideration.

Taking into consideration the pressure drops, system weights, and power requirements for the various line sizes, it appears that the optimum design would use 3/4 in. lines. As compared to 5/8 in. lines, 3/4 in. lines have pressure restriction 8 psid less at 10 gpm, and will use less pump energy to complete a typical mission. Also, system start-up and shutdown surge pressures will be lessened, and pump cooling requirements will be lowered. The only drawback is a 2.0 lbm mass penalty, which is fairly minor. Use of 1 in. lines would provide slight reductions in pressure drops and power requirements, but the additional mass penalty of 5.0 lbm is not worth the very minor gains.

FIGURE 3.2.7.1-1

ULLAGE RECOMPRESSION SYSTEM — PUMP FED SYSTEM

Blowdown supply

flow rate = 2.5 gpm

flow rates = 10.0 gpm and 2.5 gpm

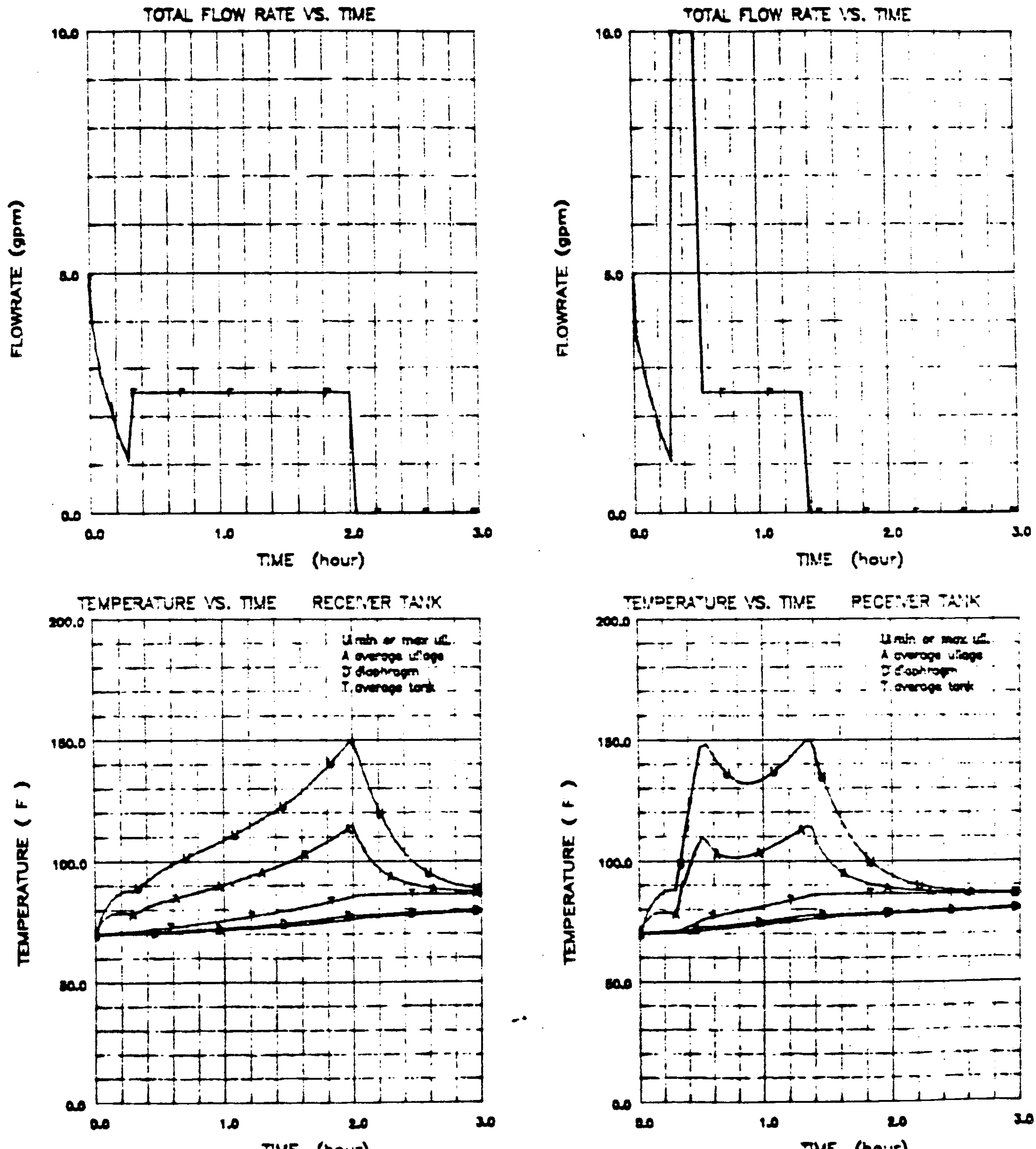


Table 3.2.7.2-1 System Pressure Drops and Plumbing Weights

Line Size (O.D.)	Pressure 2.5 gpm	Drop (psid) 10.0 gpm	Delta Weight (lbm)
1/2"	9.2	97.0	4.7
5/8"	6.5	71.2	6.5
3/4"	5.7	63.5	8.5
1"	5.3	59.2	13.3

3.2.7.3 Component Pressure Losses

Based on the anticipated flow rates and line sizes for the fluid system, the pressure drop through each component was determined. Table 3.2.7.3-1 presents the pressure loss for each fluid system node at the two anticipated flow rates. As can be seen from the table, the primary sources of restriction are the transfer coupling and the propellant isolation valves. Since the transfer coupling must be used, that pressure drop is unavoidable. The loss data for the valves however, emphasizes the need to procure low restriction type isolation valves. The data shown is based on GRO valve flow data.

3.2.7.4 Pump Pressure and Power Requirements

Knowing the pressure drops through the components and lines, and the supply and receiver tank pressures, the pump pressure requirements can be determined. The largest head pressure required will be near the completion of the transfer, where the receiver tanks will be at or near their maximum working pressure (approximately 400 psia), and the supply tanks will be just above the pump inlet cavitation pressure (approximately 50 psia). At a 2.5 gpm flow rate the plumbing losses through 3/4 in. lines would be 5.7 psid. This indicates that the pumps must supply a pressure increase of at least 356 psid. In order to account for loss of pump efficiency and additional line restrictions (clogged filters) as the system ages, it would be prudent to design or procure the pump based on a minimum positive head pressure of 400 psid.

Similarly, the total pump energy required was determined by calculating the delta pressure and flow rate through the pump at each point in the transfer, and integrating with respect to time over the duration of the resupply. The analysis showed that a 2500 lbm N_2H_4 ullage recompression transfer would require approximately 1200 watt-hours for the resupply, and would draw a maximum of approximately 1 kilowatt of power.

TABLE 3.2.7.3-1

N2H4 COMPONENTS PRESSURE LOSSES

Fluid = N2H4

Temperature = 70.0 degrees F

Line diameter = .750 inches

Total supply system line weight = 8.55 lbm

Flowrate	Tank-Pump	Pump-Coup.	Coupl.-Tank	Total
.25	.5	.5	.5	1.5
.50	.5	.6	.6	1.7
1.00	.7	.7	.8	2.2
2.00	1.1	1.4	1.7	4.3
2.50	1.5	1.9	2.4	5.7
4.00	2.9	4.0	5.2	12.0
5.00	4.1	5.9	7.7	17.7
7.50	8.2	12.4	16.5	37.0
10.00	13.7	21.2	28.5	63.5
15.00	28.8	46.1	62.5	137.3

Flowrate = 2.5 gpm

Node	Comp	Velocity (ft/s)	Reynolds #	Kfactor	Delta p (psid)
1	line	2.12	13702.9	4.43	.14
2	valve	1.82	12679.7	20.00	.45
3	line	2.12	13702.9	1.08	.03
4	filter	1.82	12679.7	1.20	.53
5	line	2.12	13702.9	2.05	.06
6	flowmeter	1.82	12679.7	5.25	.12
7	line	2.12	13702.9	4.87	.15
8	pump	.26	4754.9	.00	.00
9	line	2.12	13702.9	.51	.02
10	valve	1.82	12679.7	20.00	.45
11	line	2.12	13702.9	.25	.01
12	valve	1.82	12679.7	20.00	.45
13	line	2.12	13702.9	1.82	.06
14	filter	1.82	12679.7	1.20	.53
15	line	2.12	13702.9	4.57	.14
16	flexhose	1.82	12679.7	8.82	.20
17	valve	1.82	12679.7	3.11	.07
18	coupling	1.82	12679.7	48.90	1.09
19	line	2.12	13702.9	.47	.01
20	filter	1.82	12679.7	1.20	.53
21	line	2.12	13702.9	4.69	.14
22	valve	1.82	12679.7	20.00	.45
23	line	2.12	13702.9	4.69	.14

Flowrate = 10.0 gpm

Node	Comp	Velocity (ft/s)	Reynolds #	Kfactor	Delta p (psid)
1	line	8.48	54811.5	2.59	1.27
2	valve	7.26	50718.9	20.00	7.16
3	line	8.48	54811.5	.76	.37
4	filter	7.26	50718.9	1.20	.93
5	line	8.48	54811.5	1.30	.63
6	flowmeter	7.26	50718.9	5.25	1.88
7	line	8.48	54811.5	3.00	1.46
8	pump	1.02	19019.6	.00	.00
9	line	8.48	54811.5	.36	.17
10	valve	7.26	50718.9	20.00	7.16
11	line	8.48	54811.5	.18	.09
12	valve	7.26	50718.9	20.00	7.16
13	line	8.48	54811.5	1.05	.51
14	filter	7.26	50718.9	1.20	.93
15	line	8.48	54811.5	2.84	1.39
16	flexhose	7.26	50718.9	8.36	2.99
17	valve	7.26	50718.9	2.35	.84
18	coupling	7.26	50718.9	48.90	17.49
19	line	8.48	54811.5	.33	.16
20	filter	7.26	50718.9	1.20	.93
21	line	8.48	54811.5	2.87	1.40
22	valve	7.26	50718.9	20.00	7.16
23	line	8.48	54811.5	2.87	1.40

3.2.7.5 Ullage Tank Sizing

Analysis showed that the pump energy requirements are highly dependent upon the size of the supply system ullage tank. For a 2500 N_2H_4 ullage recompression transfer with 3/4" lines and a flowrate of 2.5 gpm, the results shown in Table 3.2.7.5-1 were obtained when the ullage tank volume was varied (note: the ullage volumes and masses shown are based on currently available, qualified tanks).

For the purposes of the preliminary design, it appears that the best choice would be the largest single tank which would fit inside the available space (19 in) would be a good choice. For example the 19.0 in O.D. tank built by Fansteel PSM could be used. This tank has an internal volume of 3653 cubic inches, weighs 25.3 lbm, and has an operating pressure of 2500 psi. If a tank of this volume were used, the total energy required for transfer would be 941 watt-hours, and the maximum peak power required would be 1178 watts.

3.2.7.6 Gear Pump Characteristics

The major advantage of a gear pump is its ability to provide high delta P's at reasonable flow rates when compared to a centrifugal pump. A gear pump can provide delta P's up to 1500 psid while the centrifugal pump is not capable of much more than delta P's in the 350 psid range at its optimum operating speed. Centrifugal pumps are inefficient when run at off-design speeds. Variation in operating speed is not as critical for the gear pump.

Figure 3.2.7.6-1 represents the recommended pump for propellant resupply from the OSCRS. The estimated length and diameter are 6 inches and 4 inches, respectively. The approximate weight of the dual speed A.C. motor and gear pump is 5 pounds. The pump is designed with a dual shaft seal and a replaceable cartridge type absorbing material for the absorption of any leakage between the seals. Motor selection for a dual speed pump will consist of a dual wound motor (8 pole) and have operating speeds of 11,000 rpm and 5,000 rpm with efficiencies of 60 and 50 percent, respectively. The design will allow for reverse flow capabilities to off-load residual propellants.

3.2.8 Safety/Hazard/Analysis/Issue Resolution

Safety analysis of the orbital spacecraft consumables resupply system consisted of an evaluation at a system and subsystem level to determine the applicability of all the technical safety requirements of NHB 1700.7A, "safety policy and requirements for payloads using the space transportation system" and KHB 1700.7, "space transportation system payload ground safety handbook".

Table 3.2.8-1 displays the Payload Safety Requirements Application Matrix against the OSCRS subsystems. No waiver deviations were identified.

The following list of potential hazards were identified against these requirements.

Table 3.2.7.5-1 Pump Energy Required VS Ullage Tank Volume

Ullage Volume (in 3)	Total Energy (watt-hours)	Max Power (watts)	Delta Mass (lbm)
1000	1060	1215	13.3
1960	1013	1201	27.5
3000	967	1187	49.5
4000	928	1173	63.4
5000	891	1159	92.0
6064	855	1145	102.0
6700	835	1137	107.0
7775	803	1123	110.0

FIGURE 3.2.7.6-1

Gear Pump With Motor Cross Section

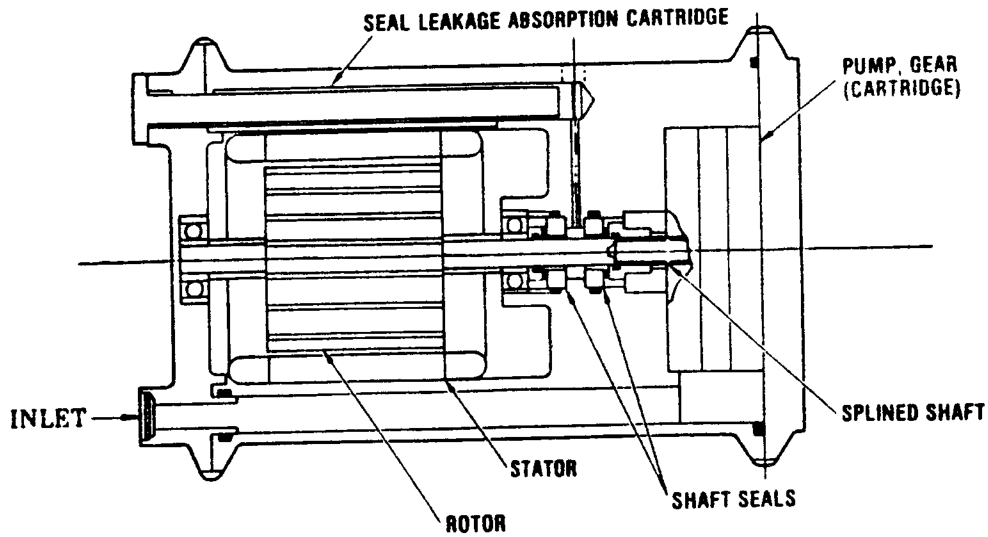


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TABLE 3.2.8-1 **STS PAYLOAD SAFETY REQUIREMENTS APPLICABILITY MATRIX**

1 PAYLOAD	2 DATE	3 PHASE REVIEW	4 PAGE
ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM	9/9/86	0	1 OF 1

6 NHB 1700 7A REQUIREMENTS

5 SUBSYSTEM	201 FAILURE TOLERANCE	202 1 CRITICAL HAZARDS	202 2 CATASTROPHIC HAZARDS	202 2A SOLID PROPELLANT	202 2B LIQUID PROPELLANT	202 2C DEPLOYMENT/SEPARATION	202 2D BAY DOOR CLOSURE	202 2E PAYLOAD RF XMTR	203 RETRIEVAL OF PAYLOAD	204 HAZARD DETECTION & SAFING	205 P/L CONTINGENCY RETURN	206 FAILURE PROPAGATION	207 REDUNDANCY SEPARATION	208 1 2 & 3 STRUCTURAL	208.4 & 5 PRESSURE SYSTEM	208 6 DECOMPRESSION
FLUID SYSTEMS	X	X	X	-	X	-	X	-	-	/	X	/	/	-	X	-
ELEC/AVIONICS	X	X	X	-	-	-	X	-	-	/	/	/	/	-	-	-
PYROTECHNICS	X	/	X	-	-	X	-	-	-	/	/	/	/	-	-	-
THERMAL CONTROL	X	X	X	-	-	-	-	-	-	/	/	/	/	-	-	-
STRUCTURES	X	/	X	-	-	-	/	-	-	/	X	/	-	X	-	-
MECHANICAL SYSTEMS	X	/	X	-	-	X	X	-	-	/	/	/	-	-	-	-

5 SUBSYSTEM	208 7 SEALED CONTAINERS	209 1 HAZARDOUS MATERIALS	209 2 CABIN MATERIALS	209 3 FLAMMABLE MATERIALS	209 4 OFFGASSING MATERIAL	210 PYROTECHNICS	211 DESTRUCT SYSTEMS	212 1 IONIZING RADIATION	212 2 NONIONIZING RADIATION	213 ELECTRICAL SYSTEMS	214 VERIFICATION REQMTS	215 HAZARDOUS PROCEDURES	216 REFLOWN HARDWARE	217 EXTRAVEHICULAR ACTIVITY	218 SERIES PAYLOAD	219 FLAMMABLE ATMOSPHERE	7 REMARKS
FLUID SYSTEMS	-	X	-	-	-	-	-	-	-	-	/	X	/	/	-	X	
ELEC/AVIONICS	/	-	/	-	-	-	-	-	-	X	/	/	/	/	-	X	
PYROTECHNICS	-	-	-	-	-	X	-	-	-	-	/	-	/	/	-	/	
THERMAL CONTROL	-	-	-	X	-	-	-	-	-	-	/	-	/	/	-	-	
STRUCTURES	-	-	-	-	-	-	-	-	-	-	/	-	/	/	-	-	
MECHANICAL SYSTEMS	-	-	-	-	-	-	-	-	-	-	/	-	/	/	-	-	

8 LEGEND

— NOT APPLICABLE

/ APPLICABLE NO HAZARD IDENTIFIED

X APPLICABLE HAZARD IDENTIFIED

■ WAIVER DEVIATION REQUIRED

9

	IMPLEMENTATION PERSONNEL	DATE	PAYLOAD ORGANIZATION PERSONNEL	DATE
PREPARED BY	[signature]	9/9/86		
REVIEWED BY	[signature]	9/23/86		
APPROVED BY	[signature]	9/23/86		

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STRUCTURES-POTENTIAL HAZARDS

Personnel Injury

Potential injury to ground personnel and potential loss of life of EVA crew (depletion of life support consumables) from contact with sharp edges or protrusions on structure.

Structural Failure

Failure of the primary or secondary structure could cause collision with the Orbiter leading to loss of Orbiter and life.

Loose Components

Improperly secured components can break loose and become projectiles which can enter the crew compartment and result in loss of life.

MECHANICAL SYSTEMS-POTENTIAL HAZARDS

Failure to Secure OSCRS After On-Orbit Relocation

Failure of the OSCRS to be secured after the on-orbit relocation could result in loss of the Orbiter entry capability.

Failure of Satellite to Separate From OSCRS

Failure of the receiver satellite to separate from the OSCRS could result in inability to close payload bay doors which in turn will result in the loss of the Orbiter entry capability.

FLUID SYSTEMS-POTENTIAL HAZARDS

Hydrazine Leakage/Spillage

The leakage/spillage of hydrazine can contaminate the surrounding structure and elements leading to a potentially toxic/flammable atmosphere.

Ground Crew Contact With Hydrazine

During ground operations the spillage/leakage of hydrazine could result in injury/illness to ground personnel through skin contact or vapor inhalation.

Rupture of Pressurized Tanks, Lines, Fittings, and Components

The rupture of pressurized tanks, lines, fittings, and components may cause injury to personnel (shrapnel, fluid contact) and damage to the Orbiter and other paylodas.

Adiabatic Compression Detonation

Opening closing of flow control devices may cause adiabatic compression detonation.

High Pressure Gas Impingement on Personnel

Release or leakage of high pressure gas during ground or EVA operations could result in impact of high velocity gas with personnel causing injury or illness.

Overpressurization of OSCRS Propellant Tank

Inadequate OSCRS propellant tank ullage can lead to pressure levels within the tank exceeding safe operating limits due to thermal expansion of the ullage/propellant.

Overpressurization of Spacecraft Fluid Systems

Excessive fluid resupply may lead to possible damage/leakage of resupplied spacecraft's fluid system.

Spacecraft Ullage Overheating

Excessive resupply flowrates could cause the spacecraft's propellant tank ullage to overheat and explode.

EVA Contact With Hydrazine

Leakage of hydrazine while performing EVA operations can contaminate the EMU and may possibly deplete the life support consumables if contact is with the EMU face shield causing the shield to crack.

On-Orbit Venting of Hazardous Fluids

OSCRS on-orbit venting or propellants or other hazardous fluids can contaminate the Orbiter, other vehicles/payloads, or the EVA crew leading to an unsafe entry due to TPS degradation or injury/illness to the crew.

Failure of Fluid Resupply Lines/Couplings To Be Disconnected

Failure of the fluid resupply lines/couplings to be disconnected after the resupply will cause interference with the closure of the payload bay doors and result in the loss of the Orbiter's entry capability.

Pump Damage/Fragmentation

The propellant resupply pump may become damaged and possibly explode which could cause further damage to the resupply system, Orbiter, and injure personnel due to fragmentation/shrapnel.

Nonconformance of Orbiter's Landing CG and Load Limits

The OSCRS payload may cause the Orbiter to exceed its center of gravity and load limits for landing.

THERMAL CONTROL-POTENTIAL HAZARDS

Propellant Tank Overtemperature

Overtemperature of loaded propellant tanks could cause excessive tank pressure resulting in tank failure and release of hydrazine.

Flaking Shredding of Thermal Insulation

Flaking shredding of thermal insulation due to improper material selection may cause contamination in the payload bay.

Hydrazine Expansion During Thawing

The freezing and subsequent expansion of hydrazine during its thaw can cause damage or a rupture within the OSCRS propellant system.

ELECTRICAL/AVIONICS-POTENTIAL HAZARDS

Electrical Shock During Electrical Cable Connection

Potential for electrical shock during connection of electrical cables.

Static Discharge During Berthing

Static discharge during initial berthing of the receiver satellite to the OSCRS destroying any sensitive electronics.

Static Discharge During Ground Operations/Servicing

Static discharge during ground operations may be a potential ignition source for a flammable atmosphere.

Electrical Cable Damage During On-Orbit OSCRS Relocation

The on-orbit relocation of the OSCRS may damage the electrical cables between the OSCRS and the aft flight deck area.

Electrical Shorts/Ignition Sources

Electrical wires may become damaged and cause system malfunctions or possibly ignite a flammable atmosphere.

Failure of Electrical Coupling To Be Disconnected

Failure of the electrical lines/couplings to be disconnected after the resupply will cause interference with the closure of the payload bay doors and result in the loss of the Orbiter's entry capability.

Venting/Explosion of Batteries

The use of batteries on remote resupplies can lead to contamination of surrounding elements due to venting and possible damage/loss of equipment/vehicles due to the explosion potential of batteries.

Continuously Energized Propellant Valve

A continuously energized hydrazine valve can cause excessive valve temperatures leading to detonation of the hydrazine.

PYROTECHNICS-POTENTIAL HAZARDS

Premature Activation of Pyrotechnics

The premature activation of the pyrotechnics may cause injury to personnel or damage to the vehicles (Orbiter, spacecraft) by collision or severing of any resupply lines or umbilicals.

Identification of these potential hazards has led to design requirements which will control and possibly eliminate these hazards. Various options are available to control these hazards and as the design progresses, a more definite plan as to which controls and how these controls are to be implemented will be verified and documented. A detailed assessment of the potential hazards has been prepared for the OSCRS, in a phase B Safety Assessment Report, submitted under contract NAS9-17584.

SAFETY CONCLUSIONS

No potential waivers or deviations have been identified against the requirements of NHB 1700.7A or KHB 1700.7 and no unaccepted risks have been identified against the listed potential hazards.

3.3 End-Item-Specification (EIS)

The End Item Specification (EIS) establishes the requirements of performance, design, and verification of the monopropellant Orbital Spacecraft Consumables Resupply System (OSCRS) which is to be used in resupply of earth storable monopropellant and other fluids. This specification also specifies unique requirements and characteristics to which the OSCRS tanker subsystems must conform in order to achieve the required OSCRS performance and operational capabilities. Therefore, this specification is the source for expanded definition of the monopropellant OSCRS subsystem requirements. Compliance with the requirements of this specification is limited to those requirements for which the monopropellant OSCRS has exclusive control and responsibility.

The purpose of the OSCRS is to supplement the Space Transportation System (STS) capability for servicing of orbiting vehicles. A large percentage of currently planned spacecraft are limited in their useful life by consumables. Many of these spacecraft will operate at orbital altitudes which are directly accessible by the STS Orbiter, or from which the spacecraft can descent (by use of either on-board propulsion or orbital transfer vehicles) and then be accessible by the Orbiter. Other spacecraft will operate at orbital altitudes which must be reached by carrier craft, such as OMV/OTV for remote resupply. It is the specific purpose of OSCRS to provide fluid resupply to all of these spacecraft, including pressurants, Earth-storable propellants, and other fluids.

To maximize OSCRS versatility, the potential use and/or modification for use of the OSCRS tanker as a detachable fluids depot that can be left attached to an orbiting vehicle and changed-out from the Orbiter when consumables are depleted was considered.

The OSCRS tanker will initially utilize the STS Orbiter payload bay as a base for all operations. Initial resupply activities will take place in LEO, although remote resupply in GEO is a potential with the operational advent of orbital transfer vehicles. The primary mode of control and monitoring of spacecraft functions when in the Orbiter payload bay will be from the Orbiter Aft Flight Deck (AFD). Normal connecting and disconnecting of fluid and electrical connectors will be accomplished manually during Extra Vehicular Activity (EVA). All other OSCRS control and monitoring functions will be from the System Control Station (SCS) in the Orbiter AFD. Automation of orbital fluid reservicing is presently envisioned as an evolutionary task that will build upon the EVA data base defined above. An awareness of the requirement for potential automation will be maintained during the OSCRS design and development to permit a minimum impacted OSCRS tanker modification.

The EIS was developed as the basis for the design, development, fabrication, certification, and operational use of the OSCRS. It has been published and submitted as a separate report, STS 86-0272.

3.4 Monopropellant OSCRS Phase C/D Program Plan

The monopropellant OSCRS Phase C/D program plan defines the scope and schedule of all development elements. The plan consists of a work breakdown structure (WBS) (Figure 3.4-1), supporting schedules (Figure 3.4-2), and identification of task interaction (Figure 3.4-3).

The complete detailed program plan is documented in DRD-8 report number STS 86-0271. Key features of the plan are summarized below.

The plan provides for a high-fidelity mock-up engineering aid to be built after the preliminary design review. The engineering aid which allows early hands-on design assessment will be available for the critical design review. The engineering aid will be used for crew and safety reviews, crew training, manufacturing aid, facility interface tool, and GSE/Handling design aid.

The program plan incorporates a make-or-buy-plan to use low cost flight proven hardware and designs, provide open competition for components unique to OSCRS, use existing facilities, and involvement of small and minority-owned businesses in the development/fabrication of OSCRS.

A detailed verification approach is defined in the program plan. It includes definition of verification requirements, verification plan for components, subsystems, systems, verification methods (analysis or test), and verification of flight operation functions with simulated vehicle interfaces and launch/space environment.

Definition of the fabrication approach for OSCRS is based on using the Payload Integration Nominal Cost Hardware (PINCH) management concept. This concept provides for a dedicated centralized collocated team with the build and flow plan under control of the program manager. The fabrication process will use simplified tooling and the engineering aid to minimize cost. Fabrication will be accomplished in phases: structure and panels, mock-up and assembly, integrated tests, refurbishment, acceptance test and delivery.

The plan also defines/implements safety and quality control elements which assure conformation to specified design and performance criteria.

FIGURE 3.4-1 **Orbital Spacecraft Consumables Resupply System (OSCRS) Work Breakdown Structure Phase C/D**

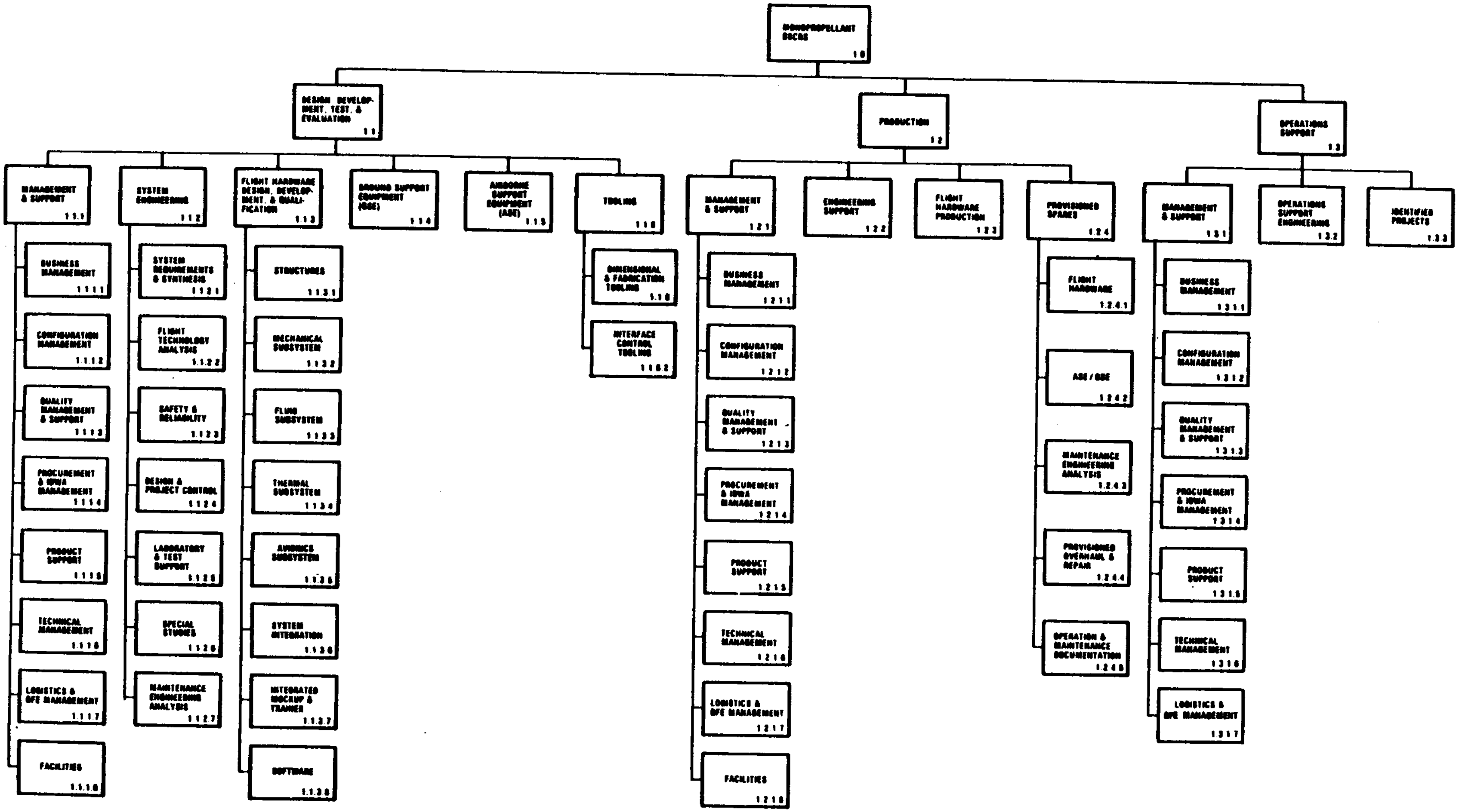


FIGURE 3.4-2 **O S C R S** - MONOPROPELLANT TANKER
PHASE C/D PROGRAM SCHEDULE

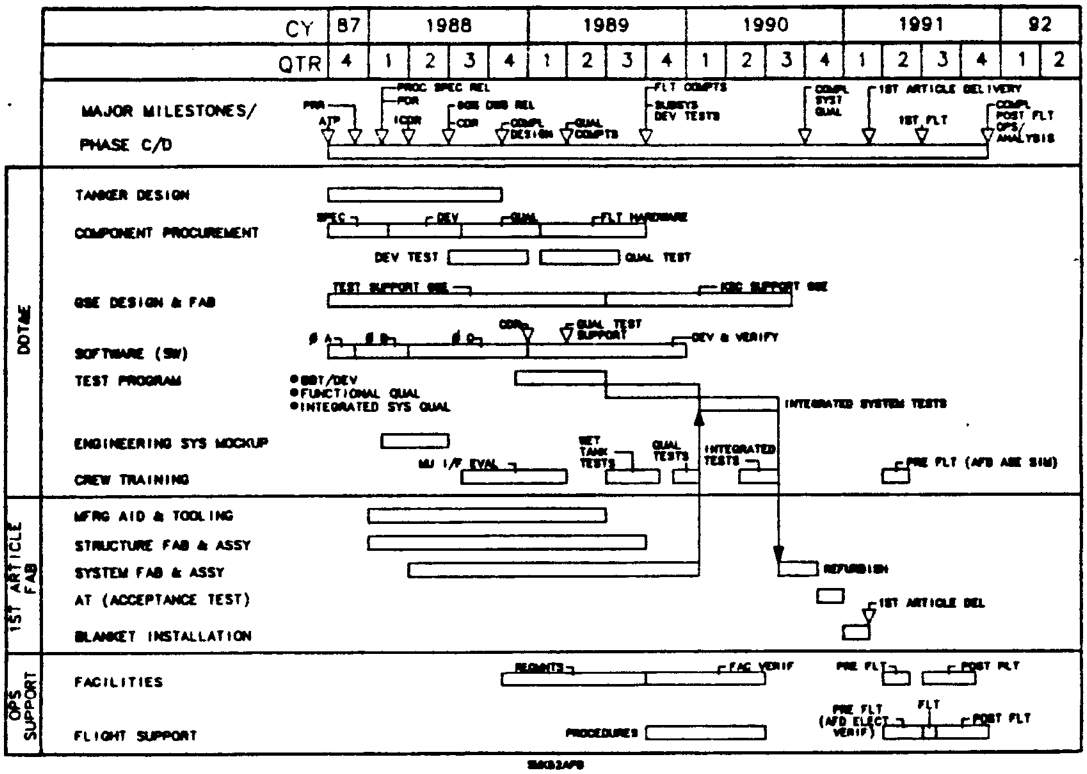
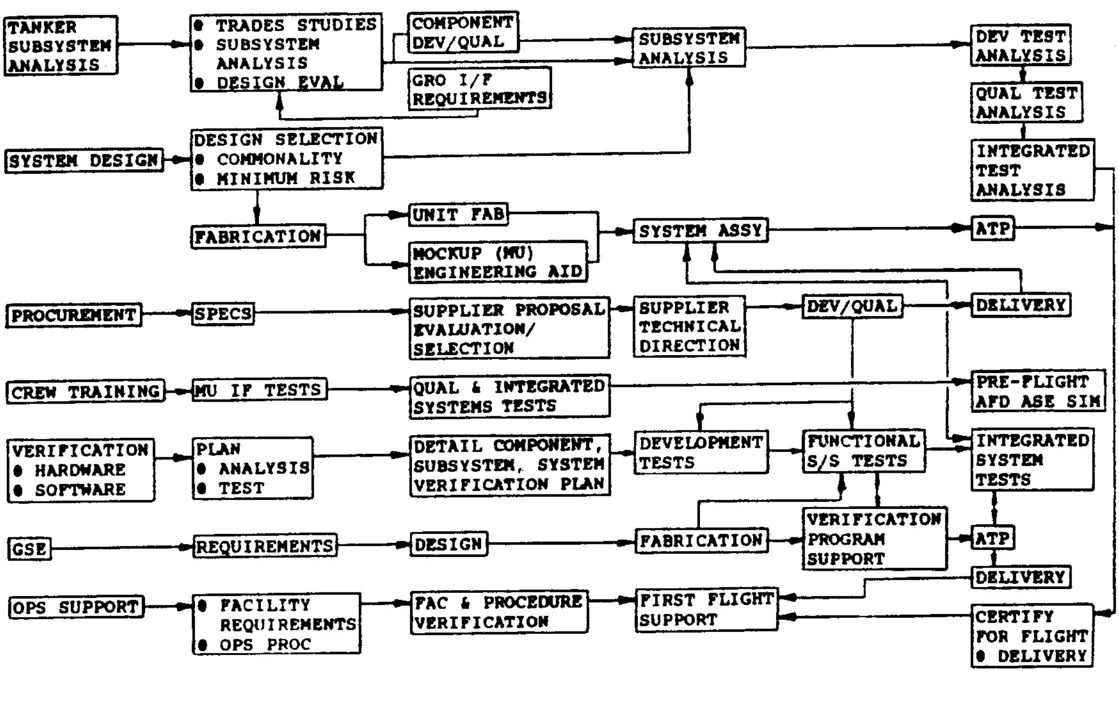


FIGURE 3.4-3 TASK INTERACTION INDEX



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4.0 Conceptual Bipropellant System Design (Study)

The conceptual bipropellant OSCRS design study provides an assessment of the concept and its commonality with the monopropellant design. The bipropellant system design is based on unique bipropellant system, hardware/software, and operational trade studies. The conceptual bipropellant design includes a definition of the potential commonality areas with the monopropellant system design and identifies any design compromises required to achieve commonalites.

4.1 Bipropellant Unique Trade Studies

The trade studies presented in paragraph 3.1, while primarily evaluating/defining the monopropellant system design, also considered bipropellant system requirements to the greatest extent possible. The trade studies presented here address the bipropellant unique areas not previously evaluated and assures the current applicability of the joint trade studies.

4.1.1 System Design Requirements for Various Fluid Retention Devices

In determining the bipropellant OSCRS fluid transfer subsystem design requirements, the type of propellant acquisition device (PAD) being used by potential resupply candidates, were identified for various propellant transfer processes: ullage recompression, ullage exchange, and ullage vent/repressurization. Fluid transfer subsystem design options were identified to accommodate the various PAD/transfer process combinations.

These options were evaluated under an IR&D study, Project 86210. The results, conclusions, and recommendations from that study have been excerpted and presented here for information.

Numerous fluid transfer subsystem designs were identified for the on-orbit transfer of bipropellants. The various design options depend on the type of PAD used by receiver vehicles, and the propellant transfer process best suited for the receiver vehicle's propulsion system. All of the design options can be placed in one of four general categories: tank/PAD design, propellant transfer subsystem design, pressurant transfer subsystem design, and the fluid disposal subsystem design.

The selection of a tank/PAD design is an important step in the design of a low-g bipropellant transfer system. In many cases the PAD design will constrain the operational capabilities of the transfer system; such as the transfer flowrates and the system's operating environment.

The propellant transfer subsystem and the pressurant transfer subsystem design define the methods in which propellant and pressurant are transferred from the resupply module to the receiver vehicles propulsion system.

If the disposal of residual propellant and venting of contaminated ullage gas is required, a fluid disposal subsystem would need to be incorporated into the resupply module design.

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Five PAD options were identified as potential resupply receiver tankage designs: surface tension screens with an ullage positioning capability, surface tension screens w/o ullage positioning, surface tension vanes, polymeric diaphragms, and welded metal bellows. Even though a nitrogen tetroxide compatible polymeric diaphragm does not exist, the PAD design was considered as a future potential receiver and supply tankage PAD design.

Several combinations of receiver vehicle PAD designs versus transfer processes were analyzed to identify potential propellant transfer scenarios. Thirteen propellant transfer scenarios were identified and are tabulated in Table 4.1.1-1. The ullage exchange resupply process, resupplying either a vane PAD or a screen PAD without any ullage control capabilities, were not considered as potential resupply transfer scenario. Since these two PAD designs do not have sufficient ullage positioning capabilities, resupply propellant could unknowingly be transfer out of the receiver tank (through the ullage transfer tank outlet) back into the resupply tanker.

Thirteen fluid transfer system designs were identified to accommodate the thirteen resupply scenarios. Commonality among the subsystem design options reduced the number of the OSCRS's fluid transfer system designs to three. These three designs are illustrated in Figure 4.1.1-1.

The option 1 resupply subsystem design can resupply any type of PAD, using the ullage recompression transfer process. The Option 2 design can resupply PAD's with ullage positioning capabilities, using the ullage transfer process. Option 3 identifies a resupply subsystem which could resupply any type of PAD, using the ullage vent/repressurization transfer process.

To satisfy the resupply requirements of all the potential users of on-orbit propellant resupply, the fluid transfer subsystem design of the OSCRS would need to accommodate all three methods of propellant resupply. Design Option 1 can only accommodate ullage recompression resupply missions. Design Options 2 and 3 can also accommodate ullage recompression missions; however, in addition to ullage recompression, the Option 2 design can accommodate ullage exchange resupplies, and Option 3 can accommodate ullage vent/repressurization missions.

A slight modification to the Option 3 design (see Figure 4.1.1-1) would permit the subsystem to accommodate ullage exchange resupplies, in addition to the other two transfer methods. Because of this versatility, the modified Option 3 design is the preferred fluid transfer system design.

4.1.2 On-Orbit Venting and Dumping Limitations for Bipropellants

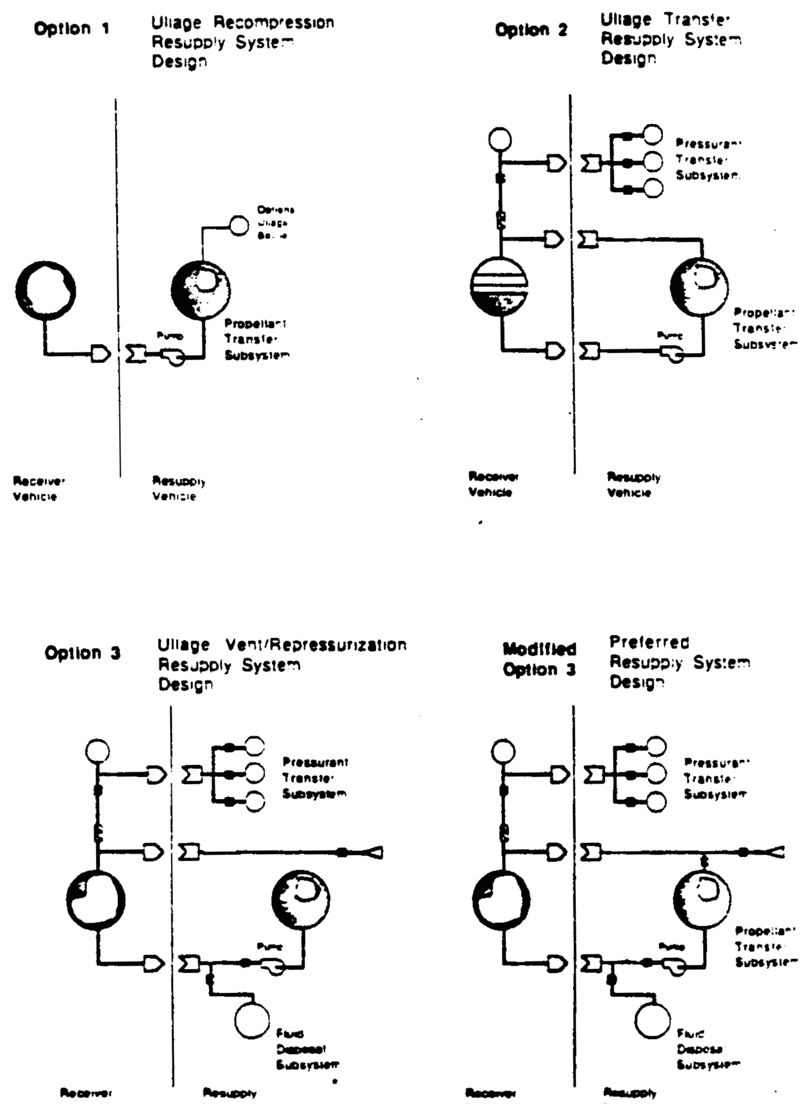
ON-ORBIT VENTING

On-orbit venting limitations for a conceptual bipropellant resupply system are based on current contamination limitations for the Orbiter, Space Station and other spacecraft users. The application of these contamination limits and the results of material exposure/compatibility tests were evaluated under an IR&D study, Project 86210. The results, conclusions, and recommendations from that study have been excerpted and are presented here for information.

TABLE 4.1.1-1 POTENTIAL BIPROPELLANT RESUPPLY SCENARIOS

RECEIVER SPACECRAFT PAD OPTIONS	VIABLE PROPELLANT TRANSFER METHOD: ULLAGE RECOMPRESSION	ULLAGE VENT/ RECOMPRESSION	ULLAGE EXCHANGE
• SCREENS W/O ULLAGE CONTROL	X	X	
• SCREENS WITH ULLAGE CONTROL	X	X	X
• VANES	X	X	
• DIAPHRAGMS	X	X	X
• WELDED BELLOWS	X	X	X

FIGURE 4.1.1-1 **Fluid Transfer System Design Options**



Exposure tests of MMH and NTO to Orbiter materials has been done by Garrard and Houston at the Physical Chemistry Laboratory. The results of MMH exposure tests are discussed in the following section. In general, the affect of NTO on spacecraft materials is rapid degradation of strength, operations life, and overall safety and reliability. A detailed summary of material affects is presented in the bipropellant conceptual design report per STS 86-0299. The reported results are from tests performed in atmospheric conditions. How these results relate to minor propellant exposures due to venting or small leaks in the hard vacuum of space is unknown. The suspected effects in space are expected to be relatively benign.

The compatibility of Teflon FEP film and Teflon covered beta cloth was determined by exposure to liquid MMH for 96 hours. No visual evidence of material degradation was observed. The fabric was wetted by the MMH and it was also noted that vapor transmission occurred through the cloth, but not liquid.

Several tests were performed simulating a MMH spill on a grouping of tiles, a thermal barrier and other samples to test the tile bond strength. Following the spill tests, the samples were tested for bond strength and examined for the amount of contamination and damage. Results show that MMH spillage on the TPS would be difficult to decontaminate and can affect the strength of the tile bond. A fuel spill would leave the TPS highly contaminated and very difficult to clean because of the absorbtion characteristics of the SIP, filler bar, and possibly the tile. The contaminated TPS would have to be physically removed for decontamination and replacement. Examination of the failed specimens revealed some effect on the adhesive-to-Koropon bond. There was no apparent reaction between MMH and SIP or the silicon adhesive. Any change in the tile bond strength appears to be due to mechanical effects resulting from fluid adsorption. But it was noted that the SIP could be easily peeled from the Koropon after 6 weeks. There was an indication that the degradation of the bond may be time dependent. However, additional tests would be required to verify this condition.

An NTO spill that occurred on the pad at KSC resulted in the removal, direct or indirect, of over 300 tiles in an area adjacent to the RCS pod. As a result of the spill, tests were performed of the "splash/soak" type for NTO compatibility on materials either in the spill area or adjacent to it such that they could have been exposed to NTO vapor.

OVERBOARD PROPELLANT DUMPING

Table 4.1.2-1 presents the result of a bipropellant dump study through the Centaur dump ports. The analysis examined the dumping of 9000 pounds of MMH/NTO in 225 seconds. The analysis indicated that about 80% of the MMH/NTO is dumped in the liquid/solid phase with the balance being vapor. The surfaces that would be contaminated from a dump through the Centaur dump ports include: 1) upper wing and elevon, 2) fuselage, and 3) the lower OMS POD. It was assumed that the MMH/NTO dump would be of sufficient duration to be absorbed into the TPS system to the extent that the structure would be wet.

TABLE 4.1.2-1 - POTENTIAL DAMAGE TO THE ORBITER BY MMH AND NTO

MATERIAL (CONTAMINATED)	IN-FLIGHT DAMAGE		REPAIRABLE DAMAGE ON THE GROUND	
METALS	**MMH**	**NTO**	**MMH**	**NTO**
Aluminum Alloys	A	B	1	2*
Titanium Alloys	A	A	1	1
CRES	A	B	1	2
Nickel Alloys	A	B	1	2
NON-METALS	**MMH**	**NTO**	**MMH**	**NTO**
AFRSI Blankets	B/F	B/E	4	4
FRSI Felt Insulation	B/F	B/E	4	4
LRSI "WHITE" Tile	A/F	B/E	3	3
FRCI-12 "BLACK" Tile	A/F	B/E	3	3
HRSI "BLACK" Tile	A/F	B/E	3	3
Gap Filler, Ames	B/F	B	4	4
Gap Filler, Pillow	B/F	B	4	4
Gap Filler, Cord	B/F	B	4	4
Gap Filler, Fabric	B/F	B	4	4
Super Koropon	C	D/E	4	4
RTV-560	C	C/E	4	4
RTV-577	C	C	4	4
Black RTV	C	C	4	4
RCC	B/F	B	4	4
Graphite Epoxy, OMS	B	B	2	2

CODES

A - unaffected
B - cosmetic
C - damage (minor)
D - damage (not functional)
E - loss of part
F - fire

1 - no repair
2 - on-board repair
2*- on-board replacement if temper is affected by re-entry heating
3 - remove, repair, & replace
4 - remove, scrap, & replace

The results are tabulated in Table 4.1.2-1, but some of the key results are as follows:

1) Waterproofing of the TPS provides no protection from wetting by either MMH or NTO.

2) C-9 coating on blankets will not prevent MMH/NTO fluid penetration.

3) All gap filler types will absorb liquid MMH/NTO.

4) NTO energetically attacks super Koropon primer and SIP.

5) Absorbed MMH in blankets will be benign until air is encountered. Atmospheric air can promote increased temperature and potential autoignition.

The key conclusion to the 9000 lb bipropellant dump study are:

- MMH Dump

1) A potential fire hazard will exist either during re-entry or upon landing, when the MMH soaked TPS insulation is exposed to heat and air.

2) The TPS insulation will probably be functional until a fire develops.

3) Vehicular survivability with a TPS fire is doubtful.

- NTO Dump

1) Degradation of the super Koropon primer and SIP will occur in minutes when soaked in NTO.

2) The degraded super Koropon primer in turn will cause the TPS insulation adhesive to debond from the structure. The degraded SIP also will cause tile loss.

3) TPS loss will expose base aluminum 2024 T81 and graphite skins to re-entry heating (600°F minimum).

4) A burn through on the OMS pod skin is expected, exposing propellant tanks to hot gases. Failure of a propellant tank is conceivable.

The information from the physical chemistry lab and the A&P group is considered as extreme contamination testing, particularly the 9000 lb dump in 225 seconds, but the results do indicate some limitations that can be applied to the venting of bipropellants.

CONCLUSIONS ABOUT ON-ORBIT VENTING OF BIPROPELLANTS

The conclusions and recommendations of on orbit venting of bipropellants is presented below.

1) Bipropellants must be expelled with minimal potential of contact with the Orbiter, spacecraft, or resupply tanker.

2) For the Orbiter, the Centaur dump ports are considered as unacceptable for bipropellants in the liquid/solid phase. The potential for Orbiter damage/contamination is too great. But, dump ports that run out of the aft fuselage may be acceptable; further analysis in this area is required.

3) If MMH/NTO must be dumped out of the Centaur dump ports, it should be in the vapor phase only.

4) NTO even as a vapor is considered as a highly corrosive chemical with the capability of damaging the resupply tanker, Orbiter, and spacecraft over extended periods of time.

5) External contamination of the resupply tanker or the Orbiter can require extensive decontamination procedures before reuse.

6) MMH dumped as vapor presents a potential fire hazard only if it is absorbed into the TPS insulation in sufficient quantity to saturate the insulation. This is not an expected problem.

7) There are indications that MMH contamination effects are time dependent. Thus there is a concern of material failure before the designed lifetime.

4.1.3 Bipropellant Hardware Availability

An assessment of the additional hardware required for a bipropellant resupply system identified specific components. These components requirements were evaluated in detail under an IR&D study, Project 86210 to identify hardware availability, weight, power required, potential supplier and present qualification status. This data is presented in DRD-6 (STS 86-0299) for the conceptual bipropellant resupply systems.

4.1.4 Fluid Capacity and Tankage Sizing

User requirements were examined to determine the type and volume of OSCRS services required. The bipropellant users results are tabulated in Table 2.1-2. These results drive the bipropellant OSCRS design to a maximum bipropellant capacity of 7,000 lbs.

Rockwell proposes that the structural design and dimensions of the bipropellant OSCRS be the same as its monopropellant counterpart. The basic structural geometry evolves from a 12-sided polyhedron periphery around a central hexagon cavity. This geometry results in six, 39 inch-square by 51.7 inch long compartments, containing 6 propellant tanks (3 fuel and 3 oxidizer).

Several propellant tanks designs have been identified for potential application in the bipropellant OSCRS. The physical and operating characteristics of these tank designs are tabulated in Table 4.1.4-1.

The GRO propellant tank is a potential bipropellant OSCRS'tank candidate. Unfortunately, the existing PAD design cannot be used with the oxidizer. The PAD is a polymeric diaphragm, which is not compatible with Nitrogen Tetroxide (NTO). However, the polymeric diaphragms are compatible with fuels, Monomethyl Hydrazine (MMH) and Aerozine-50 (A-50). The MMH capacity of the GRO tank was calculated to be 1075 lbs.

Table 4.1.4-1 Bipropellant Resupply Module Propellant Tank Options, Transferable Propellant Capacity

	MMS Mk II Option C (screen)	Modified MMS Mk II Option C (screen)	L-Sat (screen)	Orbiter ARCS (screen)	GRO (diaphr)	TDRSS (diaphr)	Welded Metal Bellows
dimension, (inches)	60 • 36 (il • id)	47 • 36 (il • id)	44.69 (id)	39.0 (id)	47 • 36.0 (il • id)	40.2 • 31.8	47 • 40
Tank Free Volume, (in^3)	48900	35625	na	31074	na	na	
Usable Tank Volume, (in^3)	48600	35400	46250 (+/- 244)	30891	36626	28144	36626 (approx)
Explusion Efficiency, (%)	98	98	95 (assumed)	97.6	97.6 (prequal)	95 (assumed)	
Weight (Lb)	98	na	56.2	82.8	99	76	210 (calc.)
Transferable Propellant Capacity, (lbs.)							
MMH, (54.7 lbm/ft^3)	1432	1043	1321	907	1075	804	
NTO, (90.2 lbm/ft^3)	2362	1720	2179	1495	1773 (*)	1326 (*)	1529
N_2H_4, (63.0 lbm/ft^3)	1650	1202	1522	1044	1238	926	1062
Nominal Operating Pressure (psia)	350 400 (max)	na	232	243 350 (max)	400	338	na
Proof Pressure, (psia)	525	na	348	385	600	507	na
Min. Burst Pressure, (psia)	800	na	464	525	800	676	na

notes: * - assuming a NTO compatible PAD
il - internal length
id - internal diameter
na - Not available

TABLE 4.1.5-1 RECEIVER TANK ULLAGE REMOVAL TECHNIQUES

VENTING TECHNIQUES	DEGREE OF CONTAMINATION			DEGREE OF COMPLEXITY			SAFETY CONCERNS			WEIGHT			COST		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
NONCATALYTIC NONPROPULSIVE	X					X	X					X			X
CATALYTIC NONPROPULSIVE		X				X		X				X			X
COLD TRAP		X		X				X			X		X		
STORAGE TANK			X		X				X	X				X	
ULLAGE EXCHANGE			X			X			X			X			X

ULLAGE EXCHANGE IS THE PREFERRED ULLAGE REMOVAL TECHNIQUES FOR RECEIVER TANKS WITH ULLAGE CONTROL.

IF OVERBOARD VENTING IS REQUIRED, USE A CATALYTIC NONPROPULSIVE VENT.

No suitable, off the shelf (in production), candidate configuration exists for the oxidizer tank. This item could conceivably represent the most costly single element in the bipropellant tanker fluid system. It is therefore recommended that this technology be developed prior to release of the bipropellant OSCRS contract.

4.1.5 Bipropellant Spacecraft Propellant Tank Venting Techniques

Conceptual venting techniques identified for bipropellant ullage removal include: 1) non-propulsive dumping of raw propellant vapor overboard, 2) venting by non-propulsive vents through bipropellant reactors, 3) use of a cold trap to remove liquid/vapor propellant from ullage gas;; 4) storage of ullage gas in waste storage tanks, and 5) use of a chemical reactor to reduce the liquid/vapor propellants to a less corrosive vent gas. These conceptual venting techniques are more complex than those evaluated for the monopropellant resupply system. These venting techniques for the conceptual bipropellant resupply system were evaluated further under an IR&D study, Project 86210. The conclusions/recommendation from that study have been excerpted and are presented here for information.

Table 4.1.5-1 presents a comparison of the several presented venting methods. Nonpropulsive dumping of hydrazine may be the most simple, have the lowest cost and weight, of the venting methods; but it presents the greatest degree of contamination of the venting methods. Venting of corrosive bipropellants is undesirable (paragraph 4.1-2) but the method still represents a viable approach if all propellant can be vented as a vapor in a judicious direction. Use of a bipropellant reactor was rejected as a viable method because it was determined to have strong safety concerns (a hot reactor in the cargo bay), high development cost, complex operation and design, and potentially a source of contamination as large as direct venting. Using a cold trap device to capture and retain MMH/NTO vapor/liquid from the ullage gas will result in a complex, heavy, and costly device with moderate contamination control.

The minimum vented MMH/NTO concentration will be the reduced vapor pressure concentration. A storage tank system to capture the ullage will have the least amount of contamination and the greatest safety of any of the methods, but for a receiver tank without ullage control and a pressure-fed system on the tanker it is the heaviest.

If a pump fed system (in the tanker) is used and an ullage exchange can be performed. This method would not only be the safest, have the lowest contamination potential, and it would also have the lowest weight and be simple to perform.

Venting of MMH/NTO through chemical reactors seems to represent an approach that is between direct venting and the more complex methods of a bipropellant reactor or a cold trap. The method has moderate cost, safety, and contamination limits. It has a lower weight than the bipropellant reactor but a greater weight than direct venting. Chemical reactors represent an undeveloped technology for NTO, but a feasible method for MMH.

All overboard venting should be performed through an extendable/retractable boom with non-propulsive vent to minimize contamination potential to the Orbiter/OSCRS and Spacecraft. This is a new technology item.

The conclusions and recommendations of this section is presented below.

1) Since the spacecraft will contain a ullage transfer quick disconnect to return ullage to the tanker for disposal - ullage exchange is the preferred method for receiver tanks with ullage control capability.

2) If venting is required and the receiver tanks do not have ullage control capability then the residual propellant should be removed to the tanker to minimize MMH/NTO disposal problems.

3) After the residual propellant is removed then the propellant saturated ullage can be disposed of by one of the suggested methods through a non-propulsive vent which is removed from the Orbiter/spacecraft vicinity by a retractable boom.

4) Development of small chemical reactors is recommended to handle the disposal of the propellant saturated ullage.

5) MMH disposal can be potentially performed by two types of reactors. One, by using a spontaneous catalyst but concentrating on the carbon deactivation problem. Two, by using a nonspontaneous catalyst with a iodine pentoxide ignitor.

6) NTO disposal by chemical reactor will require some developmental work to select an adequate solid fuel reactant.

4.1.6 Thermal Control Technique/Hardware

There is no significant difference between the bipropellant tanker thermal control system and that developed for the monopropellant tanker, except for added thermal instrumentation.

Table 4.1.6-1 shows 185 sensors are required for the bipropellant tanker. One hundred thirty three (133) sensors are used for thermal control and 52 are used for other purposes such as: valve failure detection, PVT gauging, etc.

4.1.7 Optimization of Bipropellant Avionics Control

The concepts for providing crew control of a bipropellant consumables resupply system from the orbiter aft flight deck differ from the concepts for a monopropellant control system in several areas, such as:

- A generic bipropellant avionics control system must be more highly automated than a simple monopropellant system in order to support eventual remote operations and increased complexity safely.

- The emergency separation system for the bipropellant system is significantly different from a monopropellant system, since a remote automatic umbilical is proposed for bipropellant designs versus pyrotechnic devices that separate monopropellant fluid lines.

Table 4.1.6-1 TEMPERATURE INSTRUMENTATION (ALL SUBSYSTEMS)

	2 TANK GRO		6 TANK MAXIMUM		BIPROPELLANT MAXIMUM	
	TCS	OTHER	TCS	OTHER	TCS	OTHER
FLUID SUBSYSTEM						
TANKS, VALVES, PUMPS, LINES, FLOWMETERS	7	33	15	49	17	48
TRANSFER LINES, COUPLING CHECKOUT COMPONENTS, CAT/VENT	14	3	14	3	28	4
ULLAGE TRANSFER & PRESSURANT	0	0	34	0	44	0
MISCELLANEOUS	4	1	2	0	3	0
HEATER DEDICATED	12	0	12	0	12	0
AVIONICS & RADIATOR	20	0	24	0	28	0
STRUCTURE						
BERTHING SUBSYSTEM	2	0	2	0	1	0
FIRST FLIGHT TEST	6	0	0	0	0	0
	65 +	37 = 102*	103 +	52 = 155**	133 +	52 = 185***

POTENTIAL FOR REDUCTION FOLLOWING TEST AND ANALYSIS PROGRAM: *26, **31, ***46

The concepts for control of the generic bipropellant avionics system were evaluated under in-house IR&D study Project 86210. The conclusion & recommendations from the IR&D study are presented herein for information.

The functions to be controlled by the bipropellant resupply avionics system are shown in Figure 4.1.7-1. The table shows the number of commands required for each of the functions listed and also shows whether the functions are controlled by hardwire switches on the crew control panel or are controlled automatically by FMDM's on the tanker module.

The layout of the bipropellant resupply control panel located on the AFD is shown in Figure 4.1.7-2. The switches to provide the previously identified hardwired control functions are shown on the panel. The panel also includes the crew control/status panel which provides redundant dedicated control and status paths to the FMDM's which control the automatic functions.

The automatic FMDM sequences which control the bipropellant system critical operations can only be initiated by crew activation of the ARM/EXECUTE switches on the Crew Control/Status Panel. The two-line message displays present data describing the planned FMDM sequence to assist the crew in selecting and activating sequences.

4.1.8 Launch Site Operations

The processing operations of a bipropellant tanker at KSC will differ from those of the OSCRS monopropellant tanker. These differences have been identified as: (1) types of propellants used; (2) safety concerns, (3) GSE requirements, and (4) processing schedule. These differences were investigated under an in-house IR&D Study, Project 86210.

The main conclusion of this study is that the facilities at both KSC and VAFB are capable of processing a bipropellant system equally as well as a monopropellant system. There are additional safety precautions that have to be exercised, however, the operating personnel are familiar with handling both commodities and no unusual problems are foreseen. The processing schedule of a bipropellant tanker will include more serial time operations due to the two propellants, thereby lengthening the turnaround schedule. Also, the oxidizer servicing operation at VAFB will be performed in the PCR at the Launch Mount prior to installation of the tanker into the payload bay of the Orbiter.

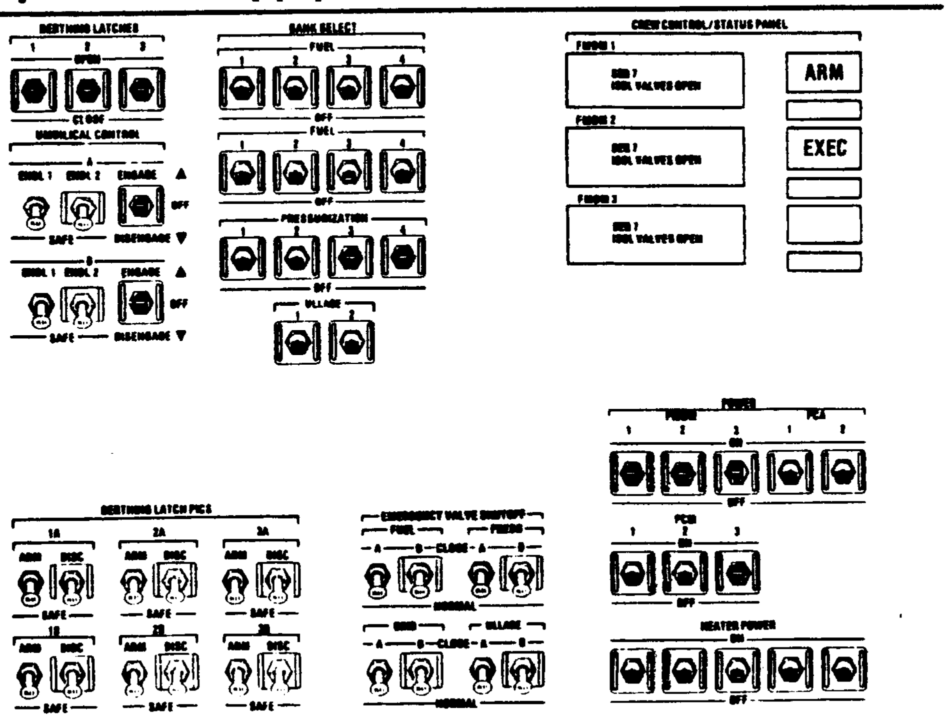
4.1.9 Landing Site Operations

The turnaround processing operations for a bipropellant tanker at the landing site may differ from those of the OSCRS monopropellant tanker. Some of the differences could be attributed to the following: (1) Use of the two hypergolic propellants; (2) the safety and handling concerns, and (3) the effect on the turnaround processing schedule. The in-house IR&D Study, Project 86210, investigated the differences.

FIGURE 4.1.7-1
Automated vs Crew Controlled Functions

FUNCTION	NUMBER	CONTROL HARDWIRE	CONTROL FMDM (AUTO)
POWER ON/OFF	8	X	
HEATER POWER	5	X	
BANK SELECT	14	X	
BERTHING LATCHES	6	X	
EMERGENCY VLV CLOSE	8	X	
EMERGENCY DISCONNECT	6	X	
VALVE OPEN/CLOSE			
. FLUID SYSTEM	190		X
. SATELLITE	12		X
PUMP START/CONTROL	12		X
VARIABLE REG & REL VLV	10		X
UMBILICAL CONTROL	6	X	
	277		

FIGURE 4.1.7-2
Bipropellant Resupply Control Panel



The bipropellant tanker ground processing operations following a successful reservicing mission will not vary much from those of a monopropellant tanker. The storage, handling and safety aspects of monomethyl hydrazine are the same as for hydrazine. Therefore, the testing, checkout and servicing of these two fuels are the same. Likewise, similar, if not identical GSE can be utilized on either program. The inclusion of an oxidizer system on the tanker adds processing operations to the turnaround time and increases the safety concerns. There will be a complete set of GSE required for the oxidizer system which will be similar to that for the fuel system in concept, but using components compatible with the oxidizer.

4.1.10 GSE and Facility Operations

The GSE identified for the OSCRS bipropellant tanker program may not be totally usable on the monopropellant tanker program due to: (1) the use of two different propellants; (2) the safety and handling concerns, and (3) design compatibility. Also, in the area of facility operations the use of all the same processing facilities as used with the monopropellant tanker is questionable due to: (1) the use of a different fuel; (2) the addition of an oxidizer system, and (3) the safety concerns. These questionable items were investigated under an in-house IR&D Study, Project 86210.

After reviewing the conceptual designs for the monopropellant tanker handling GSE, it was determined that these designs are directly usable and could possibly be shared on the bipropellant program, schedule permitting. It was also determined that while the propellant servicing and checkout GSE conceptual designs are adequate for the bipropellant tanker program, a separate set of each will be required for both the oxidizer and fuel systems. There are some unique items of GSE that will have to be procurred or fabricated for each of the bipropellant systems.

Review of the KSC facilities recommended for use on the OSCRS (monopropellant) tanker program has shown that the only facility that is suspect is the Hazardous Processing Facility. The HPF recommended for use as a dedicated OSCRS bipropellant facility is Cryogenics #1. This facility, when modified, could be made capable of handling both a monopropellant and a bipropellant tanker program.

4.1.11 Bipropellant System Weight and Power Analysis

A summary of the individual subsystem weights for a maximum growth bipropellant resupply system is presented in Table 4.1.11-1. Total estimated system masses are 3331 lbm and 11,876 lbm for dry and wet systems respectively.

In order to calculate bipropellant system power requirements, the following assumptions were made:

(1) Only two GRID computers will be operating at the same time, and they will use orbiter power.

(2) The tanker will only be subjected to short duration cold soak periods. Therefore all heaters could be energized simultaneously, but only an average of one-third of the heaters will be in operation on a time-averaged basis.

TABLE 4.1.11-1

BIPROPELLANT TANKER MASS & C.G. LOCATION SUMMARY

	WEIGHT	C.G. LOCATION X	Y	Z
6-TANK BI-PROP.				
STRUCTURES	816	26.35	-0.8	402.8
AVIONICS	645	25.2	60.7	429.7
THERMAL	150	26.35	16.5	410
MECHANICAL	33*	26.35	-29	452
FLUID SUBSYSTEM	1687	26.35	0.4	404
DRY WT. & C.G.	3331*	26.12	12.2	409.5
WET WT. & C.G.	11876*	26.3	3.4	403

*EXCLUDING TBD BERTHING MECHANISM AND UMBILICALS MASSES.

TABLE 4.1.11-2

BIPROPELLANT SYSTEM POWER REQUIREMENTS

(WATTS)

	AVIONICS		FLUIDS		THERMAL CONTROL			
TRANSFER MODE	CONSTANT	MAX.	CONSTANT	MAX.	CONSTANT	MAX.	CONSTANT	MAX.
BABYSIT	250	310	0	0	280	790	530	1100
SINGLE PROPELLANT	610	670	765	1635	280	790	1655	3095
DUAL PROPELLANTS	610	670	1530	3150	280	790	2420	4610
PRESSURANT	610	670	10	140	280	790	900	1600
PRESSURANT + SINGLE PROPELLANT	610	670	775	1655	280	790	1665	3115
PRESSURANT + DUAL PROPELLANTS	610	670	1540	3170	280	790	2430	4630

(3) A maximum of 2 fluid system isolation valves will be operated simultaneously. All valves are "dual-latching" and do not require power after actuation (valve position indicator power drain is considered negligible).

(4) Ullage recompression transfer mode is used (results in highest power consumption).

(5) Fuel and oxidizer transfer is slightly staggered so that the two systems do not draw maximum power at the same time.

(6) Number of transfer pumps and electronic regulators in operation simultaneously is defined by the transfer mode.

(7) All numbers are based on a maximum resupply mission (i.e., 6 propellant tanks and 6 pressurant tanks).

(8) Fluids subsystem and portions of avionics subsystem will be powered down during launch and re-entry.

Table 4.1.11-2 presents a summary of the bipropellant system power requirements. The results indicate that the peak power required to transfer fuel, oxidizer, and pressurant simultaneously would be 4630 watts. Continuous power drain for the same transfer mode would be slightly under 2500 watts.

4.2 Conceptual Design/Documentation

The bipropellant OSCRS system design/documentation builds on the monopropellant resupply trade studies of paragraph 3.1 supplemented by the unique bipropellant system trade studies of paragraph 4.1. The conceptual bipropellant design implements commonality with the monopropellant OSCRS.

The bipropellant tanker concept utilizes the monopropellant tanker structure, and basic avionics and thermal subsystems, and incorporates a bipropellant fluid storage and distribution system in place of the high monopropellant hydrazine system. The fluid system also incorporates a high and low pressure pressurant resupply source, a spacecraft ullage transfer system which includes a means of disposing of the propellant contaminated ullage gases, and provisions for receiving spacecraft residual propellants. The satellite specific berthing interfaces are not defined so a space on the +Z (top) side of the tanker is reserved for installing the TBD mechanism. The large number of fluid coupling interfaces (8-12 or more) required to provide redundant interfaces with the receiver bipropellant spacecraft will necessitate development of an automatic umbilical interface coupling which should be remotely operable.

Definition of the basic system design and structural concept includes:

- Structural Definition
- Fluid Subsystem Design (Schematic)
- Avionics Subsystem Design (Schematic)
- Thermal Control Subsystem Definition
- Assessment of Unique Safety Hazards

4.2.1 Structural Definition

Previous IR&D and contract studies defined several conceptual designs for structural configuration of both monopropellant and bipropellant resupply vehicles. Specific mission objectives, projected growth requirements, adaptability, and typical design objectives such as cost, weight, schedule, safety and technical risk were evaluated. A further structural study under IR&D efforts expanded on the basic structural configuration to evaluate and maximize commonality between the monopropellant and bipropellant systems.

The results of these studies indicated the structure weight penalty to the baseline monopropellant tanker was only 87 lbs (see Figure 3.1.1.1-1). It was determined that the flexibility to increase the load carrying capacity from 2450 lbs of N_2H_4 to 8545 lbs of bipropellants outweighed the small weight penalty. Therefore, the monopropellant tanker and bipropellant tanker structure are identical.

4.2.2 Fluid System Schematics

The baseline fluid subsystem design, for the bipropellant OSCRS, is presented in Figure 4.2.2-1 and 4.2.2-2.

Layout of the fluid subsystem schematic divides subsystem components into several convenient units based on their functional operations:

(1) Propellant Storage Unit

(2) Propellant Tankage Ullage Control Unit

(3) Propellant Transfer Control Unit

(4) Coupling Leak-Check/Vent Control Unit

(5) Tanker/Spacecraft Propellant Interface Unit

(6) Ullage Transfer/Vent Unit

(7) Pressure Resupply Unit

The basic operation of the first 5 units were previously discussed in the monopropellant section.

The ullage transfer/vent unit consists of dual redundant couplings, with an inline emergency pyro separation device, dual redundant liquid detectors, and associated valving. This unit will be used for the following transfer methods:

(1) Ullage exchange

(2) Ullage vent followed by repressurization

(3) Residual removal, ullage vent and then repressurization

The pressure resupply unit consists of high pressure (8000 psia) carbon-graphite expoy wrapped Ti lined pressurant tanks, a low and high pressure transfer module with associated electronically controlled pressure regulators and relief valves, and associated high pressure valving.

FIGURE 4.2.2-1 BASELINE BIPROPELLANT FLUID SUBSYSTEM SCHEMATIC

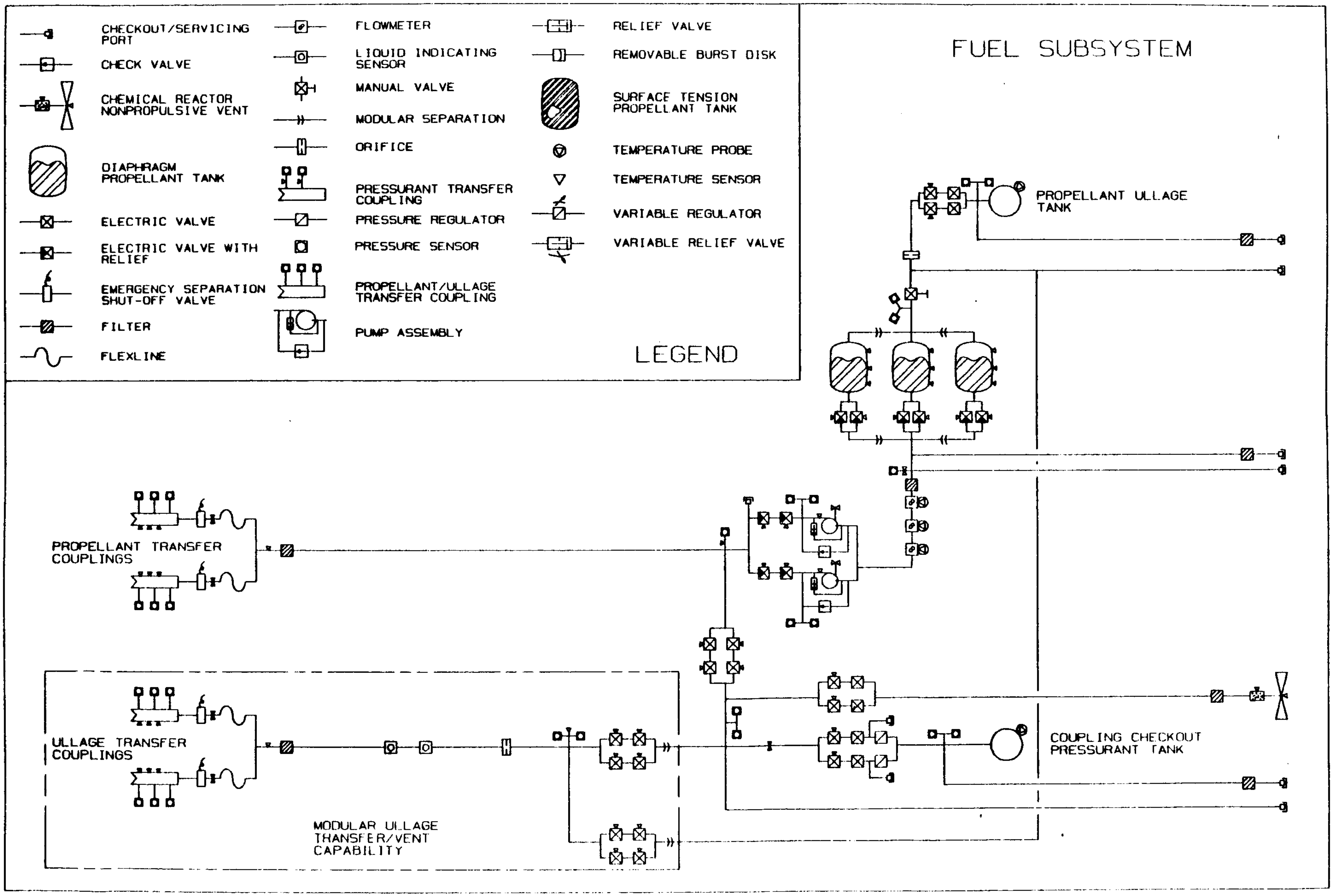
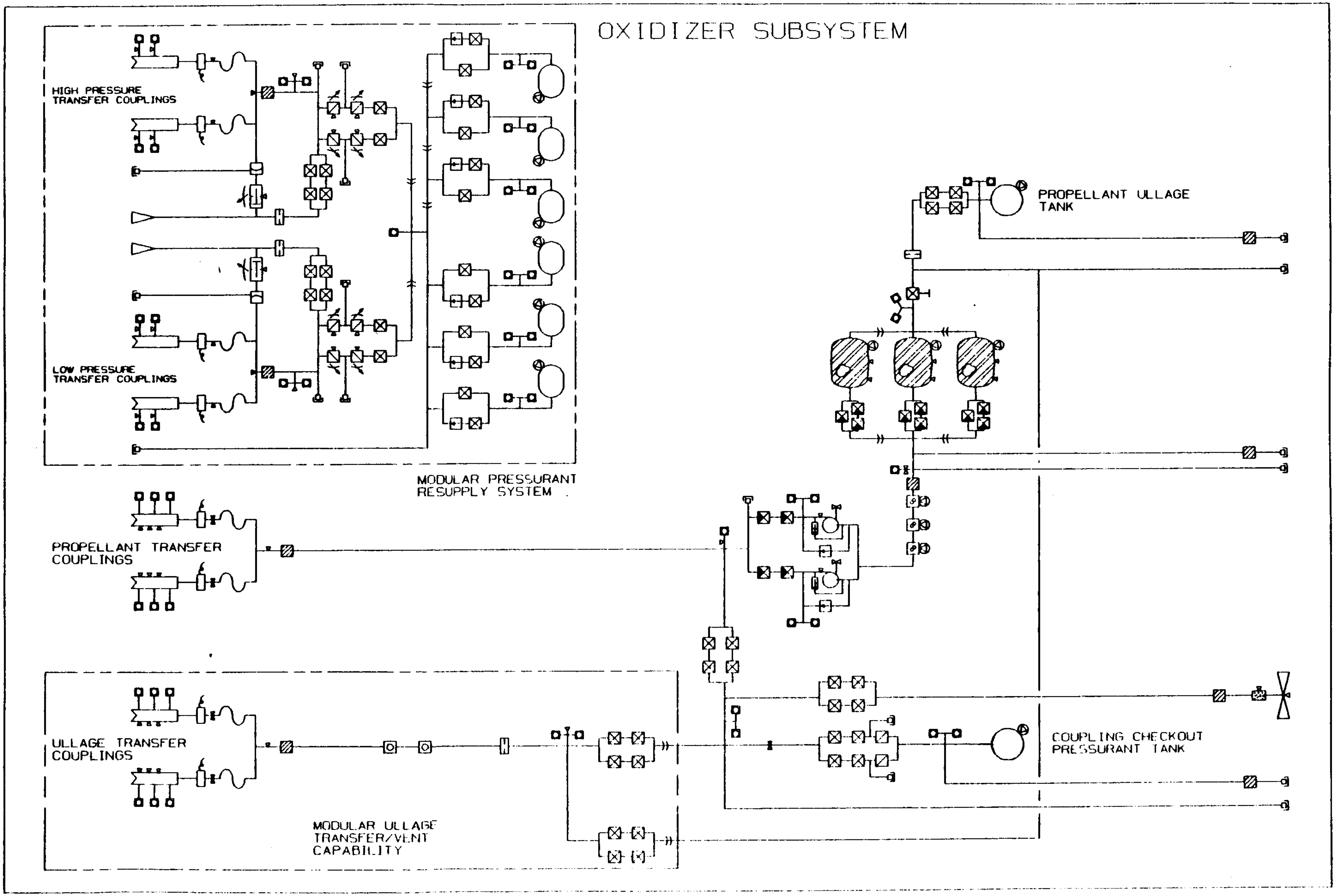


FIGURE 4.2.2-2 BASELINE BIPROPELLANT FLUID SUBSYSTEM SCHEMATIC



4.2.3 Avionics System Schematic

The description of an avionics system preliminary design for a bipropellant OSCRS system would be virtually the same as the description of the monopropellant OSCRS avionics system given in 3.2.3.

The generic avionics system concept was purposefully defined to provide a single basic design that could be utilized with the baselined, relatively simple, GRO resupply mission and that would support other monopropellant missions as well as future bipropellant resupply missions, without significant design changes.

A block diagram for the bipropellant avionics is shown in Figure 4.2.3-1. The major difference between this diagram and the monopropellant avionics block diagram, Figure 3.2.3-1, is in the area of the emergency separation system.

In the baselined bipropellant resupply system, an automated umbilical assembly would be employed for fluid and electrical lines connecting the tanker module to the receiving satellite. The automated umbilical would permit emergency separation without EVA, therefore the bipropellant avionics system would not include the pyrotechnic devices for emergency separation of fluid supply lines and electrical lines to the satellite, as had been included in the monopropellant system design. Emergency disconnect pyro's would still be required for the berthing latches however, as shown. This change reduces the number of PIC's in the Emergency Separation Controller. The number of crew-operated pyro ARM-FIRE switches on the AFD Control Panel are also reduced.

The number of FMDM units and SC/PCM units would remain the same, three of each, in the bipropellant avionics design. However, requirements to handle increased numbers of control functions and measurements for a bipropellant system would be accommodated by adding modules to the initial box designs.

The number of Power Control Assemblies (PCA's) would increase in the bipropellant avionics design. The current conservative estimate is that six PCA's would be required. This estimate was made with little valid data on the bipropellant systems and satellites to be serviced, and is likely high. The number of PCA's could easily drop to four as a better understanding is gained of the number of functions to control and measure.

The added avionics on the tanker would be mounted in the upper most triangular bay.

4.2.4 Thermal System Definition

The preliminary thermal control system design for the monopropellant tanker, shown in Figure 3.2.4.2-1, will support the bipropellant OSCRS operations under all conditions for any mission duration. Additional analysis is required to optimize the design and to verify the thermal subsystem capabilities.

4.2.5 Instrumentation and Signal Conditioning

A conceptual design for an instrumentation system capable of determining system integrity and performance of a bipropellant resupply system would be virtually the same as for the monopropellant OSCRS tanker.

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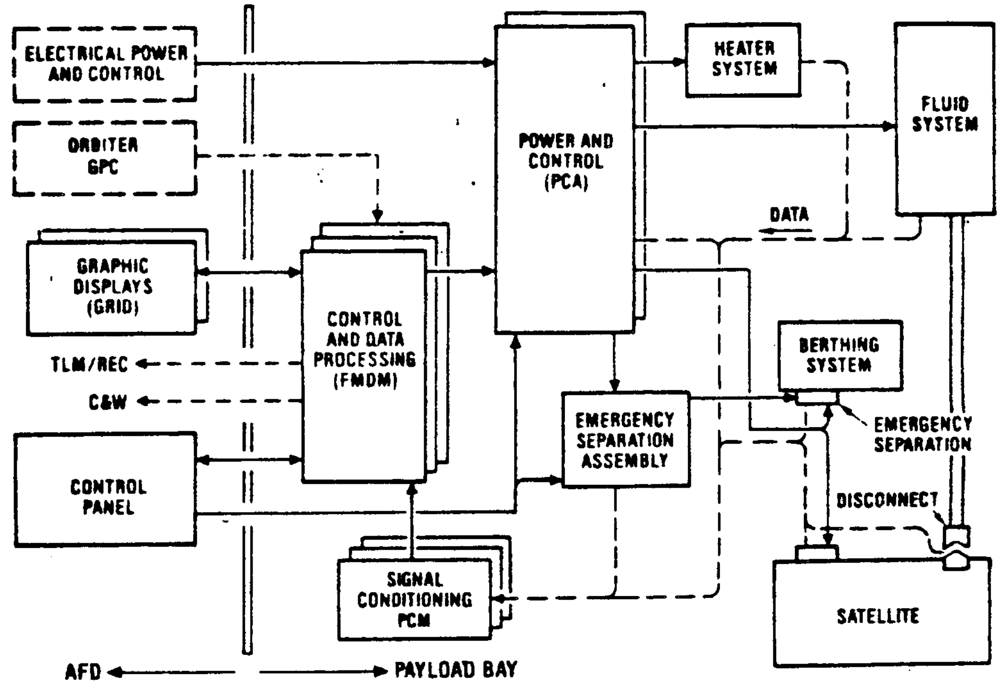
FIGURE 4.2.3-1

Bipropellant Avionics System Block Diagram



The number and types of measurements would increase for a bipropellant resupply system and will be fully defined in the Phase C/D program.

4.2.6 Preliminary Safety/Hazard Analysis

The preliminary hazard analysis of the OSCRS bipropellant system design identified only those hazards which are unique to a bipropellant system (previously identified potential hazards for the monopropellant system also apply to the bipropellant system). From a safety standpoint, growth from a monopropellant resupply system to a bipropellant system will result in additional potential hazards only in the fluid subsystems. The conceptual bipropellant design poses no additional hazards for the other subsystems (electrical/avionics, pyrotechnics, thermal control, structures, and mechanical). As with the monopropellant system, no potential waivers or deviations have been identified against the requirements of the NHB 1700.7A or KHB 1700.7 and no unaccepted risks have been identified against the potential hazards for the bipropellant design.

The following are the identified potential hazards which are unique to a bipropellant system:

Oxidizer Leakage/Spillage

The leakage/spillage of oxidizer can corrode the surrounding structure and elements which can also lead to a potentially toxic atmosphere.

Unintended Mix of Fuel and Oxidizer

The unintended mix of fuel and oxidizer will result in a fire which can potentially cause the loss of life, orbiter/vehicles, and other payloads.

Aerozine-50 Exposure to Vacuum

Aerozine-50 (A-50) if exposed to vacuum can freeze within the system and can cause a rupture or explosion due to its subsequent expansion during thawing.

4.3 Commonality Assessment

The designs that have been determined for both the monopropellant and bipropellant tanker subsystems have been compared continually throughout various trade studies in their specific areas and hardware elements for commonality.

STRUCTURE

During the trade studies in the structural area it has been shown that the baseline open truss satisfies both monopropellant and bipropellant tankers and subsystem designs with very small penalties in weight and large savings in cost and schedules. As a result, the same structure is proposed for both the monopropellant and bipropellant tankers.

MECHANISMS

The NASA NAS9-17333 fuel transfer coupling use will be limited to the monopropellant tanker and a new, remote, and automatic transfer umbilical should be developed for the bipropellant tanker.

The berthing interface utilizing the FSS latches may well be limited in use to the baseline monopropellant tanker. Berthing interfaces beyond the GRO spacecraft have not been defined at this time. A generic berthing interface should be developed by the NASA.

FLUID SUBSYSTEM

There are three significant differences between a monopropellant fluid subsystem and a bipropellant fluid subsystem. The baseline bipropellant quantities are 2.8 times greater than the baseline monopropellant requirements (7,000 pounds). This creates a need for six propellant tanks (3 oxidizer and 3 fuel). Secondly, the bipropellant system has two independent propellant storage and feed systems for the fuel and oxidizer. The fuel system can be common/or identical, to the monopropellant tanker system. However, the oxidizer components must be certified compatible with NTO. Finally, since most bipropellant systems have a pressure-regulated feed system, the ullage must be disposed of prior to or during the propellant resupply and pressurant replenishment will be required, necessitating the need for a pressurant transfer system.

The bipropellant tanker would be sized to nominally resupply up to 7,000 pounds of propellant. This could be contained in three GRO-type diaphragm fuel tanks and three equally sized oxidizer tanks with surface tension propellant management devices. The fuel flow control system could be the same as the one used on the monopropellant tanker. The oxidizer fluid control system could be different depending on how the spacecraft ullage is handled.

Most bipropellant spacecraft systems operate by a pressure-regulated feed system. This requires disposing of the ullage prior to or during the propellant resupply. Pressurant replenishment is then required. Disposal of the spacecraft tank ullage could be accomplished by several approaches, but the key to all techniques requires a definite means of separating the ullage from the propellant in the spacecraft tanks. To meet this requirement, the spacecraft tanks must contain a liquid-free vent system that allows decreasing the ullage volume by up to 90 percent without expelling the bulk propellant. To achieve this, a unique liquid/gas separator will have to be developed for the spacecraft tanks. An alternate would be to use a positive expulsion device (diaphragm or bellows) in the spacecraft tanks.

THERMAL CONTROL SUBSYSTEM

With the exception of the fluid transfer assembly, all thermal control designs and components appear common between monopropellant and bipropellant designs. Coupling commonality will be assessed pending a transfer assembly design.

AVIONICS SUBSYSTEM

A high degree of commonality exists between the monopropellant and bipropellant avionics systems defined under the OSCRS study. A major objective in all the avionics study tasks was to define concepts that would support growth without major design changes. Components and system concepts were therefore selected that would support the relatively simple GRO resupply mission, but which could be expanded to support the six-tank monopropellant mission, or a bipropellant resupply mission, through modular additions to the system.

Three FMDM's would be used for all OSCRS applications. Additional plug-in modules would be added as the number of functions to be controlled and measured increased.

The number of Power Control Assemblies (PCA's) would increase as additional capability was required. Two identical PCA's would be used for the GRO mission, two more of the identical units would be added to support the monopropellant growth concept, and two more PCA's would be required for the bipropellant resupply missions (for a total of six).

Three Signal Conditioner/PCM units would be used for all OSCRS applications. The selected design employs a modular concept, however it is not a plug-in concept since the modules must be permanently wired in place. Therefore, some physical redesign would be required to increase the number of modules as OSCRS data requirements increase.

The same Emergency Separation Control Assembly would be used for all OSCRS applications. The number of plug-in pyrotechnic controller assemblies (PIC's) would be changed as OSCRS requirements for pyro operated devices changed.

The identical GRID computers would be used on the aft flight deck for all OSCRS missions.

The dedicated OSCRS crew control panel would contain some switches and displays that would be common to all OSCRS missions, however, the panels will be different. Provisions would be made for the addition of switches to control additional resupply functions, and for deletion of some pyrotechnic control switches which would be expected to decrease as future automatic umbilical concepts are introduced.

OSCRS software will employ a modular design concept to provide a high level of commonality for all resupply missions. Requirements will be imposed to design the OSCRS software so that certain core functions are established that will be applicable to all missions and will not change. The capability will also be provided to develop software modules containing mission-unique control and data requirements, that will be prepared individually for a particular mission and will be integrated with the core software modules prior to the mission. This concept permits a high percentage of the OSCRS software to be common for all resupply missions, without change. Changes would be incorporated using the mission-unique software modules.

4.4 Draft Bipropellant System Program Plan

The draft bipropellant resupply system program plan defines the scope and schedule of all development elements. The plan consists of a preliminary work-breakdown-structure (WBS) (Figure 4.4-1) and supporting schedules (Figure 4.4-2).

The complete detailed program plan is documented in DRD-8 report number STS 86-0300. Unique bipropellant system program issues are discussed below.

Program issues unique to the development of a bipropellant resupply system have been identified. These include:

1) Development of an oxidizer propellant supply tank.

   A diaphragm design compatible with oxidizer is not currently available and surface tension and metal bellows concepts need to be assessed.

2) Venting Control Techniques

   Development of propellant chemical reactors and ullage/liquid separator is required to provide adequate venting contamination control.

3) Development of an Oxidizer Propellant Pump

   Assessment/development of oxidizer compatible material is required.

4) Development of a Remote Interface Coupling

   Remote interface coupling development for bipropellant resupply is required including assessment of operation, checkout, and emergency separation requirements.

FIGURE 4.4-1 BIPROPELLANT OSCRS PROGRAM WBS

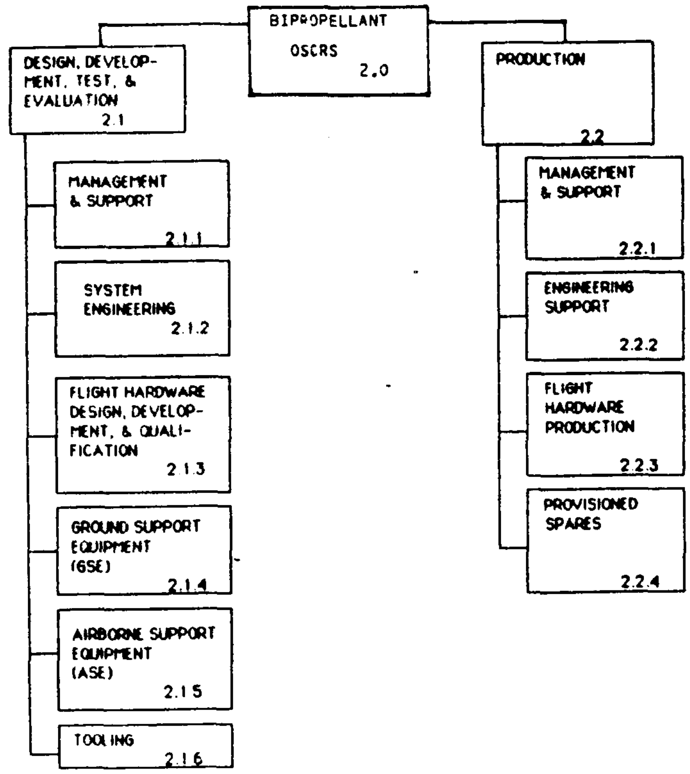


FIGURE 4.4-2 **O S C R S** - BI-PROPELLANT TANKER
PHASE C/D PROGRAM SCHEDULE